Department of Computing

Reward-Penalty Scheme for Power Distribution Companies

Sreenithya Sumesh

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DECLARATION

To the best of my knowledge and belief, this thesis contains no material previously published by any other person, except where due acknowledgement has been made.

This thesis contains no material which has been accepted, for the award of any other degree or diploma in any university.

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ABSTRACT

The important, significance of restructuring in the power industry, is the emergence of performance regulatory indices, in the power distribution companies, Reward-Penalty Scheme (RPS). RPS is a direct control, financial tool, designed for power distribution regulators, to assure the performance regulatory controls, such as system reliability. This tool rewards the distribution company that provides good reliability and penalizes those who provide poor reliability. To implement Reward-Penalty Schemes for Power Distribution Companies that maintain the appropriate reliability levels, several socio-technical challenges will need to be addressed. However, in the comprehensive literature survey of the existing Reward-Penalty Schemes, there are not really any convincing Reward-Penalty Schemes that will meet those challenges. This thesis highlights and explains the importance of developing an effective RPS, to manage the reliabilityof power supply, without any interruptions from power distribution companies and investigates the main parameters required, for designing and implementing an effective Reward-Penalty Structure, for power distribution companies.

To address the solutions to the four key issues, this thesis proposes (i) a generic framework of Reward-Penalty Structure for power distribution companies, that defines andcharacterizesthe most vital parameters todesign and implement the RPS(ii) two novel, linear reward penalty models, where rewards and penalties increase in a linear fashion,whichidentifiesby whatmeans the curve reaches the maximum reward or penalty quickly, as performance-based reliability moves away from the benchmark (iii) two novel quadratic reward penalty models, that provide increasing rewards or penalties, more slowly as performance-based reliability deviates from the target, (iv) two novel cubic reward penalty models, where the RPS curve reaches the maximum reward/ penalty moreslowly ,compared to the quadratic and linear curve, thus showing little reward or penalty around the dead band.These RPS models address the problems in improving the performance based on reliability for power distribution companies. Acapping (thresholding) on the maximum reward and penalties and a dead-band ,is introduced in all the proposed RPS models thatThis willallow companies to abstain from paying a critical penalty, or getting a huge reward and also considers the uncertainty related to the performance related components, that are outside of the

distribution company's control. The system reliability index, i.e. System Average Interruption Frequency Index (SAIFI), is chosen as the performance criteria, based on reliability of the proposed models. The theoretical concepts and the proposed solutions are tested and demonstrate the effectiveness of the reward-penalty schemes.

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LIST OF PUBLICATIONS

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CHAPTER I

INTRODUCTION

This chapter provides:

- The background information on the traditional regulated and modern deregulated power industry and the performance-based regulation schemes such as reward penalty schemes.
- An overview of reward penalty schemes.
- The significance and importance of managing performance based on reliability in reward penalty schemes.
- The objective and motivation of this research
- The dissertation structure

1.1 INTRODUCTION

Traditionally, most power distribution companies worked for a long time as vertically coordinated restraining infrastructures in which one company controls the generation, transmission and distribution facilities. In this traditional vertically integrated system, customers do not have a choice in selecting the company from whom they purchase electricity[1] and as such this organization controls all periods of framework arranging, system planning, configuration, and operations. This regulated power industry structure, has been there for a long time. One of the points of interest this traditionally regulated power industry has, is in the coordination of the considerable number of functions required, to give a very highly reliable, solid, power supply. Be that as it may, one of the critical drawbacks of the traditionally regulated industry, is the absence of rivalry in the created monopoly [1], which frequently prompts debasing framework effectiveness and administration quality.

As of late, social, financial, political and specialized changes have constrained the controlled force industry to adjust [1]–[7]. The power industry is presently experiencing significant changes because of this appropriation. The rivalry has turned into the key variable, driving the rebuilding (deregulation) process, in the electric power industry, which is designed to benefit both the customers and the participating companies [2], [4], [6]–[8]. Customers can now shop around for different service providers and select the desired companies according to their economic and technical requirements[2]. The key idea driving deregulation, is that no one organization ought to impose the monopoly of either the generation, distribution, wholesale or retail sale of power and power-based administrations. Figure 1.1-1 delineates a portion of the general contrasts between the traditionally managed (vertically coordinated) and the new deregulated, electric force industry [1].

1.1.1 TRADITIONAL REGULATED POWER INDUSTRY STRUCTURE

Over many years the traditionally regulated power industry structure, has been largely dominated by a central regulatory authority, which had full control . Thus it had often been described as a vertically integrated system. They served as the main power supplier within that geographical region and they serviced all consumersin the given region. A run of the mill structure, of a vertically coordinated force industry, is presentedin Figure 1.1-1. In this structure, the cash flow is unidirectional, i.e. payment for the utilities was made from the customer to the power industry, and there was no flow of cashto the customer. Similarly, the data flow which consists of direct commands, goals, constraints, direct measurements, control signals, estimated values, structural designs, etc., only existed between the generators and the transmission systems. In the vertically coordinated force industry, it was difficult to isolate the costs required for generation, transmission or distribution. In this way, frequently, customers are charged a normal tax rate contingent, upon their entire expense within a given time frame[1].

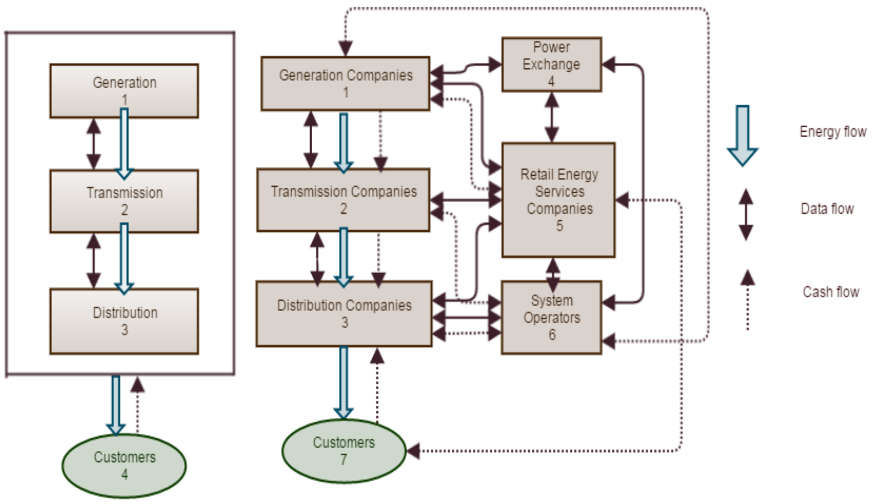

Figure 1.1-1 Power Industry Structure: Traditional & Modern Deregulate

1.1.2 MODERN DEREGULATED POWER INDUSTRY STRUCTURE

Figure 1.1-1 presents the typical structure of a deregulated power industry, with links to data, energy, and cash flow between various entities[1]. The customer carries out its transactions through a retailer, or transacts directly with a generating company.

In the modern deregulated power industry structure, generation organizations are autonomously owned and compete to trade energy with clients. They are not controlled by the same bodies that control the transmission framework [1]. Transmission organizations own high voltage transmission lines and move power in wholesale, from where it is created to where it is conveyed [1]. Distribution organizations convey power to retail end customers (clients) [1]. A Power Exchange is an association, where the purchasers and dealers of wholesale power, are permitted to purchase and offer energy as a commodity [1]. Retail energy service administration organizations, are retailers of the electric power, who purchase power from a power market and offer this directly to the client. Distribution System Operators are endowed with the duty of guaranteeing the consistent quality and security of the whole framework. They are an independent authority and do not take part in the power market exchanges.

1.1.3 PROBLEMS IN THE DEREGULATED POWER INDUSTRY

The deregulated power industry is confronting numerous issues, including how to operate the new power structure financially and be consistently reliable;how to minimize generation costs and how to pull in the new speculation required, to build the required generation and transmission services, under the instability of business competition[2-6]. The prerequisites of providing minimal cost electrical energy and high amounts of consistent reliability, are also important challenges. Adjusting these two components is a critical challenge for power system administrators.

One of the favorable conditions of this recently deregulated power industry is the subsequent competition between power suppliers, to give better administration quality. In a focused, competitive business sector, customers are allowed to switch between power suppliers if their reliability becomes unsuitable[2]. This hasposed remarkable strain on electric power organizations, to decrease costs (the expense of producing and conveying power) and to offer better arrangements to customers. Costs reductions accomplished by yielding key projects, decreasing inside skill, and expanding maintenance interim.[4], [6], [7], [8]–[11]. As an immediate result of these activities, the unwavering reliability and quality of these structures began to break down. Since these frameworks were outlined and kept up to exclusive expectations, this disintegration was not apparent immediately. The reliability quality appeared to be satisfactory for quite a long time, yet it then began to break down quickly [12], [13]. At the point of unwavering reliability, issues pertaining to quality became apparent as organizations do not regularly have the required assets to resolve the issue [1], [10]. In this way, the disintegration of the framework of unwavering reliability and quality became one of the most seriousissues connected with the deregulation procedure [11]

1.2 PERFORMANCE BASED REGULATION

To dodge the cost of reserve funds in maintenance and investment, that will compel the decay of system reliability, a method known as, Performance-Based Regulation (PBR), has been presented and includes the objective of maintaining a balance ofservice reliability and the utility expenses[10], [11]a key issue in today's energy market. PBR is an agreement that rewards a utility for giving great reliability and/or punishes a utility when the inverse happens [10], [14]. This infers the penalties are expanded as the performance deteriorates. PBR bolsters power distribution companies to become more economically effective, and in the meantime averts them from reducing service quality in the compatibility of budgetary objectives [12]. Since electricpower distribution systems constitute the most risk to the interruption of power supply [12], the possibility of PBR in the power trade, was presented to power distribution companies [5], [9]–[11], [15] and not to power generation and transmission companies. It has been reported in the literature [16]–[19], that more than 80% of all customer interruptions happen because of failures in the distribution system[20].

1.2.1 QUALITY CONTROLS

In the distribution system, performance regulation can be seen as a tool kit of quality controls, that the controller can use to acquire satisfactory quality levels, under a performance-based regulation plan[21]. Quality control is connected in three distinct concepts: commercial quality, continuity of supply (reliability) and voltage quality[14]. Amongst these three continuity of supply (reliability) is of significant importance[20], [14]. In this chapter, only the impact of quality regulation, on the coherence of supply (reliability), will be considered. Quality control is divided into classifications as direct and indirect [14]. Aim of indirect quality regulation, is to give data about the performance quality of distribution systems for clients [22], [21]. Be that as it may, in direct control, the controller specifically applies monetary motivations, for example, rewards and punishments. Punishments often consist of paying compensation to clients on distribution systems [21]. Three direct controls exist and are explained below:

1.2.1.1 PREMIUM QUALITY CONTRACTS (PQC)

Distribution system operators, can approve PQC with clients who characterize the buyer's remunerations, if the quality levels settled are not satisfied[21]. Often, these agreements are marked with large number of customers who have a requirement for high quality [20].

1.2.1.2 GUARANTEED STANDARDS FOR WORST-SERVED CUSTOMERS (GS):

Indeed, even a decent, normal quality levels of a distribution company, does not keep some customers enduring an unsuitable, lower level of service quality [21]. This is because, GS are fixed and utilized in both unplanned and planned interruptions [13] and are a concern for clients [13]. These measures can cover both long interferences and short intrusions.

1.2.1.3 REWARD AND PENALTY SCHEMES (RPS):

The most every now and again, utilized, direct quality control on the system level is RPS[21], that helps to enhance the performance and reliability for extended disruptions. RPS are characterized on the system level of performance, and GS and PQC are characterized on the customer service level of performance[21]. The Power distribution company regulators use RPS as a system quality indicator, to measure their system reliability level, their performance efficiency, and their customer's interruption costs. With RPS, the regulator specifies the target levels of the performance quality standard and the company's performance quality is related to these quality targets[10]. By direct controls, the regulator specifically provides the distribution systems monetary motivating forces as prizes[21], punishments and/or commitments to pay reimbursements to affected customers because of awful service[23].

1.3 REWARD PENALTY SCHEME (RPS)- QUALITY CONTROL ON CONTINUITY OF SUPPLY (RELIABILITY)

In the literature, the main focus has been on the effect of quality regulation upon the continuity of supply (reliability)[14]. PBR [14]depends upon the service remuneration costs concerning the competitive method for quality regulation, in light of penalties. Subsequently, incorporating RPS into PBR, implements rewards and penalties for surpassing or neglecting to individually accomplish the objective levels [5], [10]. It urges power distribution companies to maintain the appropriate levels of reliability.

RPS combined in a PBR arrangement works like an agreement between an utility and its regulatory agency[10][24]. Power distribution company regulators, adopt different reward-penalty schemes, to help guarantee their quality levels. Regulators should pay power distribution companies that provide excellent performance and receive money from power distribution companies that provide poor performance[4]. This approach revises the company's revenues as per their reliability and rewards companies with high-quality levels and penalizes companies with lower-quality levels. It not only empowers the companies to enhance their service quality, but additionally adjusts the total rewards, awarded and the total granted and aggregates penalties gathered by the regulators[10].

The key purpose of this research is to develop an approach to control the quality of the continuity of supply in the form of Reward-Penalty Schemes. However, it should be noted that the current literature highlights some key problems associated with managing reliability as RPSs; the research gap serves as the motivation for this study. In the next section, such research motivations will be discussed

1.4 RESEARCH MOTIVATIONS

Power distribution company's regulatory authorities, are progressively moving to performance-based control and using company's historic performance, as a main consideration in setting specified service reliability standards[25]. A Performance based reward penalty scheme is one of the regulatory methods used by regulatory agencies to accomplish control and prevent crumbling of power service reliability [6], [16], [26]. Keeping in mind that the end goal is to apply such schemes, it is important to construct a careful plan. Neglecting to do this may result in the creation of ineffective model putting the company in financial risk. These schemes are generally separated by their schemes (symmetrical or non-symmetrical) and the strength of their motivations (reward or penalty)[26]. Advancement of power distribution systems, depends upon balancing development costs with the capacity for financial risk because of power outages [1], [26]. For the performance-based regulation to emerge and have the ability to interact with the proposed Performance based reward penalty structure meaningfully, several services have to be in place;some of these are already deployed as a core part of the performance-based regulation, and some exist in other contexts (e.g. Data envelopment analysis, Customer interruption cost analysis), while others need to be developed. Additionally, integration of all these services must be accomplished, with performance based on reliability, being the target focus area.

The aforementioned existing research studies are associated with several open research issues being applied to the area of managing reliability, in the form of RPSs.

These problems include:

- Deficiencies in using limited input parameters and in ensuring reasonable magnitude in reward- penalty calculation when applied to the context of managing reliability.
- Complexity in adopting reward penalty formulas and its inconsistencies with the desired outcome.
- Some aspects are notcomprehensively investigated in the existing literature, such as considering those outside factors that are outside of the control of the regulatory agency whose role is to manage performance based continuity of supply, without interruptions in the form of PCGs.
- Deficiencies in settings are realistic targets that should be able to support and monitor the company's performance behavior,
- Motivation of inefficient power distribution companies in power markets,
- Improving the power distribution company's reliability in power supply,
- Developing an effective RPS scheme that is more favorable to the regulatory agency than the power distribution companies,
- Developing an effective RPS scheme, that is more favorable to power distribution companies, than regulatory agencies,
- Developing an effective RPS scheme, that is most favorable to power distribution companies,
- Presentation of financial rewards/penalties which are administratively simple.

Based on the preceding issues, it is clear that this area of performance, based on reliability research, necessitates the improvement of the aspects of developing an efficient, reward-penalty scheme. As discussed earlier, the impact of the involvement of a large number of parameters, combined with inconsistent value for reward or penalty and difficulty in adopting reward-penalty formulas that exist in literature, has indicated that several deficiencies exist in the management of reliability, leading to the necessity to develop a new method. Lack of RPS schemes that are favorable to power distribution companies or regulators, also lead to developing a new method. This research investigates the most vital parameters for designing and implementing an effective RPS. This study can also assist regulators, specifically those regulators who want to initiate the service quality regulation, designing the RPS according to their political and technical circumstances.

1.5 RESEARCH OBJECTIVES

The fundamental research goal of this study is to develop an approach to managing continuity of supply without interruptions to the power distribution, using Reward-Penalty Schemes. This will require a critical review of the related literature, the development of solutions for research of particular issues, the development of models for these arrangements, and the verification and validation of the model. Theccompanying research objectives have been developed from the fundamental objective of this thesis.

Objective 1: Proposes a framework to define and characterize the parameters for designing and implementing RPS

Objective 2: Proposes a linear RPS Structure with and without any control features, such as dead band and capping, that is more favorable to the regulatory agency than the power distribution companies.

Objective 3: Proposes a quadratic RPS Structure, with and without any control features, such as dead band and capping, that is more favorable to power distribution companies, than regulatory agencies.

Objective 4: Proposes a cubic RPS scheme with and without any control features, such as dead band and capping that is the most favorable to power distribution companies.

Objective 5: Verify the concepts of the proposed methods.

1.6 SCOPE OF THE THESIS

As mentioned earlier, there are a significant number of challenges concerned with the development of RPS for power distribution companies, while maintaining excellent reliability in electrical power supply. However, it should be noted that we will only address four key research problems in this thesis, that relate purely to the domain of managing reliability in the form of RPSs, within the domain of electric power distribution. The subsequent four research problem areas, will need to address the following issues :

- how to define and characterize the most vital parameters for designing and implementing RPS,
- how to set a realistic target, that should be able to support and monitor the company's performance,
- how to ensure a reasonable scale for rewards or penalties,
- how to reduce the complexity in adopting reward penalty formulas,
- how to maintain the consistency of the reward penalty formula, to achieve the desired outcome,
- how to include certain external factors in RPS implementation, that affect the performance of power distribution companies, that cannot be controlled by the regulators,
- how to motivate the efficient and inefficient power distribution companies within power supply market,
- how toi mprove the power distribution companies reliability of power supply,
- how to develop an effective RPS scheme, that is more favorable to the regulatory agency, than the power distribution companies,
- how to develop an effective RPS scheme that is more favorable to power distribution companies than the regulatory agencies,
- how to develop an effective RPS scheme that is most favorable to power distribution companies,
- how to present financial rewards/penalties that are administratively simple.

In next section, the significance of this research, will be analysed.

1.7 SIGNIFICANCE OF RESEARCH

The significance of the issues addressed in this proposal is two fold and the advantages come about, because this research incorporates socio-economic and technical advantages.

1.7.1 SOCIO-ECONOMIC RESEARCH

- Reliable energy supply, increases bargaining power in Power distribution markets.
- Creates the motivation for power distribution.

1.72 TECHNICAL RESEARCH

- Controls performance based on reliability in the form of RPSs
- Proposes a framework to define and characterize the parameters for designing and implementing RPS
- Proposes a linear RPS scheme that is more favorable to the regulatory agency than the power distribution companies.
- Proposes a quadratic RPS scheme that is more favorable than power distribution companies than regulatory agencies.
- Proposes a cubic RPS scheme that is most favorable to power distribution companies.

1.8 DISSERTATION STRUCTURE

The remainder of this thesis is structured as follows.

CHAPTER 2 presents a comprehensive review of related, research on, RPSs. This chapter provides a survey and evaluation, of the RPSs–survey. It also assesses the different existing approaches within the field of, erformance-based regulation, as, well as other contexts, that are possibly adaptable to RPSs and the current research gaps, in the development of RPSs.

CHAPTER 3 defines four research problems associated with managing performance based on reliability,in the,form of RPSs–problems. It defines and characterizes the most vital parameters, magnitude for reward or penalty, dropping the complexity in adopting reward penalty formulas and its inconsistencies with the desired outcome and the problem of including external factors that are not controlled by regulators.These problems are defined, taking into account the fragments of knowledge gathered from the literature review in Chapter 2.This chapter also defines a few preliminary ideas, that are utilized as a part of characterizing solution requirements. Given the plainly characterized issues, problems and needs, it then talks about the science and engineering designing methodology, that will be utilized to tackle these four issues and address these research issues.

CHAPTER 4 proposes the conceptual framework that addresses the problems of defining and characterizing parameters used for evaluating the rewards and penalties, based on reliability indices, efficiency score and interruption indices. Four conceptual models are constructed to illustrate the theoretical framework.

CHAPTER 5 proposes a linear RPS Structure with and without any control features, such as dead band and capping, to proactively analyze the performance of the power distribution companies, before assigning the reward and penalty. It also illustrates how this scheme is more favorable to the regulatory agency, than the power distribution companies. Furthermore, we also simulate the functionality of the proposed structure, using of a pre-defined reliability data set.

CHAPTER 6 proposes a quadratic RPS Structure, with and without any control features, such as dead band and capping to proactively analyse the performance of the power distribution companies, before assigning rewards and penalties. It also illustrates how this scheme is more favorable to the power distribution companies, than the regulatory agency. Furthermore, we also simulate the functionality of the proposed structure using a pre-defined reliability data set.

CHAPTER 7 proposes a cubic RPS Structure with and without any control features, such as dead band and capping, to proactively analyses the performance of thepower distribution companies before assigning the rewards and penalties. It also illustrates how this scheme is most favorable to the power distribution companies than the regulatory agency. Furthermore, we also simulate the functionality of the proposed structure using a pre-defined reliability data set.

CHAPTER 8 presents the discussion and recommendations of the proposed RPS structures.

CHAPTER 9 concludes the entire dissertation work, by outlining what has been accomplished and its fundamental advantages. It will, identify the work that remains to be done and proposes future work directions for this research direction.

1.9 CONCLUSION

An important significance of restructuring in the power industry is the emergence of service quality regulation within power distribution. Reward-Penalty Schemes for power distribution companies is implemented to assure the system and service reliability. It is a financial tool designed to prevent the service reliability and efficiency deterioration, of power distribution companies. RPS rewards the utility which is providing excellent reliability and penalizes the utility which provides poor reliability. The aim of this research is to address the initial research challenges of managing reliability performance, in the form of reward penalty schemes.

CHAPTER 2

LITERATURE REVIEW

This chapter provides:

- A critical review of existing literature on the Reward-Penalty Schemes, utilized to manage performance reliability of the company's power distribution.
- A critical evaluation of the parameters used by different existing literature, in the field of performance-based regulation, and their adaptability to control power distribution companies, in the form of RPSs.
- A classification of existing literature, based on the conceptual modules that are used to develop a framework for designing and implementing RPS.
- A discussion of the most principal aspects that should be considered while designing RPS.
- RPS design challenges and requirements based on the critical review of the existing relevant literature.

2.1 INTRODUCTION

A significant factor of restructuring in the power industry is the emergence of performance regulatory indices in the power distribution company. The Reward-Penalty Scheme (RPS) is a direct control method that regulators use, to assure the performance regulatory controls such as system reliability, service efficiency, and customer interruption cost. It is a financial tool, designed to prevent the service reliability and efficiency deterioration, of power distribution companies. Reward penalty schemes reward the distribution company which provides a reliable service and penalizes those companies that provide poor reliability[25]. The objective of this chapter is to conduct a comprehensive literature survey of the existing Reward-Penalty Schemes, proposed in the literature and those that are used by power distribution companies, to improve their reliability and efficiency. This literature review also investigates the main parameters required for designing and implementing an effective, Reward-Penalty Structure, for power distribution companies[27].

In the previous chapter, we discussed the background information, associated with managing power distribution companies by utilizing RPSs, while providing an introduction to the fundamental concepts such as, regulation and deregulation, in power distribution companies, performance-based regulations, quality control, reliability and reward-penalty schemes. We also highlighted and explained the importance of developing RPSs to manage the reliability of the power supply without any interruptions by power distribution companies.

As mentioned in Chapter 1,the RPS refers to a mechanism, based upon their reliability in supplying power, to create a financial rewards or penalties for distribution companies, to maintain or change their quality levels [11]. This chapter provides an overview of the literature about RPSs. It also povides an evaluation of existing methods, in the area of performance-based regulations and in other situations, such as risk-based maintenance in the context of RPS and service quality regulation, to address their adaptability to establish RPSs. Accordingly, this dissertation will cover the study that has been conducted of existing literature. This information will be provided in three main sections.

It is to be noted, that, in this chapter, we comprehensively explain the research work which has been conducted on RPSs. However,we do no tdiscuss all aspects of the performance-based regulation projects and research studies, as well as the research studies in other contexts,(risk based maintenance in the context of RPS, service quality regulation) in detail. This is beause the aim and scope of this thesis is related to the management of performance, based on reliability of the power supply, in the form of RPSs; thus,we focus on how those relevant approaches of existing research, can be adapted to managere liability of power supply in the form of RPSs.The rest of this chapter is structured as follows:

- In Section 2.2, we provide the different approaches used to implement RPS
- In Section 2.3, we provide a classification of different existing approaches in the field of performance-based regulation and their adaptability to control power distribution companies, in the form of RPSs.
- In Section 2.4, we discuss the parameters used by different approaches for performance-based regulation, to implement RPSs

- In Section 2.5, we classify different existing literature, based upon the conceptual modules that are used to develop a framework for designing and implementing RPS.
- In Section 2.6, we discuss the principal aspects that should be considered, while designing RPS
- Section 2.7discusses the RPS design challenges and requirements based on the critical review, of the existing relevant literature.
- Lastly, the concluding statements are given in Section 2.8.

2.2 DIFFERENT APPROACHES USED TO IMPLEMENT REWARD-PENALTY SCHEMES

In the literature, there is a scant amount of research work that proposes RPSs for managing reliable power supply, in the power market. In this section, we review existing literature, in relation to the different approaches used for implementing RPS.

Abbaspour et al. [28] has designed reward/penalty structures for power distribution companies, taking into account the parameters such as AENS and SAIFI. The Fuzzy C-implies that a calculation has been utilized to classify comparative power distribution companies. The average system reliability indices[28], for example, System Average Interruption Frequency Index (SAIFI) and Expected Energy Not Supplied (EENS), were taken as the comparative analysis standard in RPS design. The proposed RPS in [11], [28], is executed in the Iranian electric power distribution sector, to look at the potentials of various companies, in achieving the predetermined objectives.

Latify et al.[23], assessed the effect of the maintenance proposals on the unwavering reliability indices (EENS) and assigned rewards/penalties to the power generation companies; to the extent of their commitments to there liability index infringement, at a desirable level. In [26], [29] the Sequential Monte Carlo reenactment is utilized, to survey the year on year variability of bulk electric, framework reliability, performance indices. The outcomes demonstrate that the likelihood dispersions of unwavering performance-based reliability indices, have novel attributes that are in a general sen,dependent upon the framework topology, working philosophy and framework conditions[29]. The paper[29]showed that the ability to foresee performance-based reliability index distribution (SAIDI, SAIFI), could be utilized to give an appreciation of the related financial risk connected with an assigned PBR reward/penalty structure[29]. Both historic and reproduced performance-based reliability indices, actualized in a speculative PBR structure, are delineated in this chapter. Performance-based reliability index probability distribution analysis, can provide power distribution specialists and risk controllers, with ,basic information on bulk electric framework adequacy and help them with overseeing and controlling the potential future dangers, under a PBR reward/penalty structure[29].

Brown and Burke [13] have exhibited a strategy for measuring the system reliability and disclosed a method for measuring PBR risk[4]. To adequately deal with the risk of PBR's, distribution companies must have mechanisms that can anticipate system reliability quality, on both levels of the system and the customers. These mechanisms must go past expected values, and should have the capacity to survey the variation in reliabile quality from year to year. To make these mechanisms as exact as can be expected under the circumstances, it is important that power distribution companies should keep up a credible, chronicled, historyof reliability, information records. It has demonstrated a strategy that permits existing reliability, quality evaluation mechanisms, to be effectively consumed, to oversee PBR risk.

Fotuhi et al. [2] created more than one reliability indices (SAIDI and EENS) and developed reward-penalty models for expanding the exactness of PBR. Distinctive reward penalty models had been presented utilizing real system reliability information, as a part of Tehran Regional Electrical Company (TREC).

Yahav et al. [26] proposed a technique for evaluating the reliability and performance based motivations for power distribution companies, taking into account the Monte-Carlo simulation utilizing, reliabilty index SAIDI. This methodology is exhibited for a case study and amassed to the whole Distribution system of the Israel Electric Corporation (IEC)[26].

Da Silva et al. [30] introduced another strategy to ascertain the penalties and rewards in distribution systems, to keep away from an unanticipated disruption in the electric system. This strategy penalizes a utility, which has a high level of reliability in its system[30]. The proposed technique urge companies to invest in the improvement of their distribution system reliability[30].

Billinton and Pan [24] exhibited real reliability information taken from the Canadian Electricity Association (CEA) Service Continuity Reports. The financial PBR analyses connected with the historic reliability data, are shown by joining reliability index probability distribution in forced reward/penalty, approaches.

Billinton, Cui and Pan [31] concentrated on the use of the probability distribution of reliable ideas, to find a balance, between reliability improvement and cost saving methods to power utilities subject to PBR. Often, the reliability indices, for example, SAIFI, SAIDI, and ENS are the most widely recognized parameters, utilized as a part of RPS execution.

Li [32] displayed a distributed handling method for Reliability Index Assessment (RIA) for distribution companies. Likewise, an appropriate balance to deal with accomplishing better effectiveness is proposed. The appropriate preparing of RIA.is applied to the reliability based network reconfiguration (NR)[32].

Saboorideilami and Abdi [14]built up a risk-based technique, to evaluate the related financial risks created by quality regulation for DSOs. Moreover, to take the stochastic conduct of the distribution system and quality indices variations into account,the time-consecutive Monte Carlo simulation technique, is utilized. The impact of taking the reclosing time will be inspected on system quality indicators and the expense of quality regulation in Swedish Rura l Reliability Test System (SRRTS)[14] will be taken into account. The outcomes demonstrate that mulling over reclosing faults, influencing the system reliability indicators, especially yearly average interruption frequency indexes of the system (SAIFI). In addition, it also influences the quality regulations cost.

Simab and Haghifam [10] evaluated, recorded past quality levels and the efficiency scores from DEA were utilized, to discover target quality level for every company. It depends up on the recorded past reliability index (average and standard deviation of the index), the DEA effectiveness score and the interruption costs for every company[10].

In [11], a methodology was generated to get parameters of RPS for every electrical distribution company who utilized DEA, in the presence of some weighted reliability indices. With their weights. Research work in [1], [33], [34] concentrated on composite, generation and transmission framework reliability assessment, using sequential Monte Carlo simulation. Sequential simulation can be utilized to sensibly speak to most possibilities and the complex operational attributes in a bulk electric system, furthermore giving thorough scope of reliability indices, in both ampleness and consistent state security, investigations. Two huge points of interest while using sequential simulation are the capacity to get precise frequency and duration indices, and the chance to integrate the reliability index probability distribution, connected with the mean qualities. The reliability index probability distribution of SAIDI and SAIFI and their related expenses are applied to manage the bulk power system risk.

Mohammadnezhad-Shourkaei et al. [24] decided that the maintenance plan boosts the benefits for distribution companies, considering the motivating forces given by regulatory authorities. An efficient risk-based maintenance management system is applied in RPS. Decision tree and mixed- integer linear programming (MILP) formulation[24], are utilized as a part of the proposed approach, to deal with accomplishing aprecise description of the time-dependent failure rates of equipment within the distribution companies, and to assess the viability of the different maintenance methods. The primary commitment of this paper is to consolidate service reliability regulation in the distribution companies' maintenance management strategy. This gives a valuable kit to optimally allocate maintenance resources in the presence of RPS[24].

Lotero and Contreras [35] disclosed the most pertinent reliability indices and their related expenses. The outcomes demonstrate that huge contrasts can happen in the expense caused by a distribution company, when the regulator applies penalties for not abiding as far as possible for reliability indices (SAIDI and SAIFI) and the assessed cost which the clients will pay to avoid interruption (Interruption Cost). It helps to distinguish how clients are influenced, as well as the related effects on expenses

Božič and Pantoš, [36] introduced a strategy for reliability investment decisions when a reward/penalty scheme is applied to the regulation of distribution companies. The (Monte Carlo) MC simulation method [36] is used to decide upon the best improvements for system reliability. The proposed technique was tried on the Slovenian distribution network,where distribution companies were analysed, taking into account their cost- efficient improvement of SAIDI[36].

Alvehag and Awodele [12] developed a strategy to establish the effects that different RPS designs have on the distribution company's financial risk and incentives/penalties. The regulator can utilize this technique before implementing a regulation, to attain an understanding of the effect of various RPS design solutions has on the power distribution companies' financial risk along with the incentives to invest in reliability. The proposed strategy in [12] additionally incorporates a sensitivity analysis to recognize which are the most critical parameters in an RPS implementation. The interruption cost indices (IC), System Based Reliability Indices (SAIDI and SAIFI), and load based indices (AENS) were applied in [5] to survey the power distribution companies' incentive rate. This technique is applied to three regulatory challenges in order to assess their RPS design solutions; these are: (a) Reconstruction of Customer's Interruption Costs, (b) Decrease the Variation in the Distribution System's Financial Risk and (c) Limit the Distribution System's Financial Risk. This system is proposed to persuade the power distribution companies to enhance their service reliabilityand to level the aggregate rewards paid and the aggregate penaltiesreceived regulators.

Moradkhani et al. [15] built up a risk-based maintenance management, in RPS. It allowed distribution system operators to consider budgetary risk, which emerges from RPS, in the maintenance scheduling. To estimate the financial risk of actualizing the given reliability of reinforcement projects, eg preventive maintenance projects, the probability distribution of financial outcomes,derived from implementing given preventive maintenance, requires computing of the instability of system reliability. This is normally expressed using the probability distribution of SAIDI. Therefore, the paper [15] presents the outage time generation algorithm, to determine the probable distribution of outage frequency and extracts the probability distribution of SAIDI, from the probability distribution of outage frequency. Having the probability distribution of SAIDI, the probability distribution of the financial result is computed. It then characterizes the risk-based target function and finds the ideal solution, i.e. the best preventive maintenance action, using the generic algorithm[15].

Alvehag and Söder [9] built up a risk based technique for reliability investment decisions, whenthe DSO is presented financial risks characterized by quality regulation. This study is conducted for two diverse quality regulation designs. The outcomes demonstrate that essentially the quality regulation designs, as well as the risk model detailing and risk technique, majorly affect which reinvestment project is chosen.

Mohammadnezhad-Shourkaei and Fotuhi-Firuzabad [4] achieved an extensive numerical study to inspect the relevance of their proposed approach. The outcomes demonstrated that executing the proposed technique can viably enhance the service reliability and eliminated the implementation expense of PBR.

Xu et al. [27]developed a numerical parametric, enhancing models used for ideally assigning the parameters of the PBR inside a reward/penalty structure. It minimizes the expenses associated with the PBR implementation in RPS. Subsequently, the model acquired the required quality level for the distribution system operation.

The Reward-Penalty Scheme in [10], [11] depends on the historical reliability index (average and standard deviation (SD) of the reliability index), Data Envelopment Analysis (DEA) efficiency score, slack investigation and interruption cost for every company. The length of the distribution network (km), the quantity of feeders and number of transformers were considered as yields and SAIDI were considered as a contribution for characterizing a model of DEA to quantify the efficiency of electric distribution companies.

The relevant literature surveyed in this paper in the area of PBR with an RPS structure for distribution companies, emphasized the risk and management issues that the distribution companies face under this quality regulation mechanism. What is missing in the literature is a classification of different existing RPS implementation tomaintainthe required reliability level, while minimizing the related expenses. We have reviewed most of the RPS schemes and analyzed it in detail. This is explained in the next section of this chapter.

2.3 CLASSIFICATION OF THE EXISTING REWARD-PENALTY APPROACHES

Table 2.3.1 Classification of the Existing Reward-PenaltyApproaches

Performance reliability module	
Brown and Burke [13] (2000)	**Designed a risk assessment methodology capable of quantifying the uncertainty of system reliability and individual customer reliability**
Billinton, Cui, and Pan [31] (2002)	**Focused on the application of index probability distribution concepts to establish an appropriate balance between reliability improvement and cost saving strategies to power utilities subject to PBR**
Billinton and Pan [25] (2004)	**Conducted financial risk analyzes associated with the historic reliability data by incorporating reliability index probability distributions of SAIDI and SAIFI in penalty policies.**
Li[32] (2005)	**Presented a distributed processing approach of reliability index assessment (RIA) for distribution systems**
Billinton and Wangdee [29] (2006)	**Proposed a sequential Monte Carlo simulation to assess the annual variability of bulk electric system reliability performance indices.**
Fotuhi et al. [2] (2006)	**Examined multi reliability indices and multi-steps reward-penalty model.**
Yahav, Oron, and Young[26] (2008)	**Proposed reliability estimation based on a Monte-Carlo simulation of the SAIDI.**
da Silva et al. [30] (2010)	**Discussed how reliability indices could be fully used through performance-based mechanisms to establish contracts that penalize for poor services in electric power distribution systems.**
Latify et al. [23] (2013)	**Evaluated the impact of the maintenance proposals on the reliability indices (EENS) and assigned rewards/penalties to the generating com-**

	panies; in proportion to their contributions in reliability index violation at a desirable level.
Saboorideilami and Abdi [14] **(2014)**	**Developed a risk-based method to assess the financial risks and examined system reliability indicators (SAIFI, SAIDI, and CAIDI)**
Jooshaki et al. [28] **(2014)**	**Designed RPS using System Average Interruption Frequency Index (SAIFI) and Expected Energy Not Supplied (EENS).**
Wang et al. [37] **(2014)**	**Proposed a maintenance scheduling model based on distribution system reliability assessment to determine the optimal implementation time of maintenance activities to minimize distribution systems' total cost, while satisfying reliability requirements.**

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Performance reliability and efficiency module	
Simab and Haghifam [10] **(2012)**	Two reliability indices (SAIDI and SAIFI) and DES efficiency score were used to design RPS.

Performance reliability and Interruption Cost Module	
W. Wangdee [1] **(2005)**	Used the concept of applying reliability index probability distributions Customer interruption cost to assess bulk electric system risk
Mohammadnezhad-Shourkaei et al. [8] **(2011)**	Proposed a maintenance plan that maximizes the profit of Distribution companies.
Lotero and Contreras[35] **(2011)**	Evaluated a multistage optimization model for distribution systems expansion planning that takes into account: investment, maintenance, and operational (losses) costs. In addition to the optimization problem, reliability indices, and associated costs are computed.
Božič and Pantoš [36]	Presented a method for reliability investment decisions to facilitate the transition from (cost-based reg-

(2013)	ulation) CBR to (performance-based regulation) PBR for distribution utilities.
Alvehag and Awodele [5] **(2014)**	Designed Reward penalty structures using regulatory indices like SAIDI, SAIFI, AENS, and IC.
Moradkhani et al. [15] **(2015)**	Presented the risk-based maintenance management method that allowed DSOs to consider financial risk, which arises from RPS, in the maintenance scheduling. Calculated the uncertainty of system reliability, using the Probability Distribution of SAIDI
Mohammadnezhad-Shourkaei and Fotuhi-Firuzabad [4] **(2010)**	Accomplished a comprehensive numerical study to examine the applicability of their proposed approach.
Alvehag Söder [9] **(2011)**	Developed a risk-based method for reliability investment decisions when the DSO is exposed to financial risks defined by a quality regulation

Performance reliability, efficiency, and Interruption cost module	
Xu et al. [27] **(2011)**	Developed a mathematical parameterized optimization model for optimally setting the parameters of the PBR with a reward/penalty structure is presented, with the minimization of the costs associated with the enforcement of the PBR as the objective and the required reliability level for the distribution system operation as the constraint.
Simab et al. [11] **(2012)**	The proposed algorithm creates financial incentives for distribution companies to improve or maintain their reliability levels. The parameters of RPS are based on the historical reliability index (average and SD of the index), DEA efficiency score, slack analysis and interruption cost for each company.

What is missing in this section is a thorough review of the different parameters used for different RPS implementations, while maintaining the required reliability level, and reducing the related overheads. We have evaluated all the relevant parameters used in the

RPS schemes and analyzed them in detail. This is explained in the next section of this chapter.

2.4 PARAMETERS USED BY DIFFERENT APPROACHES FOR PERFORMANCE-BASED REGULATION TO IMPLEMENT RPS

Power distribution company regulators use different parameters for assessing the reward-penalty of power distribution companies. Most researchers have used performance-based reliability parameters,for assessing the reward/penalty of distribution companies.These parameters include outage duration, the frequency of outage, response time, restoration time, the total number of customers served, and the total number of customers interrupted for measuring the reliability indices(SAIDI, SAIFI, CAIDI, ENS, AENS).Some researchers have applied both the system based performance reliability parameters and Data Envelopment Analysis (DEA) efficiency score, for assessing the reward/penalty of distribution companies. Numerous researchers have related both system based performance reliability parameters and customer interruption costs for assessing the reward/penalty of distribution companies[1], [31], [36]. A few researchers have worked on system based performance reliability parameters, Data Envelopment Analysis Efficiency(DEA) scores and customer interruption costs for assessing the reward/penalty of distribution companies[11], [27].

Table 2.4-1. Parameters Used by Different Approaches

Research	Indices
[21] (2000)	SAIDI
[22] (2002)	SAIDI, SAIFI, EENS
[23] (2004)	SAIDI, SAIFI, CAIDI, MDZ➔SD(RI)[1], DZW [1]➔ SD(RI)
[24] (2005)	SAIDI, SAIFI, CAIDI
[25] (2006)	SAIDI, SAIFI
[2]	SAIDI, SAIFI

[1] SD(RI) – Standard Deviation of Reliability Index, DZW – Dead Zone Width

(2006)	
[26] (2008)	SAIDI
[27] (2010)	SAIDI
[28] (2013)	SAIDI, EENS
[18] (2014)	SAIDI, SAIFI
[11] (2014)	SAIFI, EENS
[29] (2014)	SAIDI, SAIFI, CAIDI, EENS
Research	**Indices**
[1](2005)	SAIDI, SAIFI, IC
[7]2011)	SAIDI, SAIFI, IC
[31] (2011)	SAIDI, SAIFI, IC
[32] (2011)	SAIDI, SAIFI, IC
[30] (2011)	SAIDI, SAIFI, IC
[12] (2014)	SAIDI, SAIFI, IC
[8](2015)	SAIDI, IC, MDZ➔RI, DEA, DZW ➔ SD(RI), RPR[2]➔ SD(RI)/2
Research	**Indices**
[9](2012)	SAIDI, SAIFI, DEA
Research	**Indices**
[10] (2012)	SAIDI, DEA, IC

2.5 CLASSIFICATION OF EXISTING LITERATURE BASED ON THE CONCEPTUAL MODULES TO DEVELOP A FRAMEWORK FOR RPS DESIGN AND IMPLEMENTATION

Based on the critical review of the different approaches used by existing literature for implementing RPS in section 2.2, we classify the literature based on their approaches. This classification is donefor developing a framework which assists in designing and implementing RPS. The detailed description of this frameworkis explained in the next chapter.

[2] RPR – Reward Penalty Ramp

Table 2.5-1 Classification of conceptual modules used by different existing Reward-Penalty methods

Reference papers		System based Reliabilty Indices			Load based Reliability Indices	DEA Score	Value of Interrupted Power,X	IC	MDZ	Dead Zone width	Reward/Penalty Ramp
		SAIDI	SAIFI	CAIDI							
	Performance reliability										
[21] (2000)	Designed a risk assessment methodology capable of quantifying the uncertainty of system reliability and individual customer reliability	√									
[22] (2002)	Focused on the application of index probability distribution concepts to establish an appropriate balance between reliability improvement and cost saving strategies subject to PBR	√	√		EENS						
[23] (2004)	Conducted financial risk analyzes associated with the historic reliability data by incorporating reliability index probability distributions of SAIDI and SAIFI in penalty policies.	√	√	√					SD(RI)	SD(RI)	
[24] (2005)	Presented a distributed processing approach of reliability index assessment for distribution systems	√	√	√					RI		
[25] (2006)	Proposed a sequential Monte Carlo simulation to assess the annual variability of bulk electric system reliability performance indices.	√	√						SD(RI)	SD	
[2] (2006)	Examined multi reliability indices and multi steps reward-penalty model.	√	√		EENS				SD(RI)	SD(RI)	SD/2

Reference papers		System based Reliabilty Indices			Load based Reliability Indices	DEA Score	Value of Interrupted Power,X	IC	MDZ	Dead Zone width	Reward/Penalty Ramp
		SAIDI	SAIFI	CAIDI							
[26] (2008)	Proposed reliability estimation based on a Monte-Carlo simulation of the SAIDI.	√									
[27] (2010)	Discussed how reliability indices can be fully used through performance-based mechanisms.	√							SD(RI)	SD(RI)	
[28] (2013)	Evaluated the impact of the maintenance proposals on the reliability indices and assigned rewards/penalties to the generating companies.				EENS						
[18] (2014)	Developed a risk-based method to assess the financial risks and examined SAIFI, SAIDI and CAIDI	√	√								
[11] (2014)	Designed RPS using SAIFI and EENS.		√		EENS						
[29] (2014)	Proposed a maintenance scheduling model based on distribution system reliability assessment	√	√	√	EENS				SD(RI)	SD(RI)	
Performance reliability and Interruption cost module											
[1] (2005)	Used the concept of applying reliability index probability to assess bulk electric system risk	√	√					√			

Reference papers		System based Reliabilty Indices			Load based Reliability Indices	DEA Score	Value of Interrupted Power,X	IC	MDZ	Dead Zone width	Reward/Penalty Ramp
		SAIDI	SAIFI	CAIDI							
[4] (2010)	Accomplished a comprehensive numerical study to examine the performance based regulation implementation cost related to system reliability index.	√	√				√	√			
[7] 2011)	Developed a risk-based method for reliability investment decisions.	√	√				√	√			
[31] (2011)	Proposed a maintenance plan that maximizes the profit of Distribution companies.	√	√					√			
[32] (2011)	Evaluated a multistage optimization model for distribution systems expansion planning.	√	√					√			
[30] (2011)	Designed Reward penalty structures using SAIDI, SAIFI, AENS, IC.	√	√					√			
[12] (2014)	Presented the risk-based maintenance management method using the Probability Distribution of SAIDI	√	√					√			
[8] (2015)	Developed a mathematical parameterized optimisation model for optimally setting the parameters of the PBR with a reward/penalty structure.	√						√	RI, DEA	SD	SD(RI)/2

Reference papers		System based Reliabilty Indices			Load based Reliability Indices	DEA Score	Value of Interrupted Power,X	IC	MDZ	Dead Zone width	Reward/Penalty Ramp
		SAIDI	SAIFI	CAIDI							
Performance reliability and efficiency											
[9] (2012)	Designed RPS using SAIDI, SAIFI and DES.	√	√			√					
Both Performance reliability and efficiency and Interruption cost											
[10] (2012)	**Proposed algorithm creates financial incentives for distribution companies to improve or maintain their reliability levels.**	√				√(slack)		√			

In the next three subsections, we discuss these methods in detail, while referring to relevant existing research contributions.

2.5.1 PERFORMANCE RELIABILITY BASED APPROACH

Electricity plays a necessary role in modern society. Our expanded reliance on electric power, implies increased interest on the power system, which puts weight on the system's reliability. Power system performance reliability, quality assessment, is an imperative movement, in a recently deregulated power industry. The simplest meaning of reliability is that power is accessible when it is required. To present an arrangement of terms and definitions to encourage consistency, in 1998, the Institute of Electrical and Electronic Engineers (IEEE), characterized the accepted reliability indices in its standard number, P1366, "Guide for Electric Distribution Reliability Indices" [33]. IEEE-P1366 established the common definitions and terminology for the industry and defined key reliability indices such as SAIDI, SAIFI, CAIDI, EENS and AENS (Table 2.4-2). These lists are discussed in detail in Section 3.1.1 to 3.1.2. To guide new personnel and tools for comparison, IEEE tightened the definitions in 2003 [62].

The Reliability Index, is a parameter, that measures the performance reliability of a power system. System performance reliability indicators are isolated into two classifications: *system reliability indices* and *load reliability indices*[38]. The most important system reliability indices include System Average Interruption Duration Index (SAIDI), System Average Interruption Frequency Index (SAIFI) and Customer Average Interruption Duration Index (CAIDI). The most important load-based quality indicators are Expected Energy Not Supplied (EENS) and Average Energy Not Supplied (AENS)[39], [21]. In the literature, the term load is interchangeably used to refer to energy [23]. We now describe system reliability indices and load based reliability indices in detail.

2.5.1.1 SYSTEM RELIABILITY INDICES

The Institute of Electrical and Electronic Engineers (IEEE) illustrates the accepted reliability indices in its standard number P1366 [62]. These indices consider the effects of the number of outages, the duration of each outage, and are usually calculated from historical utility data[41]. These indices aim to assess the level of customer satisfaction, which is based upon the total length of outages (interruptions)[41]. In the chapter, three different system reliability indices (i.e. SAIDI, SAIFI, and CAIDI) are discussed. These indices rely on a number of parameters such as outage duration, and the frequency of outage. These parameters are

1. *System topology*
2. *Outage duration*
3. *Frequency of* interruptions
4. *System availability*
5. *Response time*
6. *Total number of customers served*
7. *Number of customers interrupted*
8. *Protection mechanism*
9. *Restoration time*

1. *System topology* refers to different approaches to portraying the reliability of a system, including fault trees, reliability block diagrams, and failure mode effects analysis. Each topology has different strengths and weaknesses regarding reliability. Brown et al. (1998) illustrated that distribution system reliability assessment, can predict the interruption profile of a distribution system that is based on system topology.

2. *Outage duration* (or duration of the interruption) refers to the period from the start of an interruption until the service has been restored to the affected customers. It can be measured in seconds, minutes, hours, or days. One of the objectives of the power distribution system reliability assessment, is to reduce the duration of outages. Reducing outage duration, as measured by SAIDI and CAIDI, is related to the implementation of distribution automation and outage detection technologies and more efficiently operating and restoration practices for those customers experiencing sustained outages.
3. *The frequency of outages* (Frequency of interruptions) refers to the number of times that outages have occurred in a given period and is measured in seconds, minutes, hours, or days. The reliability of the power distribution system can be improved by reducing the frequency of outages. Reducing the frequency of outages, as measured by SAIFI, is related to a mix of component factors, including undergrounding, storm hardening, infrastructure improvements, and the use of automated distribution systems.
4. *System availability* refers to the probability that a repairable system is operational at a given point in time, taken after a given set of ecological conditions[42]. Reliability can be characterized as the likelihood that a device or a system will play out a given task condition for a particular timeframe, while availability is that, a system will have the capacity to play out its required capacity, over a particular timeframe, under specified environmental conditions[43].
5. *Response time*: Response time refers to the time that takes an operator to characterize a solution during contingencies. Response time during service restoration influences the reliability indices that are identified with the lengths of the failure, demonstrating that a fast decision straightforwardly adds to the system performance.
6. *A total number of customers served,* refers to the number of customers served within the reporting time frame (N)[44]. This parameter is used in the estimation of performance reliability indices such as SAIDI, SAIFI, and CAIDI.
7. *A number of customers interrupted,* refers to the number of interrupted customers for each sustained interruption event within the reporting time frame (N_i) and is used in the calculation of the reliability index, such as SAIFI[45].
8. *Protection mechanism*: With the development of advanced technology-based protection mechanisms for power distribution, outage events have become less frequent in

the modern power systems. Thus, protection mechanism has a critical part in the reliability of distribution systems.

9. Restoration time refers to the duration of time which begins when a fault is identified and ends, when services have been restored back to normal. New devices and systems make it possible for utilities to know when customers lose power and to pinpoint outage areas more decisively. This capacity enhances restoration times and abbreviates outage durations. Once an outage occurs the average time to re-establish the service is found from the Customer Average Interruption Duration Index (CAIDI).

We now describe the three indices SAIFI, SAIDI, and CAIDI, which use some of these parameters in computing the respective index.

SAIFI (System Average Interruption Frequency Index)[62], is the average number of times, that a customer experiences interruptions, during a given period and is designed to provide information about the average frequency of sustained interruptions[62], [46] per customer in a predefined region [35]. It is calculated by dividing the total number of customers interrupted (N_i) by the total number of customers served (N).

$$\text{SAIFI}=\sum_{i=1}^{N}(\frac{N_i}{N}) \quad \text{Equation 1}$$

Industrial customers are very concerned about the frequent outages since after each interruption; they may have to turn on their factory[4], which may have expensive start-up costs and could cause a loss of production time in the process, resulting in significant losses [6].

SAIDI (System Average Interruption Duration Index)[62], [47] is the average duration of outage for customers who experience an interruption during the year. To calculate SAIDI, each interruption during the period is multiplied by the duration of the interruption, to find the customer minutes of interruption. The customer minutes of all interruptions are then summed to determine the total customer minutes. To find the SAIDI value, the customer minutes are divided by the total customers.

$$\text{SAIDI}=\sum_{i=1}^{N}(\frac{r_i \times N_i}{N}) \quad \text{Equation 2}$$

Where, r_i is the duration of each interruption.

From Table 2.4-3 we can see from the literature that SAIDI is used more than SAIFI. Results in [10] show that the number of interruption (SAIFI) is less important, than the duration of the interruption (SAIDI). For example, customers residing in the rural areas may live with frequent outages but may be concerned with the duration of the outage[6], [47].

For the regulators who want to use the RPS, applying one index may be sufficient, to motivate the distribution system operators to perform better. The selection of two or more indices can satisfy all customer concerns (both industrial and rural). When applying multiple indices, the weighting of the individual index, based on the customer's type, is a significant approach that perfectly follows the customers' interest [4]. For example, in the rural area, the weight of SAIFI should be less than that of SAIDI, from the point of view of the RPS. The SAIDI and SAIFI measures discussed in this literature, are widely used, both in Australia [46]and internationally.

CAIDI (Customer Average Interruption Duration Index)represents the average time required to restore services to the average customer per sustained interruption. CAIDI is calculated similarly to SAIDI, except that the denominator is the number of customers interrupted, versus the total number of customers served.

$$\text{CAIDI} = \frac{\left(\sum_{i=1}^{N}(ri \times Ni)\right)}{\left(\sum_{i=1}^{N}(Ni)\right)} = \frac{SAIDI}{SAIFI} \qquad \text{Equation 3}$$

CAIDI is typically preferable to SAIDI, in the Canadian Energy Research Institute (CERI) study [51], because it is the duration of single (average) customer interruptions. It usually proves most intuitive and useful to evaluate the cost effectiveness of restoration and automation functions.

However, as pointed out in [62], as CAIDI is the ratio of SAIDI/SAIFI, a disproportionate improvement in one measure may lead to a misleading CAIDI result. For example, relatively higher improvements in outage frequencies, compared to outage durations, could translate to a higher CAIDI value. We will now describe the second type of performance reliability index known as the Load Reliability Index.

2.5.1.2 LOAD (ENERGY) RELIABILITY INDICES

Although power distribution system reliability and power (energy or load) quality are related, they are two distinct issues. Power quality describes the characteristics, such as continuity of voltage, voltage fluctuations, unusual waveforms, and harmonic distortions of the supplied electric power, under typical working conditions. Lacking power quality can be described by (a) failures and different operations in the system, which results in voltage reduction bringing about interruptions (b) and network disturbances from loads that outcome in flicker, harmonics, and phase imbalance.

The applied SAIDI and SAIFI measures indicate the average duration and frequency of the sustained interruptions, by weighting the impact of the interruptions, by the number of customers affected. These measures implicitly give equal weight to all customers, irrespective of their size. An alternative approach to measuring the average duration and frequency of the sustained interruptions involves weighing the impact of the interruptions, by the size of customers affected. That is, instead of scaling the impact of an interruption by the number of affected customers, divided by the total number of customers, the impact is scaled by the kVA of the load affected, divided by the total kVA of the load connected to the network. However, these measures are not so commonly used internationally, which would limit the ability to make international comparisons[46].
These indices rely on a number of parameters, which are now discussed

1. *Average load connected to load point i* ($L_{a(i)}$)
2. *Average annual outage time* (U_i)
3. *Average outage time for the load point i* (r_i)
4. *Total energy not supplied by the system(kWh/y)*
5. *Total number of customers served(N)*
6. *Total connected kVA load(energy) served*

We now describe the two indices EENS and AENS, which use some of these parameters in computing the respective index.

Expected Energy Not Supplied (EENS): By using the load characteristics by industrial customer type in the load point, the amount of expected energy not supplied is calculated[52] as

EENS = Total energy not supplied by the system or Unserved Energy (UE)

$$= \sum(L_{a(i)} \times U_i) \text{ kWh/y} \quad \text{Equation 4}$$

Where $L_{a(i)}$ = Average load connected to load point i

U_i =Average annual outage time =$\sum_{j=1}^{n} \lambda_j \, r_j$ Equation 5

r_i = Average outage time for the load point $i = \frac{U_i}{\lambda_i}$ Equation 6

Average Energy Not Supplied (AENS): Average Energy Not Supplied (AENS) is a measure of the average non-delivered energy per customer. AENS is a reliability index, used for electrical power distribution systems and usually, have unit kWh per customer.

AENS = Total energy not supplied / Total number of customers served.

$$=\left(\frac{\sum(L_{a(i)} \times U_i)}{\sum_{i=1}^{N}(Ni)}\right)\frac{(\text{ kWh/y })}{\text{N}}$$ Equation 7

Where $L_{a(i)}$ = Average load connected to load point i

U_i =Average annual outage time=$\sum_{j=1}^{n} \lambda_j \, r_j$ Equation 8

r_i = Average outage time for the load point $i = \frac{U_i}{\lambda_i}$

These measures also have a relatively weak relationship to the economic value of reliability, because they measure the durations of interruptions, and so, do not capture the scale of the interruption. On the other hand, the EENS measures, are specifically designed to aid capacity planning and other decision processes. Due to this, they inherently provide a statistical measure of the reliability that customers may be provided. They can also be defined to provide a good correlation with the economic value of reliability and provide good visibility, of the factors driving reliability.

Many stakeholders, however, will not be familiar with the EENS measure. Moreover, reporting actual reliability is still likely to be important for reasons other than capacity planning. Therefore, the EENS measure would most likely need to be supported by reporting other measures that are based directly upon actual interruption events. Consequently, there will be an increased effort to prepare and report measures based upon EENS [46].

2.5.1.3 CRITICAL EVALUATION OF THE RELEVANT LITERATURE ON PERFORMANCE RELIABILITY APPROACH

In all, we reviewed 22 relevant research works. When we refer to Table 2.3-4, we observe that 19 of the 22 pieces of researches used SAIDI, fifteen used SAIFI and only two used CAIDI. Most of the work has focused on managing financial risks [25],[29], [14], [12] maintenance risks[37], [8], [15] performance risks [13], [31], [1], [8] and management problems, that the distribution companies face in relation to performance-based regulation methods[27] [2], [4], [9], [32]. We now discuss the relevant literature.

Brown and Burke [13] has introduced a method for evaluating the uncertainty of system reliability, to manage the PBR based risk on their system reliability indices like SAIDI and SAIFI, to establish fair performance-based rates, to implement optimal RPS design solutions that maximize profits while minimizing risk. Compared to [13], which focused on evaluating the uncertainty in system reliability to manage PBR risk, the work done by Billinton, Cui and Pan [31]focussed on establishing a balance between improving reliability and saving cost, by applying probability distribution index concepts to implement optimal RPS design solutions, using the reliability indices[24] such as SAIFI, SAIDI and ENS, which maximize profits while minimizing risk.As related to the PBR based implementation of RPS in [31], Billinton and Pan [25] demonstratedthe use of the time sequential Monte Carlo simulation. They implemented the probability distribution reliability index, from the actual performance records, for designing the expected system reward/ penalty (ERP) payment method, that uses both SAIFI and SAIDI information from the Canadian Electricity Association (CEA) Service Continuity Reports[25]. As corresponded to the Monte Carlo simulation by [25], Li[32]proposed a stable task partition (distributed processing) method, to attain improved efficiency of the Reliability Index Assessment (RIA), for distribution companies to maximize their system reliability. Associated with[25], Billinton and Wangdee [29] also used thesequential Monte Carlo simulation, to determine the annual inconsistency of bulk electric system reliability performance indices. They alsoobserved thatthe skills to foresee performance index distributions based reliability(SAIDI, SAIFI) would offer a financial risk related to a given PBR based reward/penalty scheme. Past, simulated reliability performance indices, are illustrated in it. Instead of single reliability indices used by most researchers for assessing the distribution companies performance, Fotuhi et al. [2], used multi-reliability indices (SAIDI and EENS) and developed a multi-steps Reward-Penalty scheme for improving the accuracy of PBR. This model had been introduced in the Tehran Regional Electrical Company (TREC).Similar to [25] and [29], Kobi Yahav [26] proposed a method of assessing the reliability and performance-based incentives for power distribution companies, based on a Monte-Carlo simulation using SAIDI. This method is proved in a case study and applied to the Israel Electric Corporation (IEC) Distribution system andoffers numerous benefits which are related to the conventional methods [53], [54].

Da Silva et al. [30] presented a method based upon the chronologicalMonte Carlo simulation to compute the penalties and rewards for distribution companies, through performance-based rate (PBR) mechanisms, in resemblance to[31], to penalize the company and inspire companies to invest in reliability improvement. Later on, in comparison to the performance-based regulation, Latify et al. [23]used the energy based reliability index (EIR) such as EENS, instead of the common system reliability indices, for evaluating the reliability and assigned rewards/penalties to the distribution companies. Saboorideilami and Abdi [14]introduced a risk-based method using the time-sequential Monte Carlo simulation method, to determine the risks brought on by quality regulation for power distribution companies, to consider the variation of distribution network behavior and the reliability indices(SAIFI, SAIDI, and CAIDI) variations. Based on the concept of the Yardstick theory,in comparison to the Monte Carlo simulation method, used in [14], Jooshaki et al. [28] designed reward/penalty structure, that has been implemented in the Iranian electric power distribution sector, based on AENS and SAIFI for power distribution companies, using Fuzzy C-means algorithm, which ensure regulators to improve the service reliability, by creating a perfect competition between distribution systems.

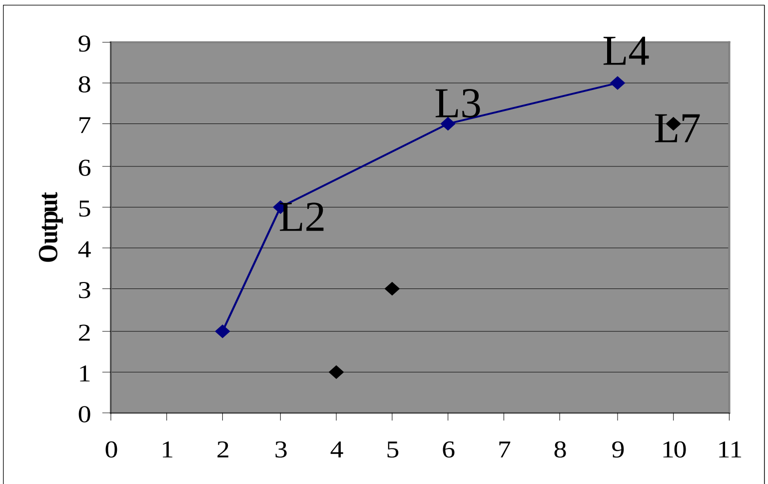
To identify the ideal usage time of maintenance activities used to reduce the power distribution company's total costs, whilst fulfilling reliability necessities, Wang et al. [37] proposed a hybrid maintenance scheduling model, based on system reliability assessment, using SAIFI and SAIDI. Similarly to the sequential Monte Carlo simulation method used in [25], [29], [26], research work in Wangdee [1] also used the same method of probability distributions of SAIDI and SAIFI and their related costs for system reliability evaluation, using sequential simulation, but focused on the bulk electric system. In the literature[4], a methodwas introducedto balance the collective rewards awarded and the penalties received by the regulator. This method does not just eliminate the performance-based regulation (PBR) implementation costs, it also eliminates further doubt among distribution companies, that the regulator can use PBR for profiting. As compared to the reliability evaluation and their related costs to manage the risk of bulk electric system[1], Mohammadnezhad-Shourkaei et al. [8] has developed an effective risk-based repair management plan in RPS, that maximizes the profit of distribution companies, using decision tree and mixed- integer linear programming (MILP) formulas.In addition to the associated impacts on costs while managing the performance-based regulation risk [1], [8], Lotero [35] identified how customers are affected by the reliability of information. This was done by computing the most relevant reliability indices (SAIDI and SAIFI) and their associated costs and comparing the impact of these costs to the distribution company,(when the regulator introduces penalties for noncompliance of reliability indices)withthe impact of customer's losses, when they experienced interruptions tothe system.As related to the above-described literature, Alvehag and Awodele [12] have studied the impact that various RPS designs have had on the distribution companies financial risk and incentives/penalties and done a sensitivity analysis, to find the critical parameters in an RPS design.As compared to [1], [8], Moradkhani et al. [15], developed a risk-based maintenance management objective function in the RPS, using a generic algorithm, to compute the financial risk of implementing reliability reinforcement projects, to analyze the ambiguity of system reliability. Xu et al. [27]developed a mathematical parametric optimizing model, for optimally minimizing the costs (loss caused by interruption to customers and reward/penalty costs), connected with the implementation of the PBR in the RPS, to obtain the requisite reliability standards for the distribution system operation. As compared to Xu et al. [27], Simab et al. [11], [10]presented an algorithm, to develop the reward-penalty schemeusing weighted reliability indices.

The literature reviewed in this paper discusses the implementation of the PBR with an RPS structure for distribution companies, placing emphasis on the financial risks, maintenance risks, performance risks and management difficulties, that the power distribution companies face when using this regulation mechanism. What is missing in the literature, is a thorough review of the different parameters used in RPS, for power distribution companies, in keeping the essential reliability range, but diminishing the related costs.

We now describe the second module presented. This is the Efficiency Module, where we describe the Data Envelopment Analysis (DEA) and the DEA Score.

2.5.2 EFFICIENCY BASED APPROACH

Before providing the mathematical aspects, the idea of production efficiency is clarified, with the assistance of a straightforward diagram [40] presented in Figure 2.5-1. To illustrate, consider seven distribution companies, which each have one input and one output: L1 = (2,3), L2 = (3,4), L3 = (7,7), L4 = (10,8), L5 = (4,3), L6 = (5,1), L7 = (11,7). Thus, the distribution company that requires fewer costs to do the same job, would be more productive in contrast with another distribution company that requires more costs. In any case, the extent of which the distribution company uses these inputs, can be totally distinctive, yet still productive. Such a conclusion can be drawn from considering the production frontier (best performance graph)) [40] presented in Figure 2.5-1. Production Frontier (or envelopment surface, because it envelops all the cases), in this circumstance, is a concave graph joining L1, L2, L3, and L4. Thus, if a distribution company is on the production frontier, it is regarded as efficient. Hence, L1, L2, L3, and L4 are efficient, and L5, L6 and L7 are inefficient. The inefficiency can be explained in two ways. Firstly, for example, L5 (comparing with L1 and L2) produces as much output, but with less input; Secondly, it could produce more output with the same input (comparing with L2 and L3). By moving their new operating point on the production frontier by lowering their inputs, L5, L6 and L7 can be made efficient.



L6

L1 L5

Figure 2.5-1 Best performance graph

2.5.2.1 DATA ENVELOPMENT ANALYSIS (DEA) METHOD

DEA strategy is perfect and capable of assessing the feasibility of multi-input and multi-output decision-making unit. In this way, DEA technique is utilized as a part of the assessment of business endeavors, healing centers, schools, open organizations and tourism ventures. As of late, DEA strategy has started to analyze the performance of the power industry. The first application of the DEA method in the power system, is the power field [44]. Dataenvelopment analysis [45] is an investigation technique, used to measure the relative effectiveness of a comparative number of organizations that play out the same actions. In this case, they are companies that distribute electricity.

The assets utilized by distribution companies is considered as inputs, and major products as outputs[55]. It represented a performance-based evaluation. It is implemented for the public and private electric distribution centers (DCs) of Nepal. Some of the inputs and outputs commonly applied for the DEA efficiency analysis of distribution companies are:

Inputs:

1. Distribution line (DLine)
2. A total number of employees (NE)
3. Distribution line transformer capacity (DTrans)
4. Distribution systems losses (DLosses)
5. Distribution operation and maintenance cost (DO&M)
6. Distribution capital expenses (DCapEx)

Outputs:

1. Sale of energy (SE)
2. The number of customers (N)

This method is focused on determining the most efficient companies and is used as a reference, with which the efficiency of the rest of the companies is compared. Thus, it is defined as a non-parametric method, for the estimation of productive efficiency of power distribution companies. The resources used by distribution companies, have been taken as inputs, whereas major products have been considered as outputs.

Efficiency based on DEA [28], is characterized as the proportion of weighted output to weighted input. More production per unit of input, reflects more prominent efficiency. On the off chance that the distribution companies' productive technology is displayed as a correspondence between input-output (supplies-products) variables, the establishment of the DEA system can be exhibited as a linear programming problem:
If x_{1j}, x_{2j},…………x_{mj} are the m inputs and y_{1j}, y_{2j}, ………, y_{sj} are the s outputs of the unit j, then its efficiency, θ, is defined as

$$\theta=\sum_{i=1}^{s}\left[\frac{uiyij}{viyij}\right]$$ Equation 9

The consideration of excessively numerous variables likewise, makes the analysis troublesome; accordingly, just the most significant variables must be incorporated. DEA technique is exceptionally adaptable and permits the expert to choose inputs and outputs. The distribution companies' efficiency scores, depend upon their performance, and the best one is approved as one of the targets, for other companies.

2.5.2.2 SLACK ANALYSIS

The slack analysis gives an approach to infer improvement directions for inefficient companies. Slack, with regards to input, implies the needed drops of the relating input components, for inefficient companies, to become efficient. Slack, with regards to output, implies a few outputs should be augmented, for inefficient companies, to end up as productive. In this manner, it is utilized to assess the quality level for every power company.

Chien, lo [46] dissected the slack variables of those inefficient companies, to recognize improvement directions and become productive. The slack analysis in [46] demonstrates that the measure of the outputs (number of customers and transformer capacity) ought to be increased for an inefficient service center to become effective, overall.

Zhang and Kim [47] introduced a successive slack-based effectiveness measure (SSBM) application to model the Total-factor energy efficiency with undesirable outputs. They directed an observational investigation of energy efficiency, incorporating greenhouse gas emissions for the Korean power companies during 2007–2011. The results in [47] indicate that most power companies are not performing at the high end of energy efficiency, and therefore, can enhance their energy efficiency.

In the next Section, we critically evaluate the relevant literature on efficiency using DEA.

2.5.2.3 CRITICAL EVALUATION OF THE RELEVANT LITERATURES ON EFFICIENCY USING DEA

In this section, we critically evaluate the relevant literature, which investigates the power distribution company's efficiency, using DEA. Haghifam et al. [10] and Simab et al. [11]developed a reward-penalty scheme, based on DEA and weighted reliability indices, by estimating the past reliability values and the DEA efficiency scores, for calculating each companies minimum quality standards. They considered SAIDI as input, for explaining a model of DEA, to analyze the effectiveness of electric distribution companies [11].

We now review the literature from six countries including Greece [56], U.S.A[57], Finland[58], Iran[11], Nepal[56] and Taiwan[31, 32]. In all of these cases, DEA was used to achieve different objectives, including evaluation of efficiency measures (Greece, Nepal), benchmarking of electric distribution utilities (U.S.A and Finland), finding quality targets for each distribution company (Iran) and measuring relative efficiencies of service centers (Taiwan). Pahwa [57]did the benchmarking of power distribution companies, based on DEA methods, used to evaluate the comparative efficiencies of fifty popular power distribution companies in the U.S.A. [4]. Pahwa also presented the details of efficiency benchmarking methods, of electricity distribution businesses in Finland. In [56], to analyze the efficiency methods for the 45 distribution districts of the Greek Public Power Corporation.The DEA method was used and compared used DEA method and are compared with simple indices, with efficiency measures produced by econometric methods and it also described the cause for the low efficiencies. Chien, Lo [31, 32] presented a DEA research which compared the efficiencies of 17 distribution centers of the Taiwan Power Company and provided specific directions to improve their operation efficiencies. Originally, it was imagined that non-profit companies, could only implement DEA, but later its advantages have increased to cover all types of industries and markets [57]. In this section, reference to Table 2.3-5, the efficiency module will be made in order to illustrate the relevant literature that deomonstrates which company used the DEA Score including the objectives of their research and the findings of their investigations into the efficiency of the power distribution companies who used DEA.

We now describe the critical review on the third module, referred to as the Interruption Cost Module. Here we will describe Interruption Cost (IC) and the associated input parameters.

2.5.3 INTERRUPTION COST-BASED APPROACH

It has been evaluated that the vast majority of the interruptions in the power supply to customers are because of failures in the distribution networks [59], [19].Some distribution companies have used interruption cost indices (calculated from the power interruptions encountered by its customers), as a regulatory indicator in their RPS implementation.

Three most frequently used Interruption cost indices are:

1. IEAR (Interruption Energy Assessment Rate), refers to the system interruption cost index represented in $/kWh.
2. VOLL (Value of Lost Load), refers to the value an average customer puts on an unsupplied kWh of energy
3. WTP (Willingness to Pay), refers to the customers' willingness to pay for improvements to its continuity of supply.

Interruption cost indices[59], [19] depends upon three main factors:

1. Type of customer, such as industrial, residential and commercial.
2. Features of interruption, such as time of occurrence, duration, etc.

The interruption cost is related to the economic consequences incurred by customers, when an electricity shortage occurs. Suitable approaches and techniques have been developed to evaluate interruption cost indices and are used for regulatory purposes and planning purposes. The distinctive strategies used to assess interruption cost indices, can be organized into four ways:

2.5.3.1 REVEALED PREFERENCES

This strategy is based on observations and customers market behaviour analysis. The main advantage is that relatively accurate data can be collected, while the main disadvantage is that only large customers can provide proper signals.

2.5.3.2 STATED PREFERENCES

This strategy is based on customer surveys. It has two main advantages:

a. It provides distribution companies with interruption cost data, suitable for planning purposes, and
b. It is customer based / bottom-up, and therefore it directly incorporates customers' preferences.

The main disadvantage is that it is expensive to implement.

2.5.3.3 PROXY METHODS

This strategy is basedupon the production task approach. The key preferred standpoint is that they are quite easy to apply, making use of easily available data, such as Gross National Product, total energy consumption, sector production functions, etc., and moreover, they are practically inexpensive to implement. The main disadvantage is that they are based on limiting and sometimes unrealistic assumptions.

2.5.3.4 CASE STUDIES

This strategy is based on the collection of as much data as possible, immediately after the occurrence of large-scale power supply interruptions. The main advantage is that interruption cost values, are directly related to customers' experiences of real interruptions, rather than hypothetical scenarios. The main disadvantage is that the number of case studies and relevant data sets are very small, and therefore the computed interruption cost indices, may be relatively weak.

Customer interruption costs, are a portion of societies of power interruptions, and they are the most challenging part for regulators to estimate, because of the uncertainties with the customer survey method. A key challenge for estimating the power interruption cost, is the information collection on the frequency and type of power quality events experienced by customers, as well as on the vulnerability of customers' equipment to these events. It is hard to develop such systematic information on either type of information. Another challenge is the limited information available. Along these lines, not all regulators need to utilize customer interruption costs, as an input, when outlining an RPS[19]. However, many regulators have used customer interruption costs, while developing RPS[1], [4], [5], [8], [9], [15], [27], [35]. According to Customer national surveys, companies collect cost data for each interruption type and duration.

The following three computing steps[60], [19], are taken as a means of assessing the interruption costs:

a) Processing of raw collected data,which mainly includes normalization of individual customer data, either by annually used energy (MWh), or by peak load demand (MW). Customer surveys always create some "awful" data, for example, unreasonably high expenses. In this manner, statistical analysis (e.g. normalization) of the raw data, ought to be directed before the data are utilized as a part of RPS.

b) Setting up of customer interruption cost models. These are based on Customer Damage Functions (CDF) that signifies the normalized interruption rate, as a function of interruption features.

c) Computing interruption cost indices, that include the use of the normalized data to construct CDF, for each customer sector that shows how the expense relies upon outage duration [39]. The customer's damage function is explained in detail in Section 4.4. Interruption Cost indices can be used as one of the inputs for computing the Midpoint of Dead Zone (MDZ). MDZ is described later in 4.6.3.

2.5.3.5 COMPOSITE CUSTOMER DAMAGE FUNCTION (CCDF)

The data caught from customer survey prompts the detailing of the individual customer damage function (CDF). It gives the interruption cost versus the interruption duration for a particularized group of customers, in different sectors such as industrial, commercial, government & institutions, residential and agricultural [11].

The CCDF [11], [19], [48], [50], [61]conveys the total interruption cost, as an element of the interference length, for the combined customers in a specific service area. For a service area [10] it is computed by weighting the sector CDF, by the customer load composition for that area.

All the CDFs of a given division (i.e. commercial, industrial, residential, and so on.) are joined into the Sector Customer Damage Function (SCDF). At that point, the CCDF [16], [37], [39], [53] is acquired by weighting the SCDFs with the electrical energy used by every customer group. CCDF is characterized as the summed interruption cost for a composite of customer sectors, in a locality and is done by weighting the customer damage function, for the distinctive zones. The results of the distinctive SCDF and CCDF cost functions, give the numerical information required to expressly consider the reliability worth, in the economic assessment of the power distribution company. CCDF provides regulators with the valuable information needed to balance the economic and reliability aspects of the distribution company. The CCDF used in the assessment of the reliability worth, might directly influence the decision-making process.

The meaning of SCDF is similar to the CCDF, however, it refers to an area, as opposed to a whole customer mix. Interestingly, the CCDF is used to describe mixed customer interruption cost. Only CCDF [19], [48] is usually proposed for RPS implementation.

$$CCDF(t) = \sum_{s=1}^{s} SCDFs(t) \times Ws \quad \text{Equation 10}$$

where $$SCDF_S(t) = \frac{1}{m} \sum_{i=1}^{m} ICi(t) \quad \text{Equation 11}$$

$ICi(t)$ is the Interruption cost for respondent i at duration of t,

M is the number of respondents in sector s,

W_S is the weighting ratio of electrical consumption in each sector, and

S is the number of sectors.

2.5.3.6 CRITICAL EVALUATION OF THE RELEVANT LITERATURE ON INTERRUPTION COST INDICES

The vast majority of the customer interruptions in power, are a direct result of the failures of the distribution system. In this section, we critically evaluate the relevant literature that investigates interruption cost indices of power distribution companies. When we refer to Table 2.3-6, we observe that 8 of the 22 sections of researches[1], [4], [5], [8], [9], [15], [27], [35], used interruption cost as a parameter for designing RPS. Interruption cost indices, are used in the literature for managing bulk electricity system risk, proposing a maintenance plan, planning distribution system expansion, presenting risk-based maintenance management methods and developing a mathematical model for setting the incentive rates.

In Wangdee [1] the reliability index probability distributions of SAIDI and SAIFI and their related costs are applied to manage bulk electricity system risk, using sequential Monte Carlo simulation. As compared to [1], Mohammadnezhad-Shourkaei et al. [8], maximized the maintenance project efficiency in the presence of RPS and the cost of planned and unplanned interruption costs. Fotuhi-Firuzabad [4]determined the performance-based regulation implementation cost, related to each system reliability index and weighted it based on its effect on the customers' interruption cost. Alvehag Söder [9], have shown a valuation of the customer interruption costs including duration of interruption, customer region in designing RPS. In addition to [1], [8], Lotero and Contreras [35] calculated the related costs of the most significant reliability indices and estimated the rate that customers are willing to pay so as to receive redundancy in the system and evade interruption cost. Hence identified how customers are affected, as well as the related effects of costs. As compared to the analysis of the impact of cost to the distribution system, Xu et al. [27] developed a mathematical parametric optimizing model for designing reward/penalty structure and minimized the customer interruption costs and reward/penalty payments, thus accomplished the required quality level of the distribution system.

As related to the above-described literature, Awodele[12] applied the interruption cost as one of the parameters to assess the power distribution companies' incentive rate. As compared to [1], [8], [12], Moradkhani et al. [15], developed a risk-based maintenance management plan in the presence of the RPS, using a generic algorithm, introduced the interruption cost generation algorithm to evaluate the probability distribution of interruption frequency, and extracted the probability distribution of SAIDI. Some countries have used customer interruption costs provided by customer surveys, to fix the incentive rates[62]. The Council of European Energy Regulators (CEER) has developed rules for customer interruption data collection and normalization [49]. Dzobo[50] identified different customer segments of electricity customers for different customer sectors, taking various forms of customer interruption cost summaries within the customersectors to generate the customer segmentation model. In this section, we illustrate the relevant literature that shows who used these indices and the objectives of this research.

In the next section, we describe the reward-penalty module to show how the different modules and parameters work together to generate a reward or penalty for the power distribution companies.

2.5.4 DIFFERENT REWARD-PENALTY SCHEMES

Reward penalty schemes, are monetary mechanisms, which encourage power distribution companies to improve their performance reliability. The Regulator predefines a performance target for the distribution companies. If the company performs better than the target, they will be rewarded. Otherwise they will be penalized. If distribution companies hit the target, there is neither a penalty nor a reward. This area is referred to as dead zone, as shown in figure 6, because there is neither a penalty nor a reward [11]. The purpose behind utilizing the dead zone is to dampen unintended penalties and rewards, inferable from stochastic changes in quality [22]. The choice of the regulated indicators (system based reliability indicators such as, SAIDI, SAIFI or CAIDI, Load based reliability indicators such as EENS or AENS and Interruption cost indicators such as IE-AR, VOLL, and WTP) has an important role in calculating the different financial incentives (reward or penalty).

A general form of RPS is shown in Figure 2.5-2. It contains three zones [11]: reward zone, dead zone, and penalty zones. The x-axis represents the reliability dimension, whereas the y-axis represents respective rewards or penalties.

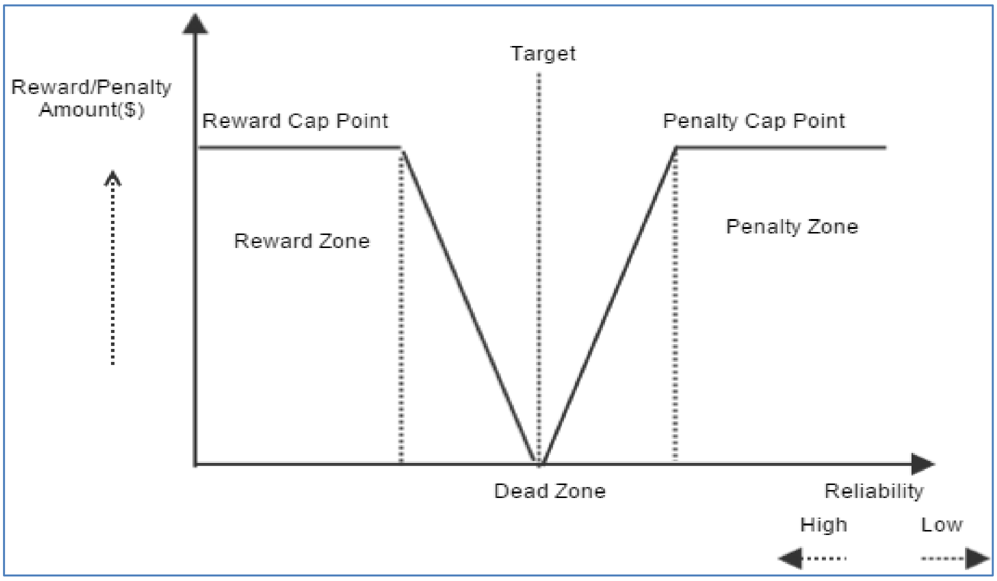


Figure 2.5-3 General Reward-Penalty Scheme

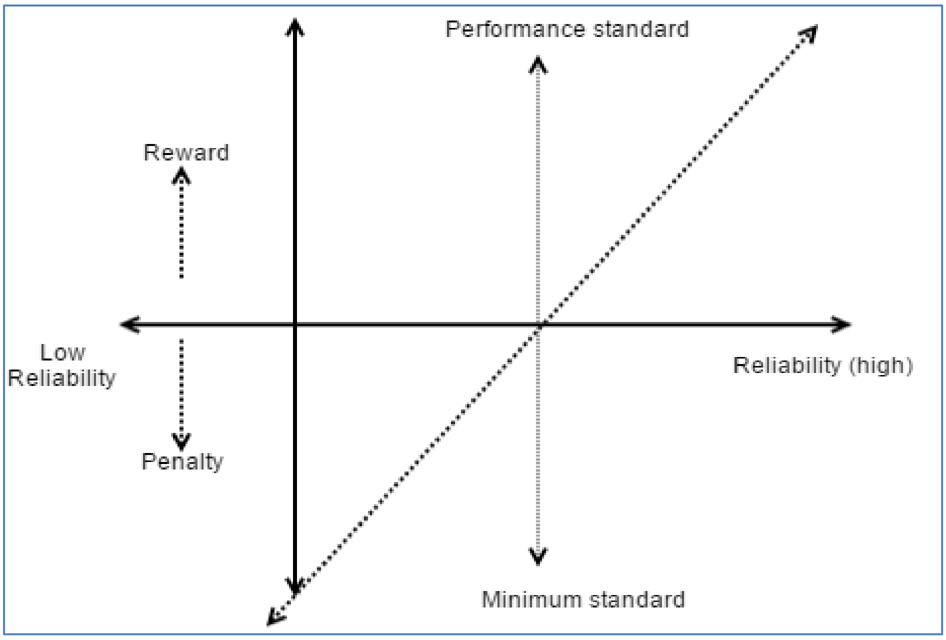


Figure 2.5-4 Linear Reward-Penalty Scheme

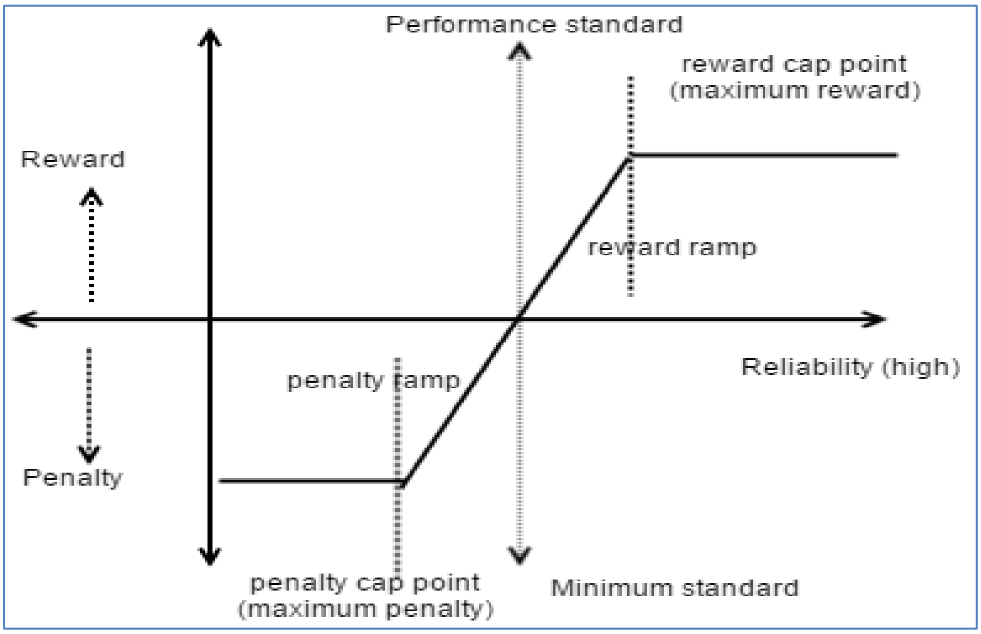


Figure 2.5-5 Capped Reward-Penalty Scheme

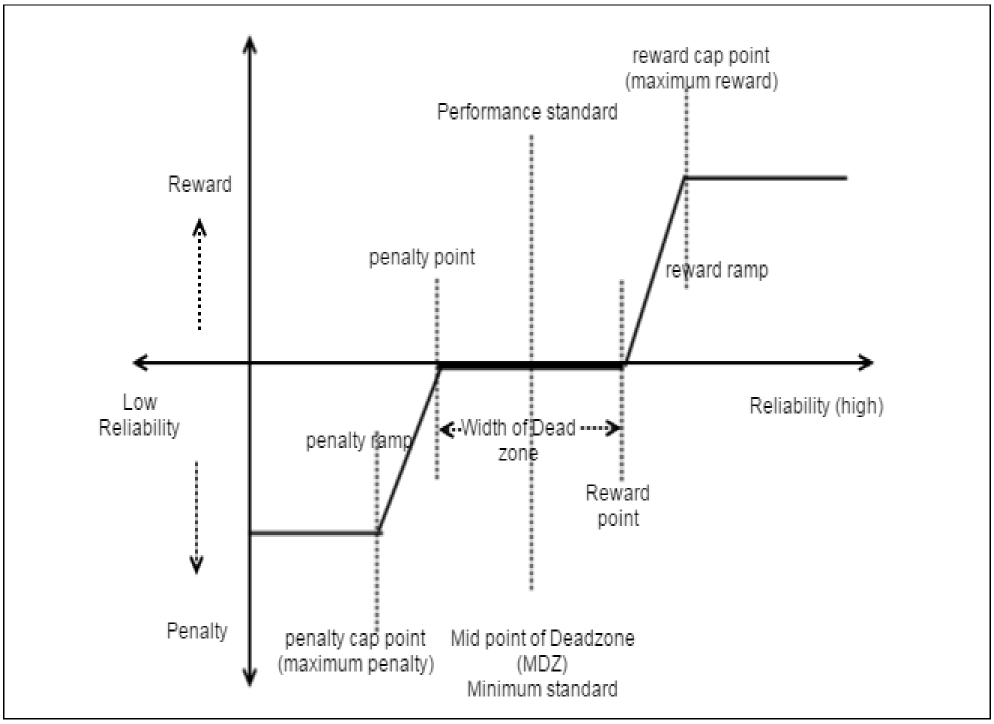


Figure 2.5-6Reward-Penalty Scheme with Dead Band

In the literature, there are several different variations of the reward-penalty schemes (shown in above figures), and it changes according to the requirements and the range of data used. The different types of reward penalty structures are now discussed.

The regulator specifies performance standards as shown in the above figures, which is defined as the level of performance reliability, which the company is relied upon to supply. There is a minimum level of service reliability that a company is required to deliver to its customers. Opposition with these levels of quality may involve penalty payments.

2.5.4.1 LINEAR REWARD-PENALTY SCHEME

In this scheme, there is a linear relationship between reliability and reward/penalty, as presented in figure 2.5-4. In most reward penalty schemes the relationships amongst quality and revenues are fundamentally linear: the same separation from the performance standard prompts to the same change in the revenues, of the distribution company. The performance measures are not fixed over time. They typically change starting with one year, then onto the next, obliging companies to meet continuously stricter performance standards [62].

2.5.4.2 CAPPED REWARD-PENALTY SCHEME

Motivating plans (Incentive schemes) in many nations [54] (counting Ireland, UK, and The Netherlands), have a lower and an upper bound (caps) for penalties and rewards (Figure 2.5-5). In the ideal case, when money related motivating forces, exactly reflect customer costs and benefits for performance reliability changes, the presentation of upper and lower limits ought not to be essential: the company will achieve the needed reliability level and stay there. Be that as it may, as may be normal, the presumption of sound data on marginal customer valuation of reliabilityis not verified in practice. In this manner, the risk of giving motivational incentives for improperly high-reliability levels, legitimizes the presentation of an upper limit on rewards. So also, there is a risk of penalizing the company to the point where it will have unbearable monetary losses. This backing the introduction, in applied mechanisms, of a lower limit on penalties. In this incentive plan as shown in figure 2.5-5 and figure 2.5-6, these upper and lower boundaries are set to guard the customers and distribution company regulators against adverse effects of poorly designing the RPS. Capping of reward penalty scheme [22], is essential when on one considers that the regulator has faulty information about customer interruption costs and willingness to pay. Since there is no perfect information about the customer judgmentfrom the reliability point of view, for reducing the risk of high rewards, a cap for reward called ***Reward cap point,*** is introduced. Similarly, a cap for the penalty, called, ***Penalty cap point,*** is also introduced and used to reduce the risk of high penalty pay. Thus, Reward Cap or Penalty Cap is defined for eliminating unacceptable monetary losses for distribution companies and customers. As for reliability increases, the reward rises, and it stops at the Reward Cap Point. There is no linear relationship between reliability and reward/penalty, as shown in linear RPS.

There are additionally two increasing and decreasing slopes in penalty and reward zones as shown in figure 2.5-5. The state of the reward-penalty curve changes for various conditions relying upon the range of data, kind of reliability index utilized, objective of the regulators and so on

Reward/Penalty ramp is related to the performance reliability of the power distribution company as shown in figure 2.5-5. The Penalty Ramp is higher for companies with lower performance reliability levels and makes money related incentives for distribution companies to increase their reliability level, so as to abstain from paying high penalties. Therefore, the Reward Ramp is higher for companies with higher performance reliability levels and rewards them. Both reward ramps and penalty ramps stops at their cap point, as shown in figure2.5-5, to reduce the financial risks to the company and its customers.

2.5.4.3 DEAD BAND REWARD-PENALTY SCHEME

Along with upper and lower limits, RPS structures can likewise incorporate dead bands (Figure 2.5-6). Dead- bands present an interval, whereas rewards and penalties do not have any significant bearing and are intended to maintain a strategic distance, to avoid tariff variations for little deviations from the baseline. Indeed, such deviations won't signify a structural variation in reliability in the case of capped RPS, but simply a stochastic effect. Compared to the linear RPS scheme, there is no linear relationship between reliability and reward/penalty. For each level of reliability, a reward or penalty can be devised, such that it is about the gap between the real level and the target as shown in figure 2.5-6. The bigger gap causes, the higher reward/penalty. The explanation behind utilizing a dead zone is to dampen unintended penalties and rewards inferable from stochastic changes in quality [17], [11], [10].

If the performance reliability is worse than the right side of the dead zone (dead zone boundary), a penalty is charged (penalty zone). As reliability deteriorates, penalty gets raised (***Penalty Ramp***) as shown in figure 2.5-6 and is stopped at the **Penalty Cap Point (Maximum Penalty)**. Most RPS schemes used Standard Deviation of reliability index, for calculating Reward/Penalty Points. Similarly, if the performance reliability is better than the left side of the dead zone (dead zone boundary), the reward is applied (reward zone) [23]. **Reward caps** or **penalty caps** are also defined for eliminating unacceptable monetary losses for distribution companies and customers. As for reliability increases, the reward rises (***Reward Ramp***), and it stops at the **Reward Cap Point (Maximum Reward)** as shown in figure 2.5-6. This point of the cap is to guarantee that the maximum reward and penalty are capped. The capping is used to decrease the financial risks to the company and customers. In Most RPS schemes, **Reward/Penalty Cap Point** is considered to be based upon customer interruption costs and the percentage of annual revenue from companies.

The midpoint of Dead Zone*(MDZ):* RPS will not bring about the regulated company to particularly deliver an ideal level of service reliability [15]. MDZ is the improvement target value for each company, which equals the dead zone center [11], [29],[25] and is based on the different parameters, such as its reliability indices, its DEA efficiency score, customer Interruption costs and the maximum reliability improvement.

The width of Dead Zone: The Width of Dead Zone is defined as the gap between the penalty point and reward point as shown in Figure 2.5-6. The width of the dead zone defines the target range that shows the start point of penalty and end of reward [7, 22]. If the performance of the company is enhanced more than the target, it will be rewarde, and if it is inferior to the target, it will be penalized. The dead zone width is equal to the average standard deviation of the reliability index. The space between the Penalty and Reward Point from MDZ ***(***half of the ***Width of Dead Zone)*** is equal; it is the same for all companies.

Possibilities for reducing the performance-based risk while designing RPS [24]include:

- Make the reward and penalty incline less steep
- Broaden the dead zone limits
- Move the dead zone to one side (right)
- Drop the reward and penalty caps

Penalty point*:* The penalty point is determined by the Midpoint of Dead Zone subtracted by a half the SD of the regulatory index.

Reward point*:* The Reward point is determined by the Midpoint of Dead Zone added by a half the SD of the regulatory index.

A Dead band Reward-Penalty scheme is introduced in [4], [28], for balancing the total rewards granted and penalties received, by the regulator. Diverse models of reward-penalty curves are applied in [2], with various dead-zone, penalty increasing slopes, reward diminishing ramps; distinctive Maximum Penalty Levels and Maximum Reward Levels, utilizing a practical data and additionally, presenting their properties and applications. Sections 2.5.1 to 2.5.4 described the main modules that form part of any reward penalty scheme implemented by power distribution companies. The discussion of all the input parameters for RPS implementation, is covered in the next section.

2.6 DISCUSSION OF DIFFERENT PARAMETERS FOR MANAGING PERFORMANCE BASED ON RELIABILITY BY EFFICIENT REWARD-PENALTY SCHEME IMPLEMENTATION

So far, we have reviewed the different parameters for reward penalty schemes (RPS). For estimating the power distribution companies performance reliability, efficiency, and interruption cost to implement RPS; apparently a large number of parameters could be applied. The first step in implementing RPS is the handling and gathering of data for calculating the different reliability, efficiency, and interruption cost parameters. This move is very time and money consuming. Also, the data verifying and the setting relationship between those parameters and RPS are very complicated for the regulator. On the other hand, providing a few precise parameters, can promote RPS implementation. Thus, it can easily be managed by the regulators [37]. While selecting those precise parameters, we should consider whether they are quantifiable, independent and their dependency on the customer type (Industrial or Residential). Usually, the reliability indices such as SAIFI, SAIDI, and EENS, are the most commonly used parameters. in RPS implementation [30].

The second step is the calculation of regulatory indicators, such as reliability indices, efficiency indices (DEA Score) and Interruption cost indices. Certain factors should be considered while performing this step. Identifying the interruption reasons are the core points of the regulatory indices calculations. Interruptions can occur based on two factors, such as external and internal factors. The interruptions due to generation and transmission failures and weather conditions can be grouped into external factors. Management of these factors is out of regulatory control. Regulators cannot reduce the duration and frequency of these interruptions, in the short term. The interruptions due to distribution equipment's failure, human failures, and equipment's maintenance can be classedas the internal factors. Regulators can manage these internal changes.

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Determining the target for calculating reward or penalty, is the major and the third step in RPS implementation. Target calculation (benchmarking), shows the start point of reward or penalty. If the distribution company's performance is better than the target, they will be rewarded, and if it is worse than the target, they will be penalized. Regulators use different ways to set targets. Based on the average of the yearly performance of previous years, (usually the past three years) [4], the target can be fixed. This approach is called the historical performance method. It can motivate the power distribution company to keep the same performance. Another method is the initially targeted value method. In this method, the target is fixed and based on the initial value followed by a yearly improvement [18]. The target can also be fixed and based on the average performance of distribution companies grouped in one cluster. This method is called the competition method. In this approach, the reliability provided by the distribution companies in one cluster is compared with that of other distribution companies, located in the same cluster.

The fourth step after reward/penalty determination, is the tariff regulation process. The regulator can choose different modes for executing the calculated penalty and reward. One method is the distribution company's tariff regulation method, where the electricity rate varies in each distribution company based on their performance reliability. With country tariff regulation methods, all distribution companies apply the same tariff. However, with direct reward and penalty tariff methods only the well-performing distribution company may get a direct reward from the regulator's fund, and the weaker distribution company may put a penalty to the same fund. With a balanced reward and penalty tariff method, the regulator may not have the funds to reward well-performing distribution companies. The regulator establishes balance between the reward granted, and the penalty received, such that the net difference tends to be nil [8]. In some countries, the distribution companies are under government control and a specified budget is set by the government. This method is called the budget regulated tariff method. In this approach, a share of the distribution company's budget, can be directly associated with performance reliability.

Recently [63] investigated a relationship between output based incentives for service quality and the utilization of capital and non-capital resources, to meet regulatory benchmarks in the power industry. They illustrated that physical assets and operational expenditures, do have an impact on service quality. For this empirical analysis, they have used a dataset from the Italian energy regulatory authority containing financial incentives and physical assets for the largest electricity distribution operator in Italy (86 % of the market).

The latest research work on RPS structure, is the impact of the demand response programs on the power distribution system, operations [64]. This approach can be used to improve load profile characteristics as well as customer satisfaction and can be used by the regulator to simulate the customer's behavior for diverse prices, incentives, and penalties. Besides the demand response program, there are many different alternatives, including direct load control, which can be considered as a future work direction. In the next section, we present the design requirements for managing performance, based on reliability in the form of RPSs.

2.7 DESIGN REQUIREMENTS FOR MANAGING PERFORMANCE BASED ON RELIABILITY IN THE FORM OF RPS

In the previous sections, we have conducted an in-depth literature survey related to the different approaches, to implementing RPS, used by different researchers, to maintain a consistent reliability on the power supply. Following this survey, we have identified the following technical challenges which still need significant attention from the researchers. It should benoted that, in this chapter, we do not discuss the technical challenges of designing or implementing RPS, however we do focus on the challenges associated with managing performance, based on reliability in the form of RPS. Some of the general challenges and issues associated with PBR reliability for managing power distribution companies are:

1. How to define and characterize the most vital parameters for designing and implementing RPS.
2. How to set a realistic target that should be able to support and monitor the company's performance behavior.
3. How to ensure a reasonable magnitude for the reward or penalty
4. How to reduce the complexity of adopting reward penalty formulas.
5. How to maintain the consistency of reward penalty formulas with the desired outcome.
6. How to include certain external factors in RPS implementation, that affect the performance of power distribution companies, that cannot be controlled by the regulators.
7. How to motivate the efficient and inefficient power distribution companiesin the power market.
8. How to improve the power distribution companies' reliability ofpower supply.
9. How to develop an effective RPS scheme that is more favorable to the regulatory agency, than the power distribution companies.
10. How to develop an effective RPS scheme, that is more favorable to power distribution companies than regulatory agencies.

11. How to develop an effective RPS scheme, that is most favorable to power distribution companies.
12. How to present financial rewards/penalties, in a way which is administratively simple.

These challenges are generally solved after finding solutions for the specific challenges that this thesis focuses on. The specific challenges associated with managing performance based on reliability in the form of RPS are:

1. Identifying the most vital parameters for designing and implementing RPS, focusing on PBR based, reliability.
2. Developing aneffective RPS scheme that is simple and easy to understand and administer; that increases rewards and penalties in a linear fashion, as the performance fluctuates from the normal and considers certain performance variations, in light of elements outside of the distribution company's control.
3. Developing an effective RPS scheme that reaches maximum reward/ penalty slowly, that provides very little incentive near the central target and considers the uncertainty related to those performance related components, that are outside of the distribution company's control.
4. Developing an effective RPS scheme, that will act like a dead band RPS structure by considering the uncertainties due to external factors and provide no reward or penalty around the central target.

2.8 CONCLUSION

This chapter has offered a state-of-the-art review,of managing performance based on reliability, in the form of RPSs,as well as the literature in the field of performance-based regulation,and the literature in other contexts, such as Data Envelopment Analysis and Customer Interruption Cost analysis, that might be adaptable to manage power distribution systems in the form of RPSs.The existing work evidently indicates that slight progress has been made in managing power distribution systems in the form of RPSs in the performance-based regulation process. However, plenty of key research issues related to this context, haves not been comprehensively addressed by the current research and requires further development. This then focuses on some of the key challenges of managing power distribution companies in the form of RPSs. Furthe attention to this issue is needed by th eresearchers concentrating on how to identify the most vital parameters for designing and implementing RPS, focusing on PBR based on reliability andhow to develop an effectiveRPS scheme, that is simple, easy to understand and administer andincreases rewards and penalties in a linear fashion as the performance fluctuates from the normal. Researchcould also consider certain performance variations in light of elements outside of the distribution company's control, how to develop an effectiveRPS scheme that reaches maximum reward/ penalty, slowly andprovides very little incentive near the central target and considers the uncertainty related to those performance related components, that are outside of the distribution company's control. Research could then coverissues concerned with how to develop an effectiveRPS scheme that acts like a dead band RPS structure, by considering the uncertainties which can be due to external factors and provide no reward or penalty around the central target. It has also explained most of the principal aspects that should be considered, while designing RPS. Based on this review, the next chapter will explicitly outline and address the above research issues.

CHAPTER 3

PROBLEM DEFINITION

This chapter provides:

- Formal definition for the problems that we address in this research
- The research issues that should be addressed
- The research methodology that will be adopted in this research methodically addresses the identified research problems

3.1 INTRODUCTION

Reward-Penalty Schemes are adopted for Power Distribution Companies to guarantee their quality levels. Regulators ought to pay money to Power Distribution Companies that give great performance and get money from Power Distribution Companies that give poor performance[5]. This methodology updates the company's incomes as indicated by their performance and penalizes companies with lower-quality levels[10]. It not just stimulates the companies to enhance their service quality but also adjust the aggregate rewards paid, and the aggregate penalties got by regulators[11].

A comprehensive state-of-the-art review of performance-based regulation literature in th e power distribution market was discussed in Chapter 2. Accordingly, there has been considerable research and commercial projects in PBR, that aim to build high performance in power distribution., However, a limited number of PBR approaches have implemented reliability involvement in the power distribution process. In Chapter2, we particularly placed emphasis on the literature relating to RPS and analyzed how existing literature on performance-based regulation through reliability. We also discussed how the existing approaches toperformance-based regulation in other contexts, such as data envelopment analysis and customer interruption cost, might be adapted to address the challenges of RPS. From the surveyed literature, we identified a series of weaknesses in the current approaches and opened research issues that require further attention from the researchers.

The main contribution of this chapter, includes a clear identification of the key problems that we expect to address in this dissertation. In Section 3.2, we propose an arrangement of definitions of those terminologies that will be used when characterizing the issues, as well as in subsequent chapters. Section 3.3 emphasizes the key problems to be addressed in this thesis to resolve the issues so as to implement sustainable RPS. Finally, this chapter closes with a brief discussion of research methodologies and a conclusion.

3.2 KEY CONCEPTS

In this segment, we display a formal definition of terminologies and concepts, which will be used to present, explain and formally characterize the problems intended to be addressed in this dissertation. Table.3.2-1 concisely illustrates the definitions. The same definitions will be adopted in proceeding chapters, as required.

Table 3.2-1: Key concepts & terminologies

TERMINOLOGY/ CONCEPT	***DEFINITION***
System topology	Refers to different approaches to portraying the reliability of a system, including fault trees, reliability block diagrams, and failure mode effect analysis. Each topology has different strengths and weaknesses regarding reliability. [13]illustrated distribution system reliability assessment can predict the interruption profile of a distribution system based on system topology.
Outage duration (or duration of the interruption)	Refers to the period from the start of an interruption until the service has been restored to the affected customers. It can be measured in seconds, minutes, hours, or days. One of the objectives of the power distribution system reliability assessmen,t is to reduce the duration of outages. Reducing outage duration, as determined by SAIDI and CAIDI, is related to the execution of distribution automation and outage discovery technologies and

	more efficiently operating and refurbishment performs for those customers suffering continued outages[44].
Frequency of outages (Frequency of interruptions)	Refers to the number of times outages occurred, in a given period and is measured in seconds, minutes, hours, or days. The reliability of power distribution company, can be enhanced by dropping the frequency of outages. Decreasing the frequency of outages, as is related to a number of factors including undergrounding, storm hardening, infrastructure improvements, and the use of automated distribution systems.
System availability	Refers to the chance that a repairable service is functioning at a defined point in time, taking after a defined set of ecological factors. It can be characterized as the likelihood that, a device or a system will play out a given task condition for a particular timeframe, while availability is that, a system will have the capacity to play out its required capacity over a particular timeframe, under a specified environment [43], [59].
Response time:	Refers to the time that it takes an operator to characterize a solution during contingencies. Response time during service restoration, influences the reliability indices that are identified with the lengths of the failure, demonstrating that a fast decision straightforwardly adds to the system performance.
Total number of customers served	Refers to the number of customers served amid the reporting time frame (N). This parameter is used in the estimation of performance reliability indices such as SAIDI, SAIFI, and CAIDI.
Number of customers interrupted	Refers to the number of interrupted customers for each sustained interruption event, amid the reporting time frame (N_i) and is used in the calculation of reliability index such as SAIFI[65].

Protection mechanism	With the development of advanced technology-based protection mechanisms for power distribution, outage events have become less frequent in the modern power systems. Thus, protection mechanisms have a critical part in the reliability of distribution systems.
Restoration time	Refers to the duration of time which begins when a fault is identified and ends when services have been restored back to normal. New devices and systems make it possible for utilities to know when customers lose power and to pinpoint outage areas all the more decisively. This capacity enhances restoration times and abbreviated outage durations. Once an outage occurs the average duration to re-establish services is found from the Customer Average Interruption Duration Index (CAIDI).
Distribution line (DLine)	Refers to the span of the power distribution system[55].
Total number of employees (NE)	Refers to the total staffs employed in a distribution company[55].
Distribution line transformer capacity (DTrans)	Refers to the total capacity in MVA of distribution transformers linked to the zone serviced by the distribution companies[55].
Distribution systems losses (DLosses)	Refer to total loss in energy within a zone[55].
Distribution operation and maintenance cost (DO&M)	Refers to the yearly expenses of both labor and non-labor inputs[55].
Distribution capital expenses (DCapEx)	Refers to the total capital expenditure of the distribution system.
Sale of energy (SE)	Refers to the yearly sale of energy in MWh[55].
Number of customers (N)	Refers to the total distribution points which is to be supplied with electricity[55].

IEAR (Interruption Energy Assessment Rate)	Refers to the system interruption cost index represented in $/kWh.
VOLL (ValueoOf Lost Load)	Refers to the value an average customer puts on an un-supplied kWh of energy
WWTP (Willingness to Pay)	Refers to the customer willingness to pay to improve its continuity of supply.

3.3 PROBLEM DEFINITION

The general problems and challenges that are addressed in this thesis are as follows:

1. Problems with defining and characterizing most vital parameters for designing and implementing RPS
2. Problems with setting a realistic target that should be able to support and monitor company's performance behavior.
3. Problems with ensuring a reasonable magnitude for reward or penalty
4. Problems with reducing the complexity in adopting reward penalty formulas
5. Problems with maintaining the consistency of reward penalty formula with the desired outcome
6. Problems with the inclusion of certain external factors in RPS implementation that affect the performance of power distribution companies that cannot be controlled by the regulators
7. Problems with motivating the efficient and inefficient power distribution companiesin power market
8. Problems with improving the power distribution company's reliability in power supply
9. Problems with developing an effective RPS scheme that is more favorable to the regulatory agency than the power distribution companies
10. Problems with developing an effective RPS scheme that is more favorable to power distribution companies than regulatory agencies
11. Problems with developing an effective RPS scheme that is most favorable to power distribution companies

12. Problems with presenting financial rewards/penalties that are administratively simple.

These problems are solved by finding solutions to the specific problems that this thesis focuses on. The specific problems associated with managing performance based on reliability in the form of RPS are:

1. Problems with identifying the most vital parameters for designing and implementing RPS focusing on PBR based on reliability
2. Problems with developing an effective RPS scheme that is simple and easy to understand and administer, that increase rewards and penalties in a linear fashion as the performance fluctuates from the normal and should considers certain performance variations in light of elements outside of the distribution company's control.
3. Problems with developing an effective RPS scheme that reaches maximum reward/ penalty slowly, that provide very little incentive near the central target and should consider the uncertainty related to those performance related components that are outside of the distribution company's control.
4. Problems with developing an effective RPS scheme that should act like a dead band RPS structure by considering the uncertainties due to external factors and provide no reward or penalty around the central target.

For each of these issues, the discussion is carried out from two alternate perspectives: the existing solutions and the technical problems innate in these solutions. The specialized concerns connected with the issues that will frame the research issues for the development of the new solution.

3.4 RESEARCH ISSUES

Using the above understanding and key ideas, we examined three ranges of problem definitions. For all, we characterized the currently available solutions and the existing technical problems inherent in these solutions. These specialized problems frame the premise of our research problems: how would we be able to address them and what are the prerequisites for the new solution? In this section, we address the research issues that should be tended to in any new solution development. We then seek the solutions from Chapter 4 onwards to focus on the research issues characterized in this chapter and to meet the objectives delineated in Chapter 1.

3.4.1 RESEARCH ISSUE 1

How to identify the most vital parameters for designing and implementing RPS focusing on PBR based on reliability?

Based on the survey of current approaches for PBR based on reliability that has been discussed in Chapter2 and problem definitions for definition and characterization of the most vital parameters for designing and implementing RPS, it is clear that the concepts of defining and characterizing the most vital parameters are not well understood. Moreover, the literature contains no approaches particularly addressing the vital parameter definition and characterization, and the approaches discussed in other contexts such as PBR based on data envelopment analysis and PBR based on customer interruption cost are difficult to adapt to RPS s and may require major revision.

Research Question 1: What are the aspects of setting a target for designing RPS?

Research Question 2: What are the factors related to the performance target?

To address this problem with defining and characterizing the most vital parameters, we design a framework, which is extensively presented in Chapter5.

3.4.2 RESEARCH ISSUE 2

How to develop an effective RPS scheme that is simple and easy to understand and administer, that increase rewards and penalties as the performance fluctuates from the normal and should considers certain performance variations in light of elements outside of the distribution company's control?

According to the survey in Chapter2, the literature has heavily overlooked the aspects of setting a target to analyze the company's behavior. In the previous section, the problem definitions for setting a realistic target and the associated technical problems are discussed. Those technical problems result in some research questions. To overcome the problems, the following research questions need to be considered:

1. **Research Question 1: How to implement an RPS scheme without any dead band and capping of maximum reward and the maximum penalty for improving the performance based on reliability for Power Distribution Companies?**

2. **Research Question 2: How to implement an RPS scheme with a dead band to control the normal fluctuations in performance and with a capping of maximum reward and maximum penalty.**

The above research questions need to be addressed so as to build an effective RPS. The answer to this question will be presented in Chapter 5.

3.4.3 RESEARCH ISSUE 3

How to develop an effective RPS scheme that reaches maximum reward/ penalty slowly, that provides very little incentive near the central target and should consider the uncertainty related to those performance related components, that are outside of the distribution company's control?

As,mentioned,in,Research,Problem,3,the,existing,literature,has,not,shown any focus on managing diverse performance goals based on reliability inthepower distribution market,thus defining an effectiveRPS scheme that reaches maximum reward/ penalty slowly, that provide very little incentive near the central target and have considered the uncertainty related to those performance related components that are outside of the distribution company's control to achieve the performance goals based on reliability. To address this problem of managingp erformance goals based on reliability within the power distribution market, the following research questions need to be considered:

1. **Research Question 1: How to calculate reward/penalty by using limited variables?**
2. **Research Question 2: How to ensure a resealable magnitude for reward/penalty?**
3. **Research Question 3: How can we efficiently achieve performance goals based on reliability within the power distribution market?**
4. **Research Question 4: What are the factors affecting the performance reliability of power distribution companies?**
5. **Research Question 5: How can we develop an approach that is more favorable to power distribution companies by considering the performance inconsistency factors that are out of the regulator's control?**
6. **Research Question 6: How can we accommodate the uncertainty factors that deviate the distribution company's performance-based reliability level in achieving the defined performance goal?**

In this research, we propose an algorithm that addresses all the above questions, and this is comprehensively illustrated in Chapter 6.

3.4.4 RESEARCH ISSUE 4

How to develop an effective RPS scheme that should act like a dead band RPS structure by considering the uncertainties due to external factors and provide no reward or penalty around the central target.

The Reward-Penalty formula which portrays the shape and slope of the curves decides how rapidly the curve[66] achieves the maximum reward or penalty as performance goes astray from the performance target. To address this issue, the following research questions need to be considered:

1. **Research Question 4.1 : How to define an RPS that increases rewards and penalties in a fashion as the performance moves away from the normal, without applying the dead band, that acts as a dead band structure by considering the uncertainties due to external factors?**
2. **Research Question 4.2: How to introduce a capping (thresholding) on the maximum reward and penalties that allow companies to abstain from paying a critical penalty or getting a huge reward?**
3. **Research Question 4.3: How can we evaluate the reward/ penalty based on performance-based reliability by including a neutral zone around the target which represents the vulnerability in regards to the ideal performance level?**

In this research,to address this issue, we introduced a model where the minimum standard (performance target) level is set taking into account of the moving average of historical performance which helps to measure the company's behaviour whether the company is well-performed that would result in reward or under-performed that would lead to a penalty and it is comprehensively illustrated in Chapter8.

3.5 RESEARCH METHODOLOGY

The science and engineering-based research methodology takes on this research in order to solve the underlying research problem. Science and engineering research prompt the advancement of new procedures, design, techniques, gadgets or a setof ideas, which can be consolidated to shape a new hypothetical system. All the more particularly, the science research technique is embraced that comprehends the problem area and plans a solution by making an application or some configuration artifacts[67], [68], [69]. To accomplish our research objectives, we plan to design algorithms and a model framework to affirm to the spirit of "making something work" [70].

This technique comprises of issue definition, theoretical solution, implementation, experimentation and testing and validation of models against existing solutions. The previously mentioned undertaking shave been partitioned into three primary stages[70]:

Issue definition

Theoretical solution

Implementation, testing and validation of models

3.5.1 ISSUE DEFINITION

In the Issue definition phase, the objective is to legitimize the criticalness of the research questions. It includes the examination, analysis, understanding, interpretation, discussion and assessment gave criteria and viewpoint. This issue definition stage has been covered in this chapter. General issues forRPS implementation are namely:problemswithdefining and characterizing theRPSs,setting a realistic target that should be able to support and monitor company's performance behavior, ensuring a reasonable magnitude for reward or penalty, reducing the complexity in adopting reward penalty formulas, maintaining the consistency of reward penalty formula with the desired outcome, inclusion of certain external factors in RPS implementation that affect the performance of power distribution companies that cannot be controlled by the regulators, motivation of inefficient power distribution companies in power market, improvingthe power distribution companiesreliability in power supply, developing an effectiveRPS scheme, presenting financial rewards/penalties administratively simple.The specific problemsforRPS implementation that we are focusing in this thesis are namely: problems with identifying the most vital parameters for designing and implementing RPS focusing on PBR based on reliability, problems with developing an effectiveRPS scheme that is simple and easy to understand and administer, that increase rewards and penalties in a linear fashion as the performance fluctuates from the normal and should considers certain performance variations in light of elements outside of the distribution company’s control, problems with developing an effectiveRPS scheme that reaches maximum reward/ penalty slowly, that provide very little incentive near the central target and should consider the uncertainty related to those performance related components that are outside of the distribution company’s control, problems with developing an effectiveRPS scheme that should acts like a dead band RPS structure by considering the uncertainties due to external factors and provide no reward or penalty around central target. For every issue, the discussion is done utilizing a formal definition of the classification, and the technical concerns. The issues connected with the technical concerns prompted the research problems for the new solution development.

3.5.2 THEORETICAL SOLUTION

The theoretical solution focuses on planning a new strategy and methodology through the configuration, design and developing of tools, environment or framework through implementation[44]. In this stage, a theoretical framework is intended for the proposed solution. A framework's theoretical structure and system architecture are the key requirements which give a research guide to the whole development of a framework or system development process. This includes the decomposition of the whole system into leaf or essential functional modules and to plainly determine the relations between these functional modules, whose collaboration, all in all, gives a far complete image of the whole system framework. Here, the configuration specification is utilized as an outline for the implementation of the framework.

3.5.3 IMPLEMENTATION, TESTING AND VALIDATION OF MODELS

In this stage, testing and validation of models are brought out through, implementation with real-life cases and field testing. The way toward testing and validating a working framework gives one of a kind experience into the advantages of the proposed ideas, frameworks and choices. By building a model framework, implementing, testing and assessing, a superior understanding of the achievability and usefulness of the theoretical structure and also the entire solution is given.

In this thesis, Chapter 4 gives a theoretical framework to the proposed solution, and Chapters 5–9 provide a complete execution and experimentation of the theoretical framework.

3.6 CONCLUSION

This chapter provides a problem definition for the problems associated with managing power distribution companies in the form of RPSs in performance based on reliability. Taking into account of the socio-economic and technica lissues of existing solutions, certain research problems have been characterized. For every research problem, the research questions came up should be tended to in the advancement of RPSs. To address every research problem, a theoretical framework has been proposed. Besides, the research approach for this research has been discussed.

In the following chapter, a review of the proposed solution alongside its theoretical framework will be given. The theoretical framework is intended to address each problem that have been talked about in this chapter.

CHAPTER 4

GENERIC FRAMEWORK OF REWARD-PENALTY SCHEME

The chapter provides:

- An introduction to the Generic Framework of Reward-Penalty Scheme
- An innovative generic framework of the Reward-Penalty Scheme
- A study of theoretical framework of the proposed framework for RPS design and implementation

4.1 INTRODUCTION

As mentioned earlier in this dissertation, the current literature for improving performance lacks a comprehensive understanding of the different parameters available for designing and implementing RPS. Moreover, the literature contains no approaches which particularly address the vital parameter definition and characterization ,and the approaches discussed in other contexts such as PBR based, that is based on data envelopment analysis and PBR that is based on customer interruption cost. These are difficult to adapt to RPSs and may require major revision. This chapter addresses those problems and whilst defining and characterizing the most vital parameters, we design a framework to design and implement RPS.

4.2 AN INNOVATIVE GENERIC FRAMEWORK OF REWARD-PENALTY SCHEME

In this section, we develop a generic framework of a Reward-Penalty structure, for power distribution companies (Figure7). This is done by integrating the methodological characteristics and purposes of related current research works. The generic framework is divided into three key modules: (i) Performance Reliability module, (ii) Efficiency module, and (iii) Interruption Cost module. In the next three subsections, we examine these modules by point of interest, whilst referring to the current pertinent research works.

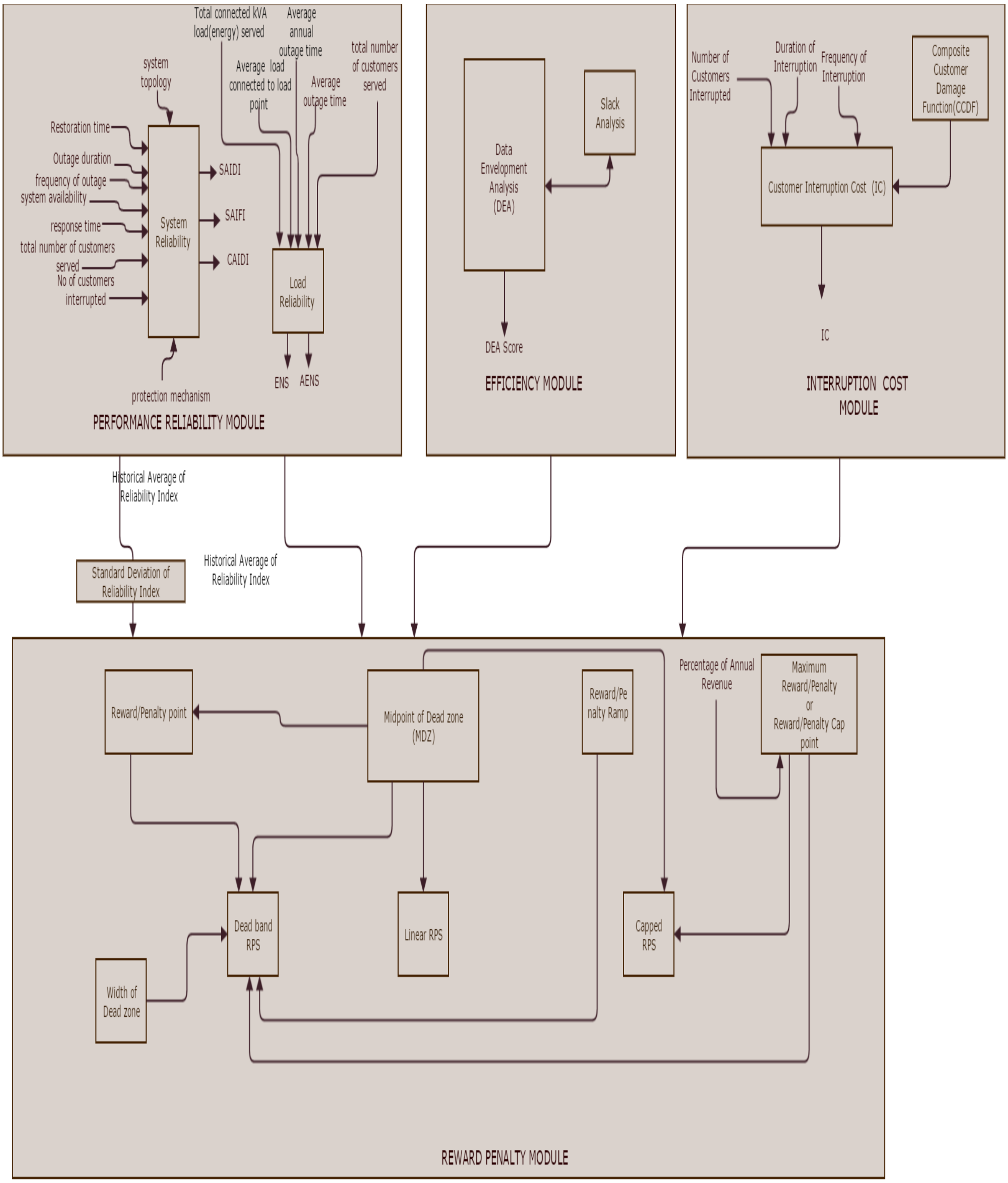

Figure 4.2-1 : Generic Framework of a Reward-Penalty Scheme for Power Distribution Companies

As illustrated in Chapter 2, not all existing research uses these three modules in their penalty function but, use a combination of different parameters in their penalty function.

4.3 THEORETICAL FOUNDATION

In the next three subsections, we discuss these modules in detail, while referring relevant existing research contributions.

4.3.1 PERFORMANCE RELIABILITY MODULE

Reliability index is a parameter that measures the performance reliability of a power system. System performance reliability indicators are classified into two groups: *system reliability indices* and *load reliability indices*. We now describe system reliability indices and load based reliability indices, in detail.

4.3.1.1 SYSTEM RELIABILITY INDICES

Standard P1366 of the IEEE, illustrates the accepted reliability indices [33], [62]. These indices aim to assess the level of customer satisfaction, which is based upon the total length of outages (interruptions) and thenumber of outages. In the literature, three different system reliability indices (i.e. SAIDI, SAIFI, CAIDI) are discussed, which rely on a number of parameters (Figure 4.2-1).

SAIFI (SYSTEM AVERAGE INTERRUPTION FREQUENCY INDEX)[62] is the average number of times that a customer experiences interruptions during a given period [62], [46], [35]. SAIFI is computed by dividing the total number of customers interrupted (N_i) by the total number of customers served (N).

$$SAIFI=\sum_{i=1}^{N}(\frac{N_i}{N})$$ Equation 12

SAIDI (SYSTEM AVERAGE INTERRUPTION DURATION INDEX)[62], [47] is the average duration of outage for customers who experience an interruption during the year.

The SAIDI valueis computed by dividing the customer minutes by the total number of customers.

$$\text{SAIDI}=\sum_{i=1}^{N}\left(\frac{r_i \times N_i}{N}\right)$$ Equation 13

where, r_i is the duration of each interruption, number of customers interrupted (N_i), the total number of customers served (N).

CAIDI (CUSTOMER AVERAGE INTERRUPTION DURATION INDEX)explains the average time required to restore service to the average customer per sustained interruption.

$$\text{CAIDI} =\frac{(\sum_{i=1}^{N}(ri \times Ni))}{(\sum_{i=1}^{N}(Ni))}=\frac{SAIDI}{SAIFI}$$ Equation 14

where, r_i is the duration of each interruption, number of customers interrupted (N_i), the total number of customers served (N).

4.3.1.2 LOAD (ENERGY) RELIABILITY INDICES

Instead of scaling the impact of interruption to the affected customers divided by the total number of customers[71], this index value, is scaled by the Kilovolt- ampere (kVA), of the load affected, divided by the total kVA of the load connected to the network. These indices rely on a number of parameters (Figure 4.2-1). We now describe the two load reliability indices EENS and AENS.

EXPECTED ENERGY NOT SUPPLIED (EENS): By utilizing the load characteristics by industrial customer type in the load point, the measure of expected energy not supplied is figured [52] as EENS = Total energy not supplied by the company or Unserved Energy (UE)

$$\text{EENS} = \sum(L_{a(i)} \times U_i) \text{ kWh/y}$$ Equation 15

Where $L_{a(i)}$ = Average load attached to load point i,

U_i =Average annual outage time

$=\sum_{j=1}^{n} \lambda_j r_j,$ Equation 16

r_i = Average outage time for the load point $i = \frac{U_i}{\lambda_i}$,

r_i = Averageoutagetimefortheloadpointi $= \frac{U_i}{\lambda_i}$

AVERAGE ENERGY NOT SUPPLIED (AENS): Average Energy Not Supplied (AENS) is a measure of the average non-delivered energy per customer. AENS is a reliability index used for electrical power distribution systems and usually, has unit kWh per customer. AENS = Total energy not supplied / a total number of customers served [31].

$$\text{AENS} = \left(\frac{\sum(L_{a(i)} \times U_i)}{\sum_{i=1}^{N}(Ni)}\right) \frac{(\text{ kWh/y })}{\text{N}}$$ Equation 17

Where $L_{a(i)}$ = Average load attached to load point$i$,

U_i =Average annual interruption time

$=\sum_{j=1}^{n} \lambda_j r_j,$ Equation 18

r_i = Average outage time for the load point $i = \frac{U_i}{\lambda_i}$

r_i = Averageoutagetimefortheloadpointi $= \frac{U_i}{\lambda_i}$

N_i = Number of customers interrupted out of the total number of customers served (N).

4.3.2 EFFICIENCY MODULE

There are various elements impacting the behaviors and attitude towards energy proficiency because of the growing cost of energy and rising social ethics. This section presents an efficiency analysis model, called the Data Envelopment Analysis (DEA) model. Applying DEA is a worth analysis method in this context over different other methodologies because of its nonparametric nature.

4.3.2.1 DATA ENVELOPMENT ANALYSIS (DEA) METHOD

The DEA method is the best and most powerful method used to analyze the relative efficiency of the power companies [72], [73] and hence determining the most efficient companies. It is also used as a reference, with which the efficiency of the rest of the companies is compared. Thus, it is defined as a non-parametric method for the estimation of productive efficiency of power distribution companies [45]. The amounts of inputs and outputs are estimated based on physical terms or financial terms. Efficiency based on DEA [28] is well-defined as the proportion of weighted yield to weighted inputs (supplies-products). The inputs are the resources used by distribution companies whereas primaryyields as output[55]. It is represented as a linear programming problem. The presence of much data also makes the process difficult; so, only the significant data must be incorporated. The DEA method is very flexible and allows the analyst to select inputs and outputs.

4.3.3 INTERRUPTION COST MODULE

It has been evaluated, that a greater part of the power supply interruptions, is due to failures of the distribution companies [20], [15], [16]. Some distribution companies have used interruption cost indices (calculated from the power interruptions encountered by its customers), as a regulatory indicator, in their RPS implementation. Three most frequently used interruption cost indices are: 1) IEAR (Interruption Energy Assessment Rate) which refers to the system interruption cost index represented in $/kWh. 2) VOLL (Value of Lost Load) refers to the value an average customer puts on an unsupplied kWh of energy. 3) WTP (Willingness to Pay) refersto the customer willingness to pay to improve its continuity of supply.

By national customer surveys, companies collect cost data for each interruption type and duration. Three computing steps[60], [19], are required to assess the interruption costs: a) processing of raw collected data, b) setting up of customer interruption cost models, based on Customer Damage Functions (CDF), that signifies the normalized interruption cost c) computing interruption cost indices, that include the use of the normalized data to construct CDF for each customer area, that illustrates how this interruption cost maybe determined by on outage duration [39].

4.3.4 REWARD-PENALTY MODULE

Reward-Penalty schemes are monetary mechanisms which encourage power distribution companies to improve their performance reliability. Regulator predefines a performance target for the distribution companies. If it performs better than the target, they will be rewarded. Otherwise, they will be penalized. If distribution companies hit the target, there is neither a penalty nor a reward. A general form of RPS is shown in Figure 4.3.1. It is comprised of three regions [11]: reward zone, dead zone, and penalty zones. In the literature, there are several different variations of the reward-penalty schemes, and it changes according to the requirements and data used. The choice of the regulated indicators (SAIDI, SAIFI, CAIDI, EENS, AENS, IEAR, VOLL and WTP) plays a major role in calculating financial incentives (reward or penalty).

The regulator specifies performance standards as shown in Figure 4.3.1, which is defined as the level of performance reliability, that the company hasanticipated would supply, or the minimum reliability that a company is supposed to supply to its customers[62]. Rebelliousness to base standards of reliability, might involve penalty payment. The structure of reward-penalty changes for various conditions, relies upon the scope of information, kind of reliability index utilized, the objective of the regulators, etc. The Reward/Penalty ramp is related to the performance reliability of the distribution company, as shown in Figure 8.

RPS schemes in few nations [62], [74] (including Ireland, UK, and The Netherlands), have a maximum and a minimum limit (caps) for rewards and penalties. In a perfect world, when monetary motivating forces effectively reflect customer expenses and advantages for performance reliability changes, the presentation of maximum and minimum limits ought not to be vital: the company will achieve the anticipated range of reliability and stay there. In any case, as may be normal, the presumption of customer marginal valuation faultless information on reliability, is not confirmed in practice. Consequently, the risk for awarding the company for improper high-reliability levels, legitimizes the presentation of a maximum limit on rewards. A risk of punishing the company, is also there, whenever it will have deplorable monetary misfortunes. It offers the presentation of a minimum limit on penalties. The scheme, as shown in Figure 4.3.1, indicates that these maximum and minimumboundaries are set to guard the customers and distribution company regulators, against adverse effects of poorly designed RPS.

Capping of the Reward-Penalty scheme [22], [62] is essential to consider, because the controller may have faulty data about customer interruption expenses and their willingness to pay. ***Reward Cap*** or ***Penalty Cap*** is defined for eliminating unacceptable monetary losses for distribution companies and customers alike. As reliability increases, the reward rises, and it stops at the ***Reward Cap Point***. Similarly, as reliability decreases, the penalty rises, and it stops at the ***Penalty Cap Point***. In Figure 4.3.1, two rising and sinking ramps are present in the penalty and reward zones[2]. For companies with lower performance reliability levels, the Penalty Ramp is higher than Reward Ramp, which forces the distribution companies to improve their reliability level [11]. Similarly, for companies with higher performance reliability level, the Reward Ramp is placed higher as an incentive to maintain/ improve their reliability. Both the reward ramp and the penalty ramp stops at their cap point to reduce the financial risks to the company and customers. Notwithstanding the maximum and minimum limits[62], RPS structure includes the dead band. Dead-bands are presented at an interim, where financial incentives do not make a difference. They are intended to keep away from tariff variations, for little deviations from the baseline[62]. Thosedifferences would not speak to a basic alteration in reliability, in the case of capped RPS, but simply create a stochastic effect. To dampen unplanned penalties and rewards attributable to merely changes in quality [17], [11], [10], it is essential to use a dead band. ***The midpoint of Dead Zone****(MDZ):* MDZ is the improvement target value for each company, which equals the middle of the dead zone[75][11], [29],[25]. ***The width of Dead Zone(DZW):*** The Dead Zone Width [4], [75]is defined as the gap between the penalty point and the reward point as shown in Figure below*.* The width of the dead zone represents the target range, that shows the start point of penalty and end of reward [7, 22]. ***Penalty point and Reward point*** are the endpoints of the dead zone.

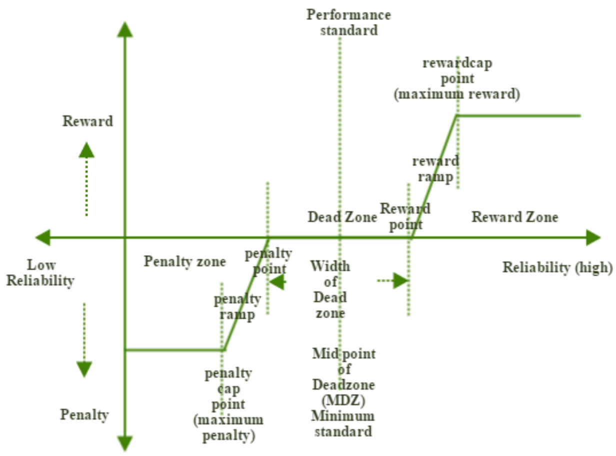

Figure 4.3-1. Reward-Penalty Structure

4.4 CONCLUSION

In this chapter, an innovative framework is presented for designing and implementing RPS. The proposed framework presents the different parameters and has shown how to implement RPS, using those parameters as well as its stability, and accordingly shows which scheme is appropriate for the corresponding power distribution company. The methodology that we propose in this chapter, will assist the regulator to determine the suitable RPSs. The preliminary point for achieving this methodology would be the performance based reliability analysis of distribution companies.

CHAPTER 5

LINEAR REWARD PENALTY STRUCTURE

This chapter provides:

- The Requirements and design rationale for the proposed linear reward penalty structure
- The theoretical foundation and prototype of implementation within Experimental settings
- Results and observations
- Validation
- Comparative analysis and discussion for the linear reward penalty structure.

5.1 INTRODUCTION

In this chapter, we describe how regulators can guide the Power Distribution Company's performance, using performance reward penalty mechanisms. We specifically consider the effect of quality regulation on continuity of supply (reliability). We present a newmodel that is based upon a cost of service remuneration[11]towards establishing an economical way of regulating quality [10]using rewards and penalties. This model encourages Power Distribution Companies to maintain the appropriate reliability levels. The novelty of this reward penalty scheme lies in the use of a linear reward penalty formula, whereby rewards and penalties increase in a linear fashion that is definedby what means the curve reaches the maximum reward or penalty quickly,while performance-based reliability, moves away from the benchmark(or the ends of the dead band, in the case of linear reward-penalty dead band structure).Hence this scheme is termed the Linear Reward-Penalty Scheme(LRPS). The proposed LRPS implements rewards and penalties for exceeding or failing to achieve the targeted performance levels, respectively. This chapter provides detailed theoretical foundation for the LRPS. By considering all of the requirements laid out in this section, it also clarifies the algorithm design. A flowchart is given to bring clarity to this explanation. It clarifies how the algorithm is applied in order to complete the various analyses. It also tests the validity of performance-based reliability. Additionally, we contrast the proposed scheme as well as the existing Reward-Penalty Schemes [4], [5], [10], [11], [28], [66], [76], [77] to show the relevance of the LRPS for practical incentive calculations. This chapter formerly concludes with results that offer validation to this proposal. Now we outline the fundamental prerequisites and the design rationale for LRPS.

5.2 PROPOSED LINEAR REWARD PENALTY STRUCTURE (LRPS)

This section provides an overall outline of LRPS followed by an explanation of the requirements needed to address the issue of the linear reward penalty structure. This then leads to the design rationale, where we examine the vital design decisions for the LRPS.
We now provide a general overview of LRPS.

5.2.1 GENERAL OVERVIEW OF LRPS

Power System Distribution Company Regulators, have utilized the reward penalty methods for a long time, to address traditional performance areas, for example, reliability, energy efficiency, interruption duration, and safety. Lately, these methods have been given greater consideration because of regulatory concerns over flexibility and the power distribution company's capacity to respond to technological change[78]. Many RPS models previously proposed, were surveyed in Chapter 2. However, most of the existing RPS mechanisms, cannot simultaneously address the following issues:

The proposed QRPS scheme addresses all of the following issues:

- Use oflimited variables to calculate the reward or the penalty.
- Ensuringa reasonable magnitude for the reward or the penalty.
- The uncertainty concerning the best performance based reliability level and the performance inconsistency factor,s that are outof the regulator's control.

The main objectives of this proposed scheme areto:

- Introduce a set of well-defined goals for the LRPS scheme
- Present two novel linear reward penalty schemes, which provide an efficient way for improving the performance; based on reliability for Power Distribution Companies.
- Demonstrate a linear RPS scheme, without any dead band and capping of the maximum reward and the maximum penalty.
- Demonstrate a linear RPS scheme with a dead band being used to control the normal fluctuations in performance and a capping of maximum rewards and maximum penalties.
- Provide a comparative study of the strengths and limitations of both the proposed approach and other existing approaches, that are proposed in existing literature.

5.2.2 REQUIREMENTS

To address the issues of reward penalty schemes, the following prerequisites have been established for the proposed LRPS algorithm. These requirements are as follows:

1. Define a specific performance metric that measures reliability
2. Set a realistic target that support and monitor the company's performance behaviour.
3. The Reward-Penalty formula, which defines the shape and slope of the curve, should be easy to understand and administer, and consistent with the desired outcome.
4. The algorithm should have the capacity to control typical performance fluctuations due to external elements, which cannot be managed by the power distribution company's' regulator.
5. The algorithm should provide a reasonable scale for reward/penalty, ensuring that the magnitude of the reward/penalty, should remain within reasonable boundaries.
6. Presentation of financial rewards/penalties should be administratively simple.

5.2.3 DESIGN RATIONALE

To fulfill the requirements laid out in 5.2.2, the hypothetical foundation for LRPS is proposed and addressed all of the prerequisites by settling the design decisions. The design decisions proposed in this framework are as follows:

1. To assess thePower Distribution Company's performance, so as to indicate the extent to which the service is reliable and to measure how fast interruptionsare resolved quickly. The parameter performance reliability index, plays a central role in enabling regulators. In the proposed approach, the metric, System Average Interruption Duration Index (SAIDI)[79], is used for measuring this performance reliability. It shows the sustained interruptions experienced by customers. The data required for calculating this index includes the average number of customers and the number of sustained interruptions[78].

2. The minimum standard (performance target) defined, should be made possible by a well-managed distribution company. In the event that the performance of the company is now acceptable, then the performance target could be fixed so as to set the standard for work performance , thus ensuringthese targets are consistently met. On the off chance that companies need to meet higher standards of performance, a sensible target can be set, in light of past recorded performance levels. In this proposed model, the minimum standard (performance target) level is set by taking into account the changing average of historical performance, which assists in measuring the company's behavior, whether the company is performing well and will receive rewards or under-performing, that would lead to penalties.
3. The Reward-Penalty formula, which portrays the shape and slope of the curves, decides how rapidly the curve achieves the maximum reward or penalty, as performance goes off course from the performance target. Here we have presented a linear reward penalty formula, simple and easy to understand and administer. It increases rewards and penalties in a linear fashion as the performance fluctuates from the normal, on either side of the performance target.

4. We have introduced a dead band called the neutral zone around the target performance level, where the company does not get a reward or penalty. It represents vulnerability in regards to the ideal performance level and additionally considers certain performance variations, in light of elements outside of the distribution company's control.
5. We have introduced a capping (thresholding) on the maximum reward and penalties that allow companies to abstain from paying a critical penalty or getting a huge reward.
6. During the reward-penalty calculation process, it is valuable to display financial rewards or penalties in numerous units. Be that as it may, management of these rewards/penalties calculations are, in the most part, simplest when defined in dollars rather than as different units, such as pennies per share, basis points of return on equity(ROE), percentage of base incomes, percentage of aggregate income and so on. Consequently, here, we have utilized dollars for showing financial rewards or penalties.

5.3 THEORETICAL FOUNDATION FOR LRPS

The theoretical foundation for LRPS is proposed in this section. The proposed scheme offers performance-based regulation which is based on reliability. In contrast to the scheme proposed in [25], [24], [4], [80], [81], [11],which favours the power distribution company, while implementing the reward-penalty scheme, our proposed scheme is described after carefully analysing the design decisions and is favourable to both regulator and power distribution companies.A novel feature of our scheme is the use of the linear reward/penalty formula, which varies in a linear fashion, based on the behaviour of the performance-based reliability.

Our LRPS scheme comprises two methods:

- LRPS with no dead band and no reward/penalty capping(LRPS-NC)
- LRPS with dead band and reward/penalty capping(LRPS-C)

5.3.1 ALGORITHM FOR LRPS

In this section, we explain the two algorithms of LRPS.

5.3.1.1 ALGORITHM FOR LRPS-NC

Input:

- Multiyear historical SAIDI values (4 years)
- Current actual SAIDI value

Output:

- Reward or Penalties in Dollars

Step 1: Evaluate the reliability index, SAIDI

To calculate SAIDI, each interruption during the period, is multiplied by the duration of the interruption, to find the customer minutes of interruption. The customer minutes of all interruptions are then calculated to determine the total of customer minutes. To find the SAIDI value[79], the customer minutes are divided by the total of customers.

SAIDI=$\sum_{i=1}^{N}(ri \times Ni \div N)$(Eq. 1)

Where, ri is the duration of each interruption

Step 2: Establish Performance targets

In this step, the company's previous performance reliability index (SAIDI) calculated over a set period (for example, the past five years) is used to establish the target. This process presumes that the data has been collected in the past, is readily available and indicates that the historical performance was satisfactory.

Step 3: Designing the Linear RPS curve as shown in figure. 5.3-2, without using dead band and capping for each distribution company, is based on the SAIDI.

Step 4: Evaluate the rewards and penalties for each distribution company based on its reliability level as needed. The formula for calculating reward or penalty for the distribution company is based on their performance and assessed using the reliability index is presented below.

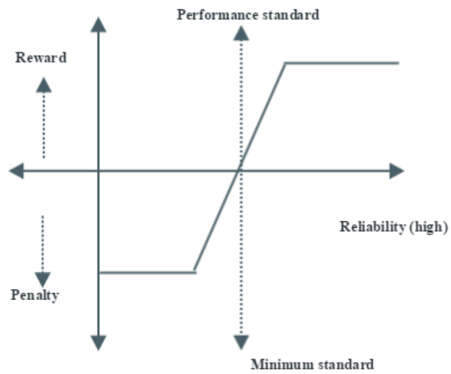

Figure 5.3-1 LRPS NC structure

$$Reward/Penalty(x, Target) = \begin{cases} Slope * (Target - x), & x < Target \\ 0, & x = Target \\ Slope * (Target - x), & x > Target \end{cases}$$

Where x=Reliability Index SAIDI, $Reward/Penalty(x, Target)$ is the reward/penalty payment of the distribution company for x.

When x is smaller than the target, a reward payment is awarded to the distribution company. Similarly, when x is larger than the target, a penalty payment is charged to the distribution company. The reward payment increases as x decreases.

5.3.1.2 ALGORITHM FOR LRPS-C

Secondly, we explain the algorithm of LRPS-C.

Input:

- Historical (Multi-year) SAIDI values (e.g.: 4 years)
- Current actual reliability index, based on SAIDI value
- Annual Revenue

Output:

- Reward or Penalties in Dollars
-

Step 1: Assess the current year SAIDI value, i.e., the company's current, actual performance score.

Step 2: Establish Performance targets

In this step, the company's previous performance re liability index (SAIDI) during a set period (for example, the past five years) is used to set the target. This process presumes that the data has been collected in the past and is readily available and indicates that the historical performance was satisfactory.

Step 3: Establish the Dead Zone

Step 4: Establish the Midpoint of the Dead Zone(MDZ)

MDZ=Historical Average SAIDI Values, for the past four years

Step 5: Establish the Dead Zone width

Standard Deviation (SD) of the pastfive years SAIDI values

Step 6: Establish the Reward Point (RP) and the Penalty Point(PP)

RP=MDZ-SD/2

PP=MDZ+SD/2

Step 7: Establish the Reward Cap point (RCP) and the Penalty Cap point (PCP)

RCP=MDZ-SD

PCP=MDZ+SD

Step 8: Establish the Max. Reward Cap (Max. R) and the Max. Penalty (Max. P) Cap

Capping is introduced to the proposed scheme, with the assumption that the aggregate reward or penalty is based upon the reliability indices being lower than five percent of the yearly income of each distribution company. Here we assume that the reward cap value and the penalty cap value are the same. Consequently, it is defined as:

Max.reward=0.05*Rev

Max.Penalty=0.05*Rev

WhereRevis the annual revenue of thedistribution company.

Step 9: Establish Reward Ramp (RR) and Penalty Ramp (PR)

RR=Max.Reward/ (RP-RCP)

PR=Max.Penalty/ (PCP-PP)

Step 10: Design the Linear RPS curve with dead band and capping for each distribution company, based on the SAIDI

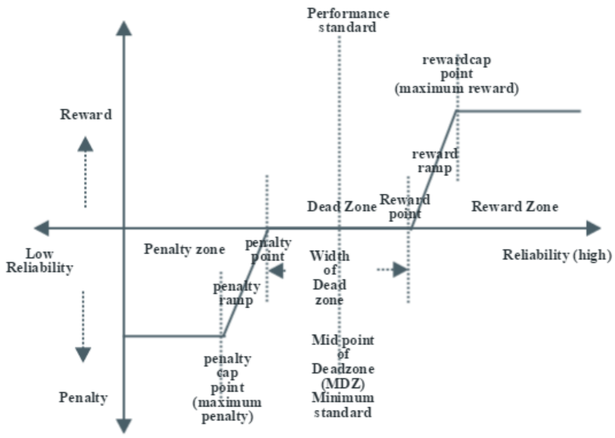

Figure 5.3-2 LRPS C Structure

Step 11: Evaluate rewards and penalties based on the performance of the power distribution company using the reliability index, SAIDI.

$$Reward\ Penalty/(x, Target) = \begin{cases} Max.Reward & x \leq RCP \\ \frac{Max.Reward}{RP-RCP} Target - x & RCP < x < RP \\ 0 & RP \leq x \leq PP \\ \frac{Max.Penalty}{PCP-PP} x - Target & PP < x < PCP \\ Max.Penalty & PCP \leq x \end{cases}$$ Equation 19

The RPS is explained using a flowchart for easier understanding. This is given in the next section.

5.3.2 FLOWCHART FOR LRPS

In this section, we explain the Linear RPS process, using a flowchart. The flowchart is presented in figure 5.3-3 and.figure 5.3-4.

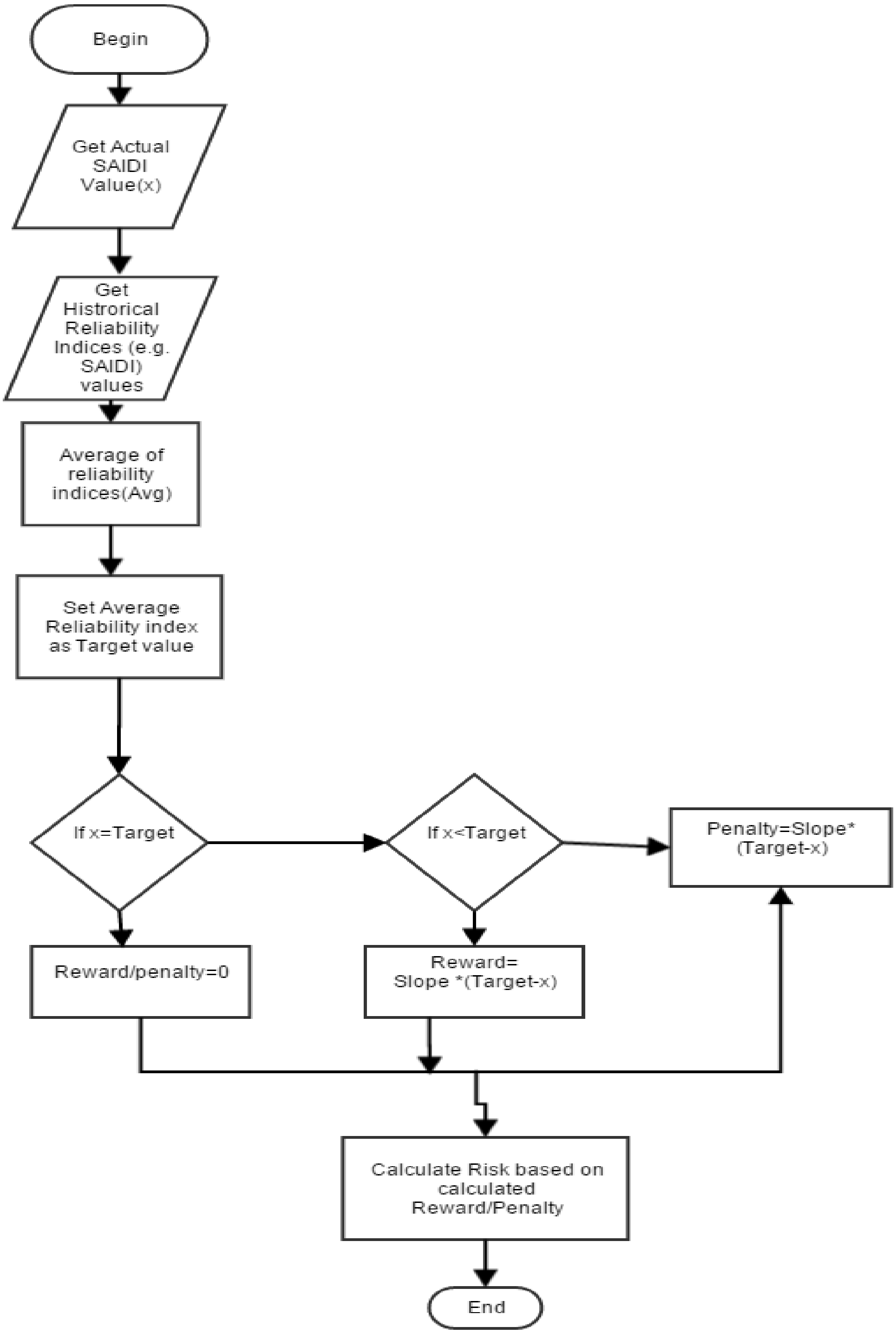

Figure 5.3-3 Flow Chart for LRPS NC

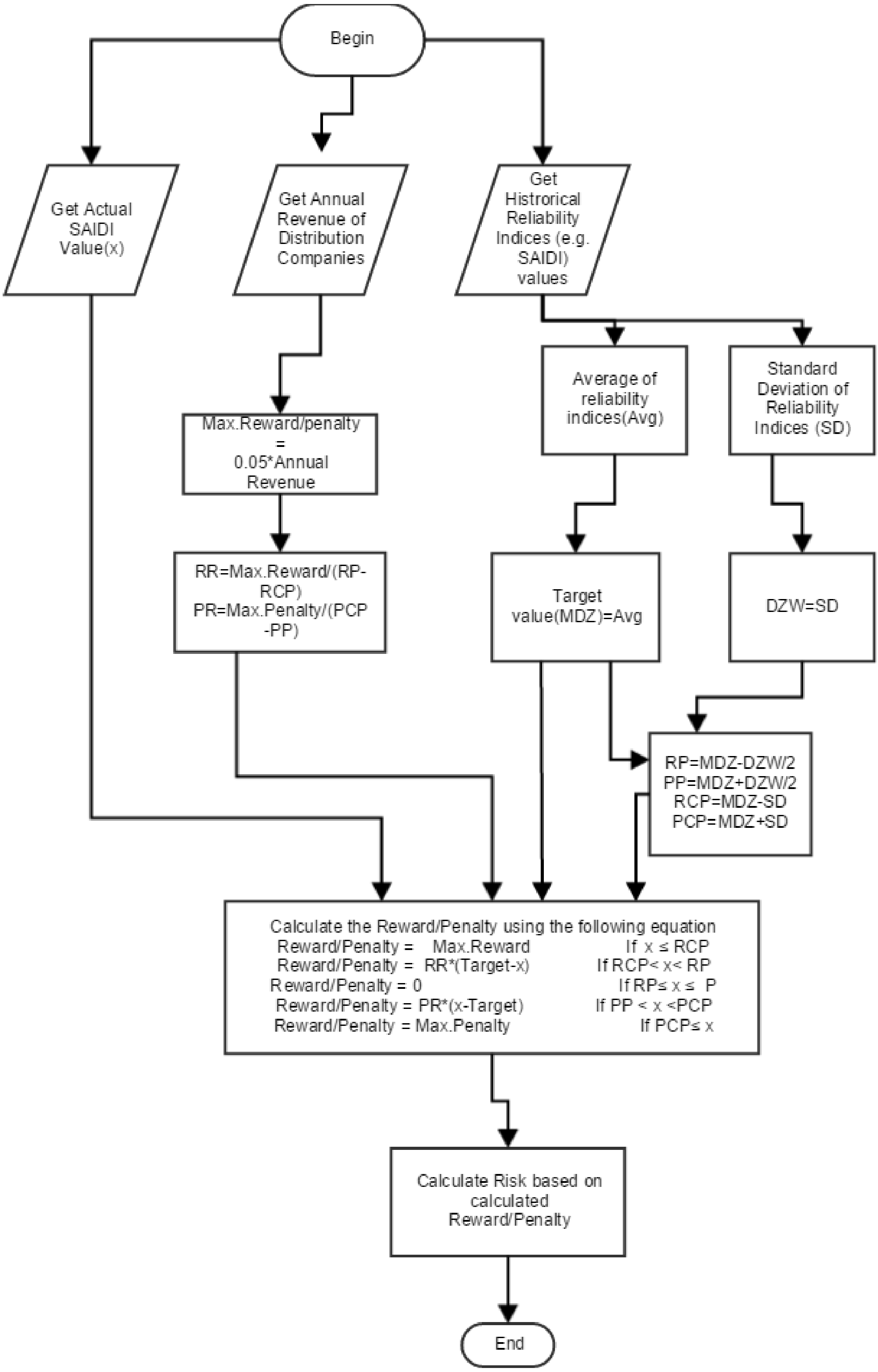

Figure 5.3-4 Flow Chart for LRPS-C

5.4 PROTOTYPE IMPLEMENTATION

To test the feasibility of the proposed algorithm, we implemented the algorithm in section 5.3 using the given pseudo code in Appendix 1.

5.5 EXPERIMENTAL SETTINGS

In the experiments that we conducted, we used the following parameter specifications. We also discussed the obtained results using existing literature.

5.5.1 PARAMETER SPECIFICATION

All the parameters used for gathering the results from the algorithm are listed in Table6

Table 5.5-1 Parameter Specification

Parameter	Description
x	Actual SAIDI value
SD	Standard Deviation of a set of historical (Past 5 years) reliability indices (SAIDI values)
Avg	Average of a set of historical (Past 5 years) reliability indices(SAIDI values)
MDZ	Midpoint of Dead Zone
DZW	Dead Zone Width
PP	Penalty Point
RP	Reward Point
RCP	Reward Cap Point
PCP	Penalty Cap Point
RR	Reward Ramp (slope in the reward zone)
PR	Penalty Ramp (slope in the penalty zone)
Max.Rew	Maximum Reward Cap
Max.Pen	Maximum Penalty Cap
Rev	Annual Revenue of Distribution Companies

5.6 RESULTS AND OBSERVATIONS

In this section, we examine the experiments that we carried out and the outcomes that we observed, in the wake of running our model. Perceptions are made by examining these outcomes which were accumulated from the model. Table 5.6-1 shows the the summary statistics of the 42 Iranian distribution companies' variables which is available at : www. tavanir.org. Applying these parameters to LRPS NC algorithm and LRPS C algorithm helps to identify the inefficient companies that need to improve their service reliability to maintain the target performance reliability level. It also contributes to estimate the corresponding reward or penalty payment based on their performance based reliability index.

For example, Consider the application of LRPS-NC model on a power distribution company D16 which has an average SAIDI of 712 min, which is fixed as the target performance reliability level. It can be seen from the table 5.6-2 that current reliability index for D16 using SAIDI is found as 820min, which is higher than the target performance reliability level, as this company is inefficient.

Consider the case LRPS-C application on the same inefficient power distribution company D16 which has an average SAIDI of 712 min. This value (712 min) is defined as the target performance reliability level and sets as MDZ in LRPS C structure. The average SD of historical reliability index for D16 are 106 min, and the width of the dead zone is equal to this value. The penalty and reward points for D16 are 765 and 606 respectively which are defined by 'mean - SD/2' and 'mean + SD/2', respectively. It can be seen from Table 5.6.1 that current reliability index using SAIDI is found as 820min which is higher than the target performance reliability level, as this company is inefficient. Since it is greater than the penalty cap point, it can expect to receive a penalty payment which is set as the maximum penalty cap for D16, from the regulator.

Table 5.6-3 Results of LRPS

Distribution Companies	MAX.Reward Cap M$	Reward Ramp Slope	RCP(a)	RP(b)	Width of Dead Zone	MDZ	Pp©	PCP(d)	Penalty Ramp Slope	MAX. Penalty Cap M$	SAIDI (RI)	LRPS-NC (M$)	LRPS C (M$)

D1	1.37	0.02	208	287	158	366	445	524	0.02	-1.82	410	-1.01	0.00
D2	2.87	0.04	218	297	158	376	455	534	0.08	-5.93	376	0.00	0.00
D3	0.14	0.00	46	125	158	204	283	362	0.01	-0.85	224	-0.22	0.00
D4	1.50	0.02	414	493	158	572	651	730	0.02	-1.50	657	-1.61	-1.50
D5	2.27	0.03	2457	2536	158	2615	2694	2773	0.03	-2.28	3077	-13.33	-2.28
D6	1.97	0.02	470	549	158	628	707	786	0.05	-3.88	653	-1.23	0.00
D7	1.76	0.02	209	288	158	367	446	525	0.03	-2.75	392	-0.87	0.00
D8	0.27	0.00	285	364	158	443	522	601	0.04	-2.85	460	-0.61	0.00
D9	3.88	0.05	1571	1650	158	1729	1808	1887	0.05	-3.88	1954	-11.05	-3.88
D10	2.79	0.04	307	386	158	465	544	623	0.04	-2.79	518	-1.87	0.00
D11	3.27	0.04	234	313	158	392	471	550	0.06	-4.54	426	-1.95	0.00
D12	5.35	0.07	697	776	158	855	934	1013	0.10	-7.77	889	-3.35	0.00
D13	2.61	0.03	960	1039	158	1118	1197	1276	0.03	-2.61	1267	-4.93	-2.61
D14	2.35	0.04	743	797	108	851	905	959	0.04	-2.35	986	-5.86	-2.35
D15	0.97	0.02	399	453	108	507	561	615	0.02	-0.97	551	-0.79	0.00
D16	1.02	0.02	606	659	106	712	765	818	0.02	-1.02	820	-2.08	-1.02
D17	2.85	0.05	589	643	108	697	751	805	0.06	-2.97	735	-2.09	0.00
D18	1.02	0.02	409	462	106	515	568	621	0.04	-2.31	527	-0.52	0.00
D19	1.49	0.03	685	738	106	791	844	897	0.03	-1.49	886	-2.67	-1.49
D20	0.17	0.00	135	188	106	241	294	347	0.02	-0.91	243	-0.03	0.00
D21	0.72	0.01	587	641	108	695	749	803	0.01	-0.72	812	-1.56	-0.72
D22	0.94	0.02	216	270	108	324	378	432	0.03	-1.42	324	0.00	0.00
D23	1.38	0.03	441	495	108	549	603	657	0.05	-2.52	575	-1.21	0.00
D24	1.95	0.04	663	716	106	769	822	875	0.04	-1.95	846	-2.83	-1.95
D25	0.86	0.02	464	517	106	570	623	676	0.02	-1.32	618	-1.19	0.00
D26	0.68	0.01	527	581	108	635	689	743	0.01	-0.68	742	-1.36	-0.68
D27	2.93	0.05	896	950	108	1004	1058	1112	0.05	-2.93	1078	-4.01	-2.93
D28	1.68	0.03	451	504	106	557	610	663	0.06	-3.14	557	0.00	0.00
D29	1.08	0.02	959	1012	106	1065	1118	1171	0.02	-1.08	1253	-3.83	-1.08
D30	1.73	0.03	473	527	108	581	635	689	0.03	-1.73	639	-1.86	-1.73
D31	1.68	0.05	414	446	64	478	510	542	0.08	-2.68	507	-2.43	0.00
D32	0.72	0.02	349	381	64	413	445	477	0.05	-1.71	438	-1.34	0.00
D33	0.80	0.02	309	341	64	373	405	437	0.16	-5.17	384	-1.78	0.00
D34	1.09	0.03	90	122	64	154	186	218	0.11	-3.55	156	-0.22	0.00
D35	1.72	0.05	101	133	64	165	197	229	0.16	-4.98	165	0.00	0.00
D36	0.91	0.03	142	174	64	206	238	270	0.11	-3.36	207	-0.11	0.00
D37	1.38	0.04	95	127	64	159	191	223	0.13	-4.19	159	0.00	0.00
D38	1.66	0.05	161	193	64	225	257	289	0.14	-4.38	225	0.00	0.00
D39	3.78	0.12	428	460	64	492	524	556	0.13	-4.28	579	-11.64	-4.28
D40	0.87	0.03	127	159	64	191	223	255	0.11	-3.53	192	-0.11	0.00
D41	0.83	0.03	443	475	64	507	539	571	0.17	-5.51	507	0.00	0.00
D42	1.04	0.03	314	346	64	378	410	442	0.10	-3.29	378	0.00	0.00

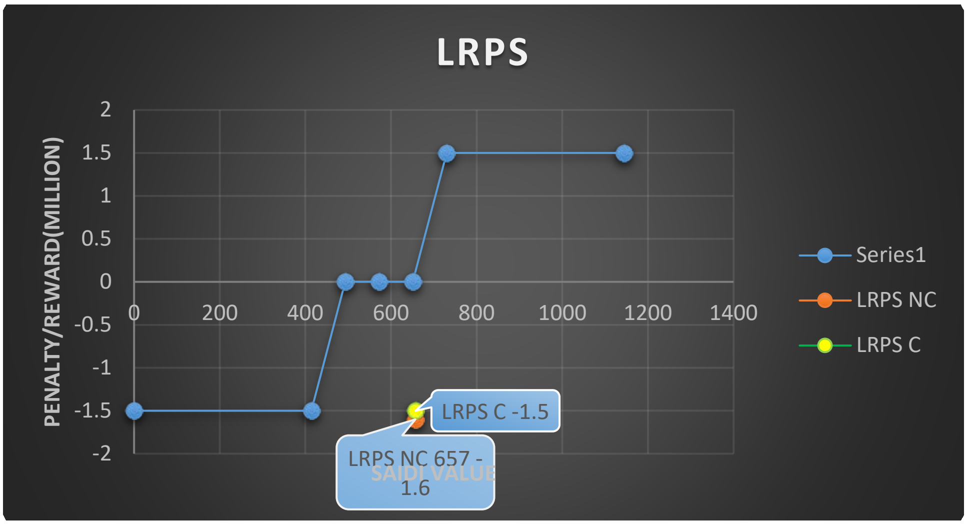

Figure 5.6-1 LRPS Structure

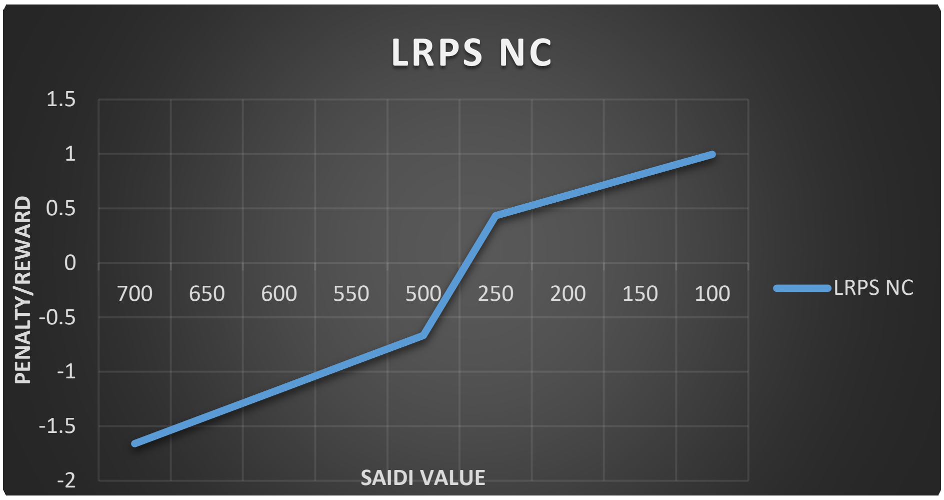

Figure 5.6-2 LRPS NC Structure

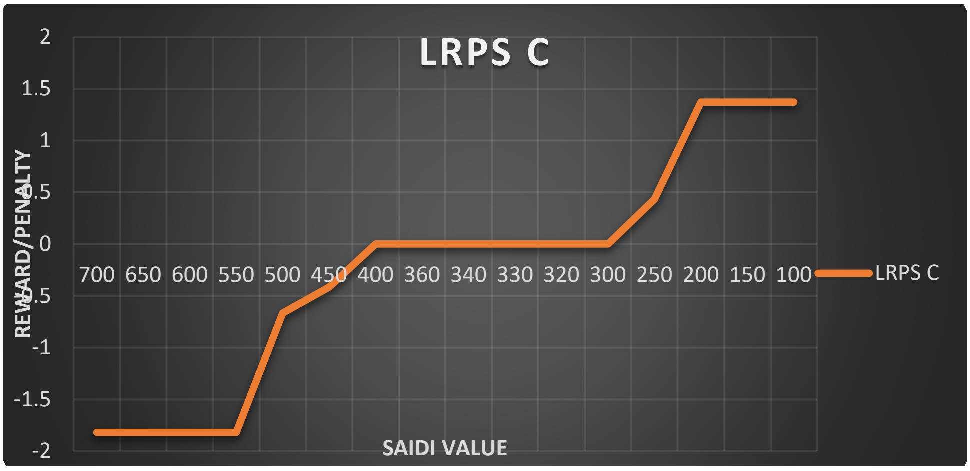

Figure 5.6-3 LRPS C Structure

5.7 VALIDATION

In this Chapter, we proposed a Linear Reward-Penalty Scheme, termed LRPS, in two different ways- without a deadband and capping and with the dead band and capping.

From the experiments that we conducted, we made the following observations:

- By Using limited variables, we can calculate reward/penalty.
- Reward/penalty values are significant, if we are not setting the dead band and capping(LRPS-NC)
- Ensured a reasonable magnitude for reward /penalty,by setting the capping(LRPS-C)
- By setting the dead band, the proposed scheme considered the vulnerability of the ideal performance level, and additionally took into account, certain performance variations occurring in light of elements outside of the distribution company's' control(LRPS-C).
- When compared to the existing algorithms, this linear algorithm is more favourable to regulatory authorities.

5.8 COMPARATIVE ANALYSIS AND DISCUSSION

In this section, the proposed solution is compared with the existing schemes by implementing the same dataset. A comparative study is depicted in the table 5.8-1, which shows our algorithm (LRPS) and its comparison with the existing schemes in [25], [24], [4], [80], [81], [11]. The parameters for LRPS design implementation largely affect the financial risk of electric distribution companies and in this way setting these parameters is a basic issue in the reward and penalty payment. It is very reliant on the goal of the regulator. There are various elements that ought to be considered which influence the reliability and the behavior of individual companies when setting the parameters of LRPS. The nature and assortment of customer effects, coming about because of duration and recurrence of interruptions, ought to be considered while selecting the distinctive parameters for LRPS outline.

The reward–penalty schemes do not have a steady structure in all conditions and change as per necessities. Structures of these models rely on upon scope of data, kind of reliability index, the objective of system regulators, RPS execution time and so forth. If RPS is mainly designed using performance-based reliability, then the type of reliability index used in designing RPS has a significant impact on the reward and penalty payment. There are distinctive structures of RPS, be that as it may, Dead-Band RPS for reliability is the most proficient one since it incorporates the uncertainty about the optimal performance level and the performance related components that are outside of the distribution company's control. We implemented two approaches mainly intended for those regulators who concern more to customers that are affected by outage duration factor, the first approach is for those regulators who want to apply RPS for the first time, and they can apply RPS for money making. In the second method, we designed a dead-band RPS, which achieve an effective RPS for enhancing service reliability. The performance of the proposed approaches is illustrated by reliability data of various electric distribution companies. A comparison between existing algorithms is provided in Table 5.8.1.

Mid-Point of Dead-Zone is the point where we set the performance target on an RPS curve which determines whether a company gets reward or penalty, so it has a vital importance in designing RPS curve. Billinton and Pan[24], [25] utilized both reliability indices SAIDI and SAIFI, with every index is weighted in light of the customer's concern, for determining this point. In [4], they utilized an Equivalent Probability Distribution of reliability indices for designing the RPS. A mix of cluster analysis and DEA is utilized by [80] for ascertaining MDZ while [81] utilized a mix of Historical normal Reliability Index, density area, and improvement target. In [11], MDZ is computed in light of the estimations of Historical Average Reliability Index, DEA efficiency score and the maximum reliability improvement. Even though the results have shown to be better, [4], [11], [24], [25], [80], [81] have used too many parameters and takes longer computation time.

In the proposed LRPS approach, we set MDZ as the average of the last five years' reliability indices. Since the characteristic of the customers who are more concern towards the outage duration is taken into account in the LRPS design, so we applied SAIDI as the reliability index for determining the performance target(MDZ). In our design, only one parameter, SAIDI, is used, the results have proven to be fairly robust and take lesser computation time.

The parameter width of the dead zone(DZW) is highly subject to parameters of probability distribution measures, for example, mode, mean, range, variance, standard deviation, and skewness. Picking a bigger dead zone size estimate makes the LRPS design inadequate as many data might be situated in this fair-minded zone. Then again, a smaller dead zone size estimate brings about a high hazard for a distribution company as little change in the reliability index may shift the incentive payment from the reward zone to the penalty one or the other way around. Applying a dead zone with the mean of the historical reliability data as the center of the zone was recommended in [24], [25]. In view of this strategy, the dead zone size is two times the standard division with the end goal that the 'mean + SD' is the reward point and the 'mean - S.D.' is the penalty point. Applying this strategy may locate many data in the dead zone. A wide dead zone may lose the primary idea behind the RPS execution with the end goal that a large number of the information is situated in this zone and there is no any inspiration for distribution company to enhance the reliability.

This thesis considers the midpoint of the dead zone(MDZ) as the mean of historical data. The penalty and reward points are defined by 'mean - SD/2' and 'mean + SD/2', respectively. This model prompts to a narrower dead zone than the one proposed in [24], [25] and normally reduced data are situated in this zone. A regulator can utilize this model when the performance-based reliability index is near the average of historical reliability data. Additionally, we proposed one standard deviation as DZW when contrasted with Billinton and Pan [24], [25], who proposed two standard deviations. This delineates that the regulator needs distribution companies to keep up their future performance reliability in view of the average values. This procedure presumes that the information has been gathered in the past and is promptly accessible furthermore that the historical performance was satisfactory. Utilizing these methodologies, the regulator can ensure that service reliability has not been weakened after privatization.

The regulator does not always have impeccable and correct data about customer interruption costs. Thus, a cap value as a rate of the company's yearly income ought to be considered by the regulator to legitimize the risk of giving high rewards or penalties for improperly high-quality or low-quality reliability levels [62]. In UK and Ireland, maximum reward and maximum penalty are capped and are set at 3 and 4% of price control incomes [62]. In Netherlands, the adjustment in revenues is capped at 5% [62]. The reward and penalty payments are also related to interruption cost. In [5], the maximum cap values are set in light of rate of average yearly earnings by each distribution companies. In [11], CCDF and cap value are utilized to decide the maximum reward. In Norway and Italy[62], the consequences of customer interruption cost surveys are utilized as a part of setting the capping limits. In this paper, a few rates of aggregate revenue of a distribution company is fixed as the maximum reward and maximum penalty caps. The maximum reward cap is same as maximum penalty cap, and it depends on the regulatory goal. Maximum reward and maximum penalty are set as a rate of yearly revenue and is controlled by the regulator. In our method for RPS design, we set the maximum reward and maximum penalty caps for each company as five percentage of their yearly revenue.

We conducted lots of experiments for comparing the proposed ranking outcomes with the existing outcomes. From the results, we made the following observations which shows our proposed scheme does outperforms than others. The inclusion of deadband and capping in our RPS design shows that our ranking results are more reasonable.

- Using limited variables, we can calculate reward/penalty efficiently with less computation time than the existing schemes.
- The Linear formula is easy to understand and administer
- As performance moves, away from the pre-defined performance target, the curve quickly achieves the maximum reward and maximum penalty
- This scheme is more favourable to regulatory authorities than distribution companies
- Ensures a reasonable scale for reward/penalty
- Considers those performance related components that are outside of the distribution company's control, which causes uncertainty regarding the variations from the optimal performance level.
- By setting the dead band, the proposed scheme considered vulnerability in regards to the ideal performance level, and additionally took into account certain performance variations in light of elements outside of the distribution company's control

- The simulation results of LRPS model show that those companies with very low reliability received the maximum penalty.

Table 5.8-2 Comparative study

PROPERTIES	[25]	[24]	[4]	[80]	[81]	[11]	LRPS-C ALGORITHM
MDZ	Historical average Reliability Index	Historical average Reliability Index	Equivalent Probability Distribution	DEA efficiency scores after a clustering process	Historical average Reliability Index, density area and improvement target	Historical average Reliability Index, DEA efficiency score and the maximum reliability improvement	Historical Average Reliability Index (SAIDI)
DZW	Standard Deviation	Standard Deviation	Standard Deviation	-	5% of MDZ	Average standard deviation for each cluster	Standard Deviation of the Historical Reliability index(SAIDI)
PP	MDZ-Half of Standard Deviation	MDZ-Half of Standard Deviation	MDZ-Half of Standard Deviation	-	-	MDZ+Half of Standard Deviation	MDZ+Half of Standard Deviation of the Historical Reliability index(SAIDI)
RP	MDZ+Half of Standard Deviation	MDZ+Half of Standard Deviation	MDZ+Half of Standard Deviation	-	-	MDZ-Half of Standard Deviation	MDZ-Half of Standard Deviation of the Historical Reliabil-

							ity index(SAIDI)
RCP	MDZ+Standard Deviation	MDZ+Standard Deviation	MDZ+Standard Deviation	-	-	MDZ-Standard Deviation and Slack Analysis	MDZ-Standard Deviation of the Historical Reliability index(SAIDI)
PCP	MDZ-Standard Deviation	MDZ-Standard Deviation	MDZ-Standard Deviation	-	-	PP+Max.Penalty/Penalty Ramp	MDZ+Standard Deviation of the Historical Reliability index(SAIDI)
RR	-	Max.Reward/Sloping area width	Max.Reward/Sloping area width	-	Varies according to the density and reliability level score	Max.Reward/Sloping area width	Maximum Reward/(Reward Point-Reward Cap Point)
PR	-	Max.Penalty/Sloping area width	Max.Penalty/Sloping area width	-	Varies according to the density and reliability level score	Depends on DEA Score	Maximum Penalty/(Penalty Cap Point-penalty Point)
MAX.REW	-	1M$	% of average income of utilities in each cluster	-	-	CCDF and Cap value	5% of average income of distribution companies

MAX.PEN	-	1M$	% of average income of utilities in each cluster	-	-	% of average earnings of utilities	5% of average earningsof distribution companies

In the first case (LRPS-NC), from the experiments that we conducted, we created the following advantages and disadvantages:

Advantages:

- The Linear formula is easy to understand and administer
- As performance moves, away from the pre-defined performance target, the curve quickly achieves the maximum reward and maximum penalty
- Limited parameters for defining the reward/penalty
- This scheme is more favourable to regulatory authorities

Disadvantages:

- Does not ensure a reasonable scale for reward/penalty
- Does not consider thoseperformance related components that are outside of the distribution company's control.

In the second case (LRPS-C), from the experiments that we conducted, we created the following advantages and disadvantages:

Advantages:

- The Linear formula is easy to understand and administer
- As performance-based reliability strays away from the target, the curve quickly achieves the maximum reward and maximum penalty
- Limited parameters for finding reward/penalty
- Ensures a reasonable scale for reward/penalty
- Considers those performance related components that are outside of the distribution company's control, which causes uncertainty regarding the variations from the optimal performance level.
- When compared to the existing algorithms, it is more favourable to regulatory authorities

Disadvantages:

- The Curve reaches maximum reward/ penalty quickly. For instance, the decreasing slope shows that this algorithm provides a significant reward or penalty around the dead band.

5.9 CONCLUSION

In this chapter, we introduced and formulated the problem of LRPS. We proposed a novel LRPS scheme, for power distribution companies. The fundamental advantage of our approach, is that it ensures a reasonable scale for the reward/penalty and has also taken out the vulnerability ofthe variations from the optimal performance level,caused by thoseperformance related factors, that are outside of the distribution company's control. A comparative study of our technique with previously proposed techniques ,indicates that our technique is superior and can work in the best interests of the copyright holder.

CHAPTER 6

QUADRATIC REWARD PENALTY STRUCTURE

This chapter provides:

- Requirements and design rationale of the proposed quadratic reward penalty structure,
- The theoretical foundation and the prototype implementation
- Experimental settings,
- Results and observations,
- Validation,
- Comparative analysis and discussion for quadratic reward penalty structure.

6.1 INTRODUCTION

In this chapter, we describe how regulators can guide Power Distribution Company's performance through the use of performance reward penalty mechanisms, by considering the disadvantages that are mentioned in the previous chapter. Here we also specifically consider the effect of quality regulation on continuity of supply (reliability). We present a novel model that is basedon a cost of service remuneration[10], [11] thus moving towards the competitive approach to quality regulation, that is based on rewards and penalties and encourages Power Distribution Companies to maintain the appropriate reliability levels. The novelty of this reward penalty scheme, lies in the use of the quadratic reward penalty formula, where rewards and penalties increase in a quadratic fashion that defines, by what means,that the curve reaches the maximum reward or penalty quickly. This is because performance-based reliability moves away from the benchmark(or the ends of the dead band in the case of Quadratic Reward-Penalty dead band structure); Hence this scheme is termed the Quadratic Reward-

Penalty Scheme(QRPS). The proposed QRPS implements rewards and penalties for exceeding or failing to achieve the targeted performance levels, respectively. The quadratic function is designed to provide increasing rewards or penalties as performance-based reliability deviates from the target, but the rewards or penalties increase more slowly. The chapter provides a detailed theoretical foundation for the QRPS. By considering all the requirements laid out in this part, it also clarifies the algorithm design. A flowchart is given to bolster the clarification. It clarifies how the algorithm is applied for completing the various analyses. It also tests to validate the performance-based reliability. Additionally, we contrast the proposed conspire and existing Reward-Penalty Schemes [4], [5], [10], [11], [28], [66], [76], [77] to show the advantage of QRPS, for practical incentive calculations. This chapter formerly concludes with a validation of results. Now we sketch the fundamental prerequisites and the design rationale for QRPS.

6.2 PROPOSED QUADRATIC REWARD PENALTY STRUCTURE (QRPS)

This section gives an overall outline of QRPS and after that explains the requirements to address the issue of the quadratic reward penalty structure. It is then followed by the design rationale, where we examine the vital design decisions for QRPS.

We now provide a general overview of QRPS.

6.2.1 GENERAL OVERVIEW OF QRPS

Power System Distribution Company Regulators, have utilized reward penalty methods for a long time to address traditional performance areas, for example, reliability, energy efficiency, interruption duration, and safety. Lately, these methods have be given greater consideration because of regulatory concerns over flexibility and the power distribution company's capacity to respond to technological change[78]. Many RPS models previously proposed, were surveyed in Chapter 2. However, most of the existing RPS mechanisms cannot simultaneously address the following issues:

The proposed QRPS scheme addresses all these issues.

- By using limited variables, we can calculate reward/penalty.
- Ensuringa reasonable magnitude for reward /penalty
- Consideringthe uncertainty concerning the best performance, based on the reliability level and the performance inconsistency factor ,that are outside of the regulator's control.
- As compared to the linear algorithm, described in the previous chapter, this quadratic algorithm is more favourable to power distribution companies.

The main objective of this research is to:

1. Introduce a set of well-defined goals for the QRPS scheme
2. Present two novel quadratic reward penalty schemes, which provide an efficient way for improving the quality of performance based on reliability, for Power Distribution Companies.
3. Demonstrate a quadratic RPS scheme, without any dead band and capping to maximum rewards and maximum penalties.
4. Demonstrate a quadratic RPS scheme, with a dead band to control the normal fluctuations in performance and with a capping of maximum rewards and maximum penalties.
5. Provide a comparative study of the strengths and limitations, of both the proposed approach with other existing approaches, proposed in the literature.

6.2.2 REQUIREMENTS

To address the issues of reward penalty schemes, the followingprerequisites are set down for the proposed QRPS algorithm. These requirements are as follows:

1. Define a specific performance parameter that measures reliability
2. Set a realistic target, that should be able to support and monitor the company's performance behavior.
3. The Reward-Penalty formula, which defines the shape and slope of the curve, should be simple to understand and administer and as well as consistent with the desired outcome.

4. The algorithm should be able to control the typical performance fluctuations because of the external elements, which cannot be managed by the power distribution company regulator.
5. The algorithm should ensure a reasonable value for reward/penalty, that is the magnitude of the reward/penalty scale should remain within reasonable bounds.
6. Presentation of financial rewards/penalties- should be administratively simple.
7. Should consider a little incentive near the central target.

6.2.3 DESIGN RATIONALE

To fulfill the requirements laid out in 6.2.2, the hypothetical foundation for QRPS is proposed and addresses all of the prerequisites by settling the design decisions. The design decisions proposed in this framework are as follows:

1. To assess the Power Distribution Company's performance, to indicate the extent to which the service is reliable and to measure how fast interruptionsare resolved quickly. The parameter performance of the reliability index plays a central role in enabling regulators. In the proposed approach, the metric, System Average Interruption Duration Index (SAIDI)[79], is used for measuring this performance reliability. It shows the sustained interruptions, experienced by customers. The data required for calculating this metric includes the average number of customers and the number of sustained interruptions[78].
2. The minimum standard (performance target) defined, should be made possible by a well-managed distribution company. In the event that the performance of the company is now acceptable, then the performance target could be fixed to keep up these performance levels, by defining the expected outcomes. On the off chance that they need to provide a higher performance levels, a sensible target can be set in light of the past recorded performance levels. In this proposed model, the minimum standard (performance target) level, is set, taking into account of the moving average of historical performance, which assists in measuring the company's behavior and performance. With high performance resulting in a reward and low performance leading to apenalty.
3. The Reward-Penalty formula, which portrays the shape and slope of the curves, decides how rapidly the curve achieves the maximum reward or penalty if the

performance goes off course from the performance target. Here we have introduced a quadratic reward penalty formula, simple and easy to understand and administer, that increase rewards and penalties in a quadratic fashion, as the performance fluctuates from the normal, on either side of the target. Without applying the dead band, due to the nature of the quadratic curve, it acts as a dead band structure, thus considering the uncertainties which are due to the external factors and provide alittle amount of reward or penalty, as compared to the linear curve, that provides a certain amount of reward or penalty, around the central target.

4. We have introduced a dead band called the neutral zone, around the target performance level, where the company does not get a reward or penalty. It represents vulnerability in regards to the ideal performance level and additionally considers certain performance variations, in light of elements outside of the distribution company's control. Thus, provides no reward or penalty within the dead band. As compared to the linear curve that gives certain rewards/penalties around the dead band, this curve provides only small amounts of rewards/penalties around the dead band.
5. We have introduced a capping (thresholding) on the maximum reward and penalties that allow companies to abstain from paying a critical penalty or getting a huge reward.
6. During the reward-penalty calculation process, it is valuable to display financial rewards or penalties in numerous units. Be that as it may, management of these reward/penalty calculations, are in the most part simplest when defined as dollars than as different units like pennies per share, basis points of return on equity(ROE), percent of base incomes, percent of aggregate income ,and so on. Consequently, here we have utilised dollars for showing financial rewards or penalties.
7. In the case of the linear reward/ penalty, due to the increasing slope, the reward/penalty near to the target (dead band) is significant. So we introduced the quadratic reward/penalty formula. Due to the decreasing slope of a quadratic curve, it results in a limitedincreasein reward/penalty when close to the target (dead band).

The above design decisions should be considered by any RPS scheme, when developing a new RPS algorithm. All these design decisions are incorporated in the QRPS approach, to improving the accuracy of the proposed scheme, which in turn significantly regulates and improves the performance-based reliability of power distribution companies. We now discuss the theoretical foundation for QRPS.

6.3 THEORETICAL FOUNDATION FOR QRPS

The theoretical foundation for QRPS ,is proposed in this section. The proposed scheme offers performance-based regulation, based on reliability. In contrast to the scheme proposed in [25], [24], [6], [80], [81], [11], which favors the power distribution company while implementing the reward-penalty scheme, our scheme is proposed after carefully analyzing the design decisions and is favorable to both the regulator and power distribution companies. A novel feature of our scheme is the use of the quadratic reward/penalty formula which varies in a quadratic fashion based on the behavior of the performance-based reliability.

Our QRPS scheme is comprises of two methods:

QRPS with no dead band and no reward/penalty capping (QRPS-NC)

QRPS with dead band and reward/penalty capping (QRPS-C)

In this section, we explain the two algorithms of QRPS.

6.3.1 ALGORITHM FOR QRPS NC

Firstly, we explain the algorithm to determine the parameters for QRPS-NC.

Input:

Multiyear historical SAIDI values (4 years)

Current actual SAIDI value

Output:

Reward or Penalties in Dollars

Step 1: Evaluate the reliability index, SAIDI

To calculate SAIDI, each interruption during the period is multiplied by the duration of the interruption to find the customer minutes of interruption. The customer minutes of all interruptions are then summed, to determine the total customer minutes. To find the SAIDI value, the customer minutes are divided by the total customers.

SAIDI=$\sum_{i=1}^{N}(ri \times Ni \div N)$ Equation 20

Where, ri is the duration of each interruption

Step 2: Establish Performance targets

In this step, the company's previous performance reliability index (SAIDI) is recorded over a set period (for example, the past five years) is used to set the target. This process presumes that the data has been collected in the past and is readily available and also that the historical performance was satisfactory.

Step 3: Designing the Quadratic RPS curve, without dead band and capping for each distribution company ,based on the SAIDI

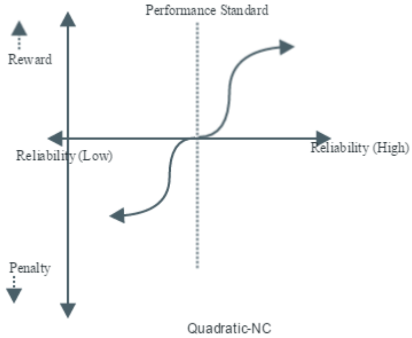

Figure 6.3-1 QRPS NC Structure

Step 4: Evaluate the rewards and penalties for each distribution company based on its reliability level. Equation 1 is the functional form of the curve in Fig.16.

$$Reward\ or\ Penalty = \begin{cases} \left(\frac{\text{Max.Reward}}{Target^2}\right) * (\text{Target} - \text{SAIDI})^2, & x < Target \\ 0, & x = Target \\ -\left(\frac{\text{Max.Penalty}}{Target^2}\right) * (\text{Target} - \text{SAIDI})^2, & x > Target \end{cases}$$ Equation 21

where x=Reliability Index SAIDI, *SD*=standard deviation of a set of 4 historical SAIDI values, *Reward or Penalty* is the reward/penalty payment of the distribution company for x. When x is smaller than the target, a reward payment is awarded to the distribution company. Similarly, when x is larger than the target, a penalty payment is charged to the distribution company. The reward payment increases as x decreases.

6.3.2 ALGORITHM FOR QRPS C

Secondly, we explain the algorithm of QRPS-C.

Input:

Historical (Multi-year) SAIDI values (e.g.: 4 years)

Current actual reliability index based on SAIDI value

Annual Revenue

Output:

Reward or Penalties in Dollars

Step 1: Assess the current year SAIDI, i.e., the company's actual performance score

Step 2: Establish Performance targets

In this step, the company's previous performance reliability index (SAIDI) calculated over a set period (for example, the past five years) is used to set the target. This process presumes that the data has been collected in the past and is readily available and also that the historical performance was satisfactory.

Step 3: Establish Dead Zone

Step 4: Establish Midpoint of Dead Zone(MDZ)

MDZ=Historical Average SAIDI Values for the past five years

Step 5: Establish Dead Zone width

Standard Deviation(SD) of the pastfive years SAIDI values

Step 6: Establish Reward Point (RP) and Penalty Point(PP)

RP=MDZ-SD/2

PP=MDZ+SD/2

Step 7: Establish Reward Cap point (RCP) and Penalty Cap point (PCP)

RCP=MDZ-SD

PCP=MDZ+SD

Step 8: Establish Max. Reward (Max. R) and Max. Penalty (Max. P)

Capping is introduced in the proposed scheme in a manner that the aggregate reward or penalty is based on reliability indices that would be lower than fivepercent of the yearly income of each distribution company. Here we consider that both the reward cap value and penalty cap value are the same. Consequently, it is defined as

*Max.reward=0.06*Rev*

*Max.Penalty=0.06*Rev*

where *REV* is the annual revenue of thedistribution company.

Step 9: Establish Reward Ramp (RR) and Penalty Ramp (PR)

RR=Max.Reward/ (RP-RCP)

PR=Max.Penalty/ (PCP-PP)

Step 10: Designing the Quadratic RPS curve with dead band and capping for each distribution company based on the SAIDI

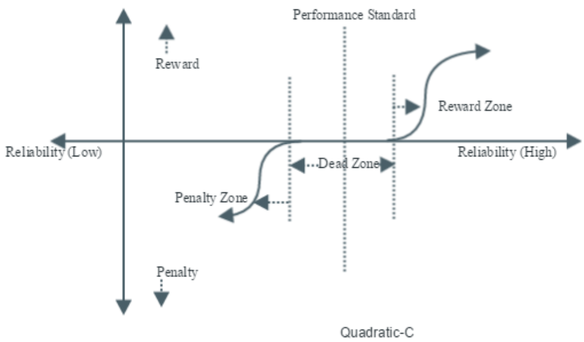

Figure 6.3-2 QRPS C Structure

Step 11: Evaluate rewards and penalties according to the performance based on reliability.

$$Reward/Penalty(x,Target) = \begin{cases} Max.Reward & x \leq RCP \\ \frac{Max.Reward}{MDZ^2}(x - Target)^2 & RCP < x < RP \\ 0 & RP \leq x \leq PP \\ \frac{Max.Penalty}{MDZ^2}(x - Target)^2 & PP < x < PCP \\ Max.Penalty & PCP \leq x \end{cases}$$

Equation 22

The RPS is explained using a flowchart for easier understanding. This is given in the next section.

6.3.3 FLOWCHART FOR QRPS

In this section, we explain the RPS process using a flowchart. The flowchart is shown in the below figures.

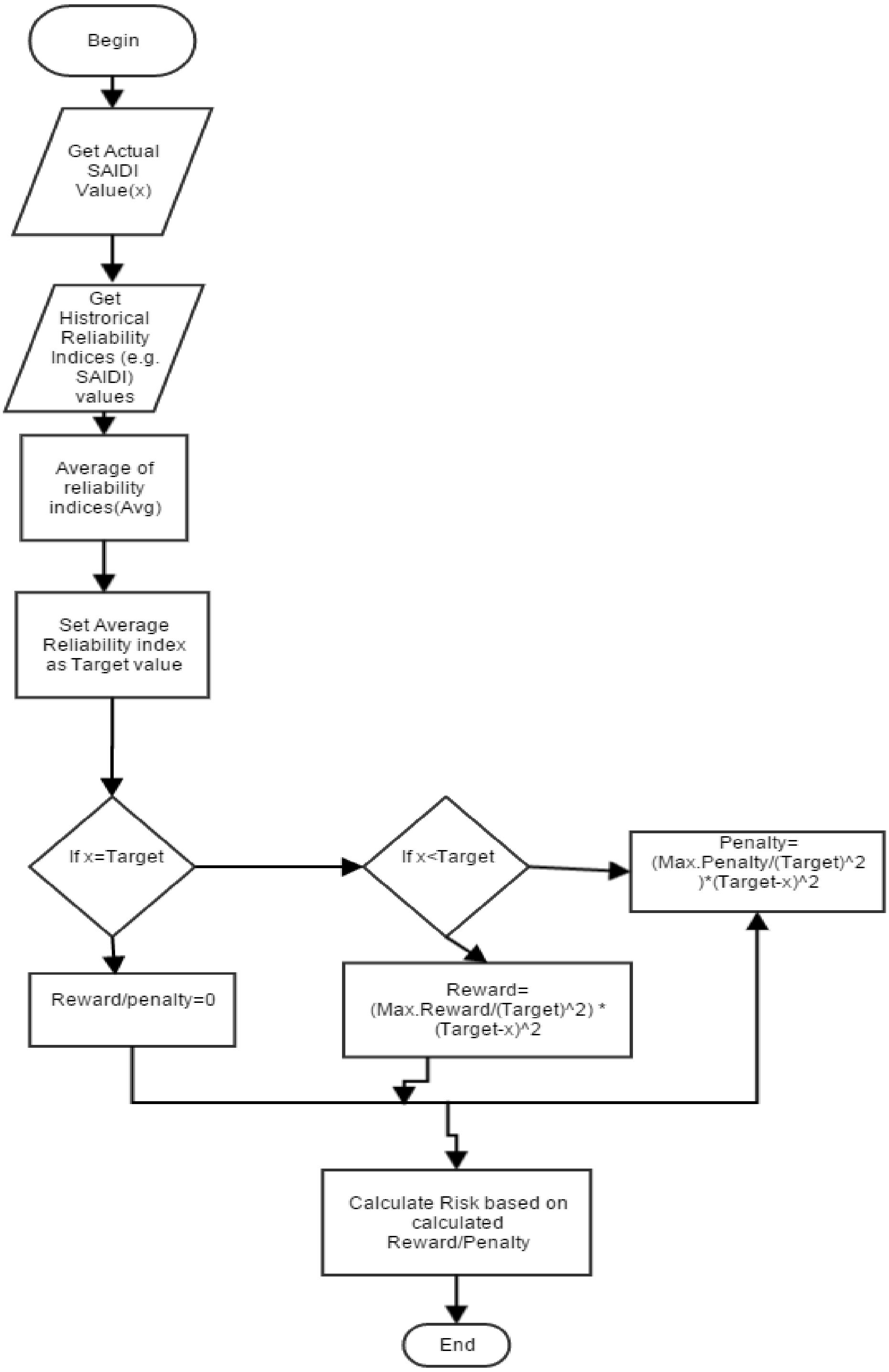

Figure 6.3-3 Flow Chart for QRPS NC

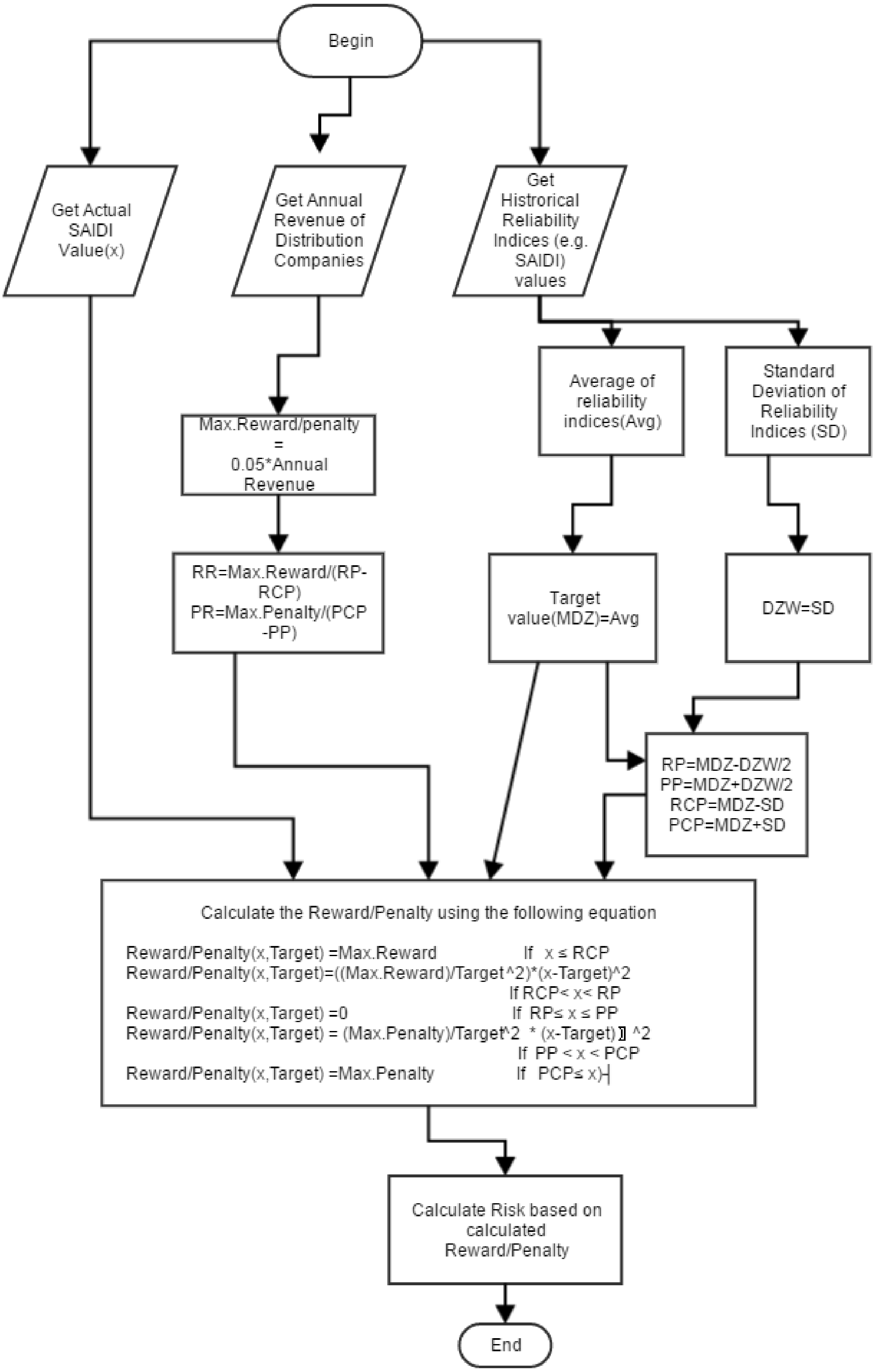

Figure 6.3-4 Flow Chart for QRPS C

6.4 PROTOTYPE IMPLEMENTATION

To test the feasibility of the proposed algorithm, we implemented the algorithm in section 6.3 using the given pseudo code in Appendix 1.

6.5 EXPERIMENTAL SETTINGS

In the experiments that we conducted, we used the following parameter specification. The description of all parameters with values and their results and observations are discussed in this sections.

6.5.1 PARAMETER SPECIFICATION

All the parameters and their associated values, used for gathering the results from the algorithm, are listed in Table 6.5-1.

Table 6.5-1 Parameter Specification

Parameter	Description
X	Actual SAIDI value
SD	Standard Deviation of a set of Historical (Past 6 years) Reliability Indices (SAIDI values)
Mean, A	Average of a set of Historical (Past 6 years) Reliability Indices (SAIDI values)
MDZ	Middle point of Dead Zone
DZW	Width of Dead Zone
PP	Penalty Point
RP	Reward Point
RCP	Reward Cap Point
PCP	Penalty Cap Point
RR	Reward Ramp
PR	Penalty Ramp
Max.R	Maximum Reward Cap
Max.P	Maximum Penalty Cap
Rev	Annual Revenue of Distribution Companies

6.6 RESULTS AND OBSERVATIONS

In this section, we examine the experiments that we carried out and the outcomes that we observed, in the wake of running our model. Perceptions are made by examining these outcomes which were accumulated from the model. Table 6.6-1 shows the the summary statistics of the 42 Iranian distribution companies' variables which is available at : www. tavanir.org. Applying these parameters to QRPS NC algorithm and QRPS C algorithm helps to identify the inefficient companies that need to improve their service reliability to maintain the target performance reliability level. It also contributes to estimate the corresponding reward or penalty payment based on their performance based reliability index.

For example, Consider the application of QRPS-NC model on a power distribution company D16 which has an average SAIDI of 712 min, which is fixed as the target performance reliability level. It can be seen from the table 6.6-2 that current reliability index for D16 using SAIDI is found as 820min, which is higher than the target performance reliability level, as this company is inefficient. Since there is no dead-zone or capping in QRPS NC, it can expect to receive a penalty payment of 0.02M$ from the regulator.

Table 6.6-3 Results of QRPS

Distribution Companies	MAX.Reward Cap M$	Reward Ramp Slope ab	RCP(a)	RP(b)	Width of Dead Zone	MDZ	Pp©	PCP(d)	Penalty Ramp Slope cd	MAX. Penalty Cap M$	SAIDI(RI)	QRPS-NC(M$)	QRPS-C (M$)
D1	1.37	0.02	208	287	158	366	445	524	0.02	-1.82	410	-0.03	0
D2	2.87	0.04	218	297	158	376	455	534	0.08	-5.93	376	0	0
D3	0.14	0	46	125	158	204	283	362	0.01	-0.85	224	-0.01	0
D4	1.5	0.02	414	493	158	572	651	730	0.02	-1.5	657	-0.03	-0.03
D5	2.27	0.03	2457	2536	158	2615	2694	2773	0.03	-2.28	3077	-0.07	-2.28
D6	1.97	0.02	470	549	158	628	707	786	0.05	-3.88	653	-0.01	0
D7	1.76	0.02	209	288	158	367	446	525	0.03	-2.75	392	-0.01	0
D8	0.27	0	285	364	158	443	522	601	0.04	-2.85	460	0	0
D9	3.88	0.05	1571	1650	158	1729	1808	1887	0.05	-3.88	1954	-0.07	-3.88
D10	2.79	0.04	307	386	158	465	544	623	0.04	-2.79	518	-0.04	0
D11	3.27	0.04	234	313	158	392	471	550	0.06	-4.54	426	-0.03	0
D12	5.35	0.07	697	776	158	855	934	1013	0.1	-7.77	889	-0.01	0
D13	2.61	0.03	960	1039	158	1118	1197	1276	0.03	-2.61	1267	-0.05	-0.05
D14	2.35	0.04	743	797	108	851	905	959	0.04	-2.35	986	-0.06	-2.35
D15	0.97	0.02	399	453	108	507	561	615	0.02	-0.97	551	-0.01	0

D16	1.02	0.02	606	659	106	712	765	818	0.02	-1.02	820	-0.02	-1.02
D17	2.85	0.05	589	643	108	697	751	805	0.06	-2.97	735	-0.01	0
D18	1.02	0.02	409	462	106	515	568	621	0.04	-2.31	527	0	0
D19	1.49	0.03	685	738	106	791	844	897	0.03	-1.49	886	-0.02	-0.02
D20	0.17	0	135	188	106	241	294	347	0.02	-0.91	243	0	0
D21	0.72	0.01	587	641	108	695	749	803	0.01	-0.72	812	-0.02	-0.72
D22	0.94	0.02	216	270	108	324	378	432	0.03	-1.42	324	0	0
D23	1.38	0.03	441	495	108	549	603	657	0.05	-2.52	575	-0.01	0
D24	1.95	0.04	663	716	106	769	822	875	0.04	-1.95	846	-0.02	-0.02
D25	0.86	0.02	464	517	106	570	623	676	0.02	-1.32	618	-0.01	0
D26	0.68	0.01	527	581	108	635	689	743	0.01	-0.68	742	-0.02	-0.02
D27	2.93	0.05	896	950	108	1004	1058	1112	0.05	-2.93	1078	-0.02	-0.02
D28	1.68	0.03	451	504	106	557	610	663	0.06	-3.14	557	0	0
D29	1.08	0.02	959	1012	106	1065	1118	1171	0.02	-1.08	1253	-0.03	-1.08
D30	1.73	0.03	473	527	108	581	635	689	0.03	-1.73	639	-0.02	-0.02
D31	1.68	0.05	414	446	64	478	510	542	0.08	-2.68	507	-0.01	0
D32	0.72	0.02	349	381	64	413	445	477	0.05	-1.71	438	-0.01	0
D33	0.8	0.02	309	341	64	373	405	437	0.16	-5.17	384	0	0
D34	1.09	0.03	90	122	64	154	186	218	0.11	-3.55	156	0	0
D35	1.72	0.05	101	133	64	165	197	229	0.16	-4.98	165	0	0
D36	0.91	0.03	142	174	64	206	238	270	0.11	-3.36	207	0	0
D37	1.38	0.04	95	127	64	159	191	223	0.13	-4.19	159	0	0
D38	1.66	0.05	161	193	64	225	257	289	0.14	-4.38	225	0	0
D39	3.78	0.12	428	460	64	492	524	556	0.13	-4.28	579	-0.13	-4.28
D40	0.87	0.03	127	159	64	191	223	255	0.11	-3.53	192	0	0
D41	0.83	0.03	443	475	64	507	539	571	0.17	-5.51	507	0	0
D42	1.04	0.03	314	346	64	378	410	442	0.1	-3.29	378	0	0

Consider the case QRPS-C application on the same inefficient power distribution company D16 which has an average SAIDI of 712 min. This value (712 min) is defined as the target performance reliability level and sets as MDZ in QRPS C structure. The average SD of historical reliability index for D16 are 106 min, and the width of the dead zone is equal to this value. The penalty and reward points for D16 are 765 and 606 respectively which are defined by 'mean - SD/2' and 'mean + SD/2', respectively. It can
be seen from Table 3 that current reliability index using SAIDI is found as 820min which is higher than the target performance reliability level, as this company is inefficient. Since it is greater than the penalty cap point, it can expect to receive a penalty payment of 1.02M$, which is set as the maximum penalty cap for D16, from the regulator.

The simulation results of the QRPS-NC in Table 3 shows that 35.7% of 42 power distribution companies has no penalty, 64.3% has a penalty, the maximum penalty was 0.13 million dollars, and the minimum penalty was 0.01 million dollars. The simulation of the

QRPS-C in Table 3 shows that 66.7% of 42 power distribution companies has no penalty, 33.3% has a penalty, the maximum penalty was 4.28 million dollars, and the minimum penalty was 0.02 million dollars. Generally, when observed, we found that those companies with very low reliability received the maximum penalty.

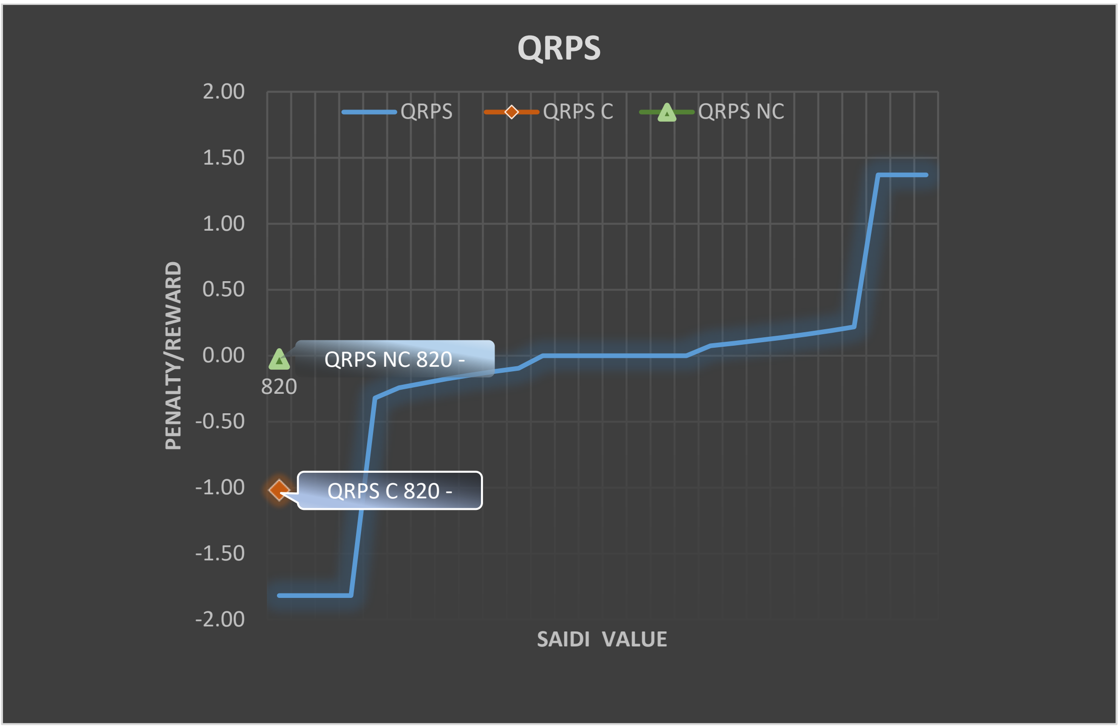

Figure 6.6-1 QRPS Structure

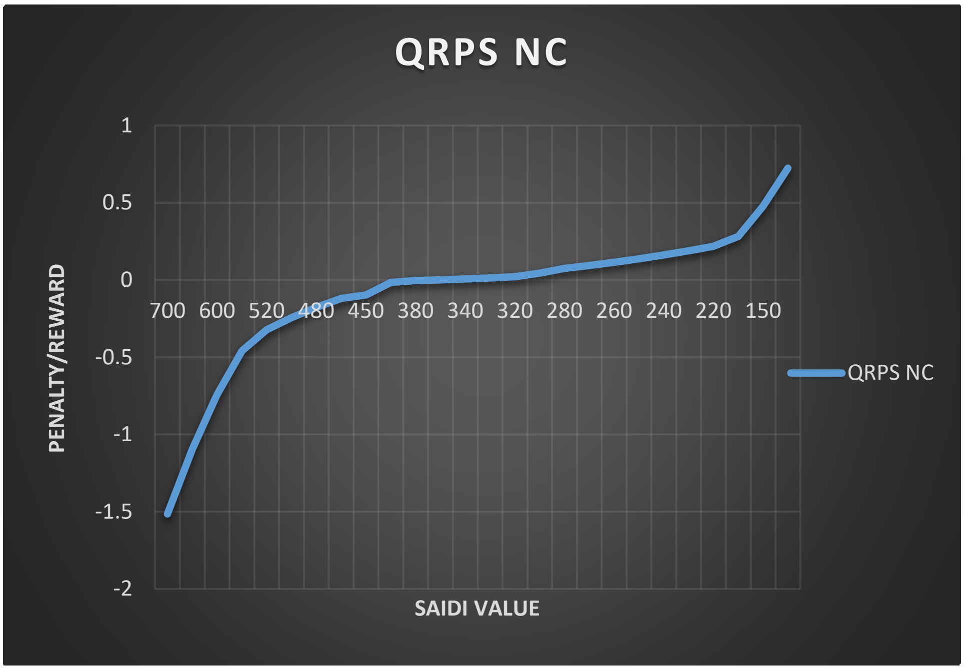

Figure 6.6-2 QRPS-NC Structure

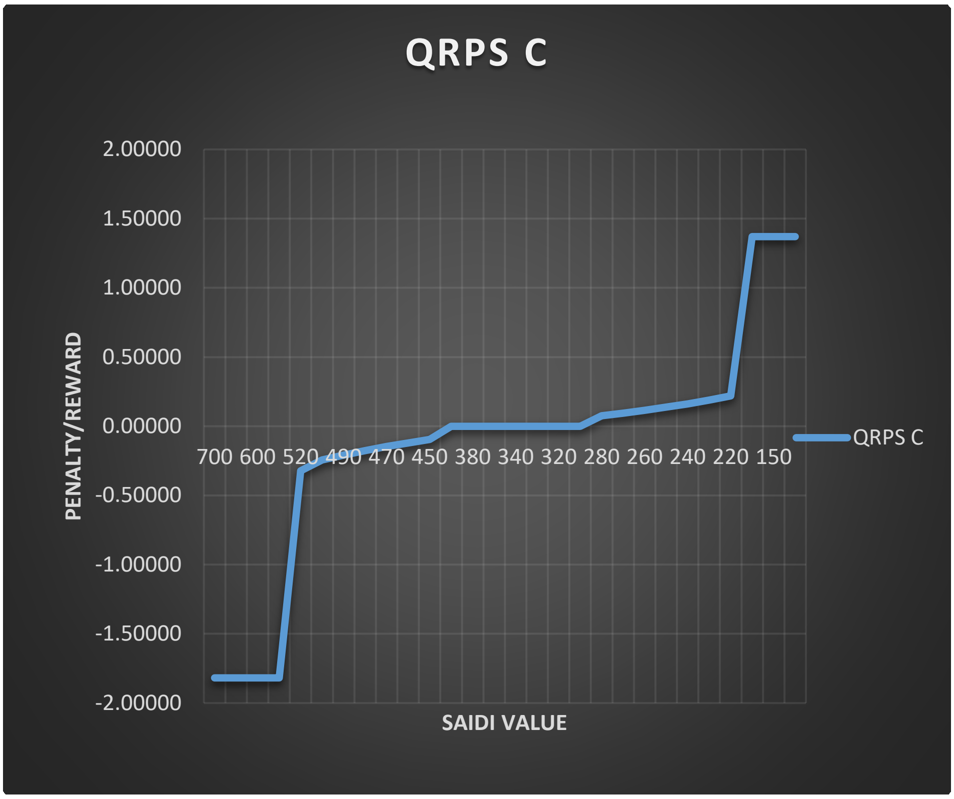

Figure 6.6-3 QRPS-C Structure

6.7 VALIDATION

In this Chapter, we proposed a Quadratic Reward-Penalty Scheme (termed QRPS) in two different ways- without a dead band and cappingand with the dead band and capping.

From the experiments that we conducted, we made the following observations

- By Using limited variables, we can calculate reward/penalty.
- Without setting the dead band, the quadratic curve acts similalyr to a dead band by providing little incentive near the central target (QRPS-NC)
- Ensured a reasonable value for reward /penalty by setting the capping(QRPS-C)
- By setting the dead band, the proposed scheme considered vulnerability in regards to the ideal performance level, and additionally tookinto account certain performance variations in light of elements outside of the distribution company's control (QRPS-C)
- When compared to the existing algorithms, this quadratic algorithm is more favourable to power distribution companies.

6.8 COMPARATIVE ANALYSIS AND DISCUSSION

In this section, the proposed solution is compared with the existing schemes by implementing the same dataset. A comparative study is depicted in the table 6.8-1, which shows our algorithm (QRPS) and its comparison with the existing schemes in [25], [24], [4], [80], [81], [11]. The parameters for QRPS design implementation largely affect the financial risk of electric distribution companies and in this way setting these parameters is a basic issue in the reward and penalty payment. It is very reliant on the goal of the regulator. There are various elements that ought to be considered which influence the reliability and the behavior of individual companies when setting the parameters of QRPS. The nature and assortment of customer effects, coming about because of duration and recurrence of interruptions, ought to be considered while selecting the distinctive parameters for QRPS outline.

The reward–penalty schemes do not have a steady structure in all conditions and change as per necessities. Structures of these models rely on upon scope of data, kind of reliability index, the objective of system regulators, RPS execution time and so forth. If RPS is mainly designed using performance-based reliability, then the type of reliability index used in designing RPS has a significant impact on the reward and penalty payment. There are distinctive structures of RPS, be that as it may, Dead-Band RPS for reliability is the most proficient one since it incorporates the uncertainty about the optimal performance level and the performance related components that are outside of the distribution company's control. We implemented two approaches mainly intended for those regulators who concern more to customers that are affected by outage duration factor, the first approach is for those regulators who want to apply RPS for the first time, and they can apply RPS for money making. In the second method, we designed a dead-band RPS, which achieve an effective RPS for enhancing service reliability. The performance of the proposed approaches is illustrated by reliability data of various electric distribution companies. A comparison between existing algorithms is provided in Table 4.

Mid-Point of Dead-Zone is the point where we set the performance target on an RPS curve which determines whether a company gets reward or penalty, so it has a vital importance in designing RPS curve. Billinton and Pan[24], [25] utilized both reliability indices SAIDI and SAIFI, with every index is weighted in light of the customer's concern, for determining this point. In [4], they utilized an Equivalent Probability Distribution of reliability indices for designing the RPS. A mix of cluster analysis and DEA is utilized by [80] for ascertaining MDZ while [81] utilized a mix of Historical normal Reliability Index, density area, and improvement target. In [11], MDZ is computed in light of the estimations of Historical Average Reliability Index, DEA efficiency score and the maximum reliability improvement. Even though the results have shown to be better, [4], [11], [24], [25], [80], [81] have used too many parameters and takes longer computation time.

In the proposed QRPS approach, we set MDZ as the average of the last five years' reliability indices. Since the characteristic of the customers who are more concern towards the outage duration is taken into account in the QRPS design, so we applied SAIDI as the reliability index for determining the performance target(MDZ). In our design, only one parameter, SAIDI, is used, the results have proven to be fairly robust and take lesser computation time.

The parameter width of the dead zone(DZW) is highly subject to parameters of probability distribution measures, for example, mode, mean, range, variance, standard deviation, and skewness. Picking a bigger dead zone size estimate makes the QRPS design inadequate as many data might be situated in this fair-minded zone. Then again, a smaller dead zone size estimate brings about a high hazard for a distribution company as little change in the reliability index may shift the incentive payment from the reward zone to the penalty one or the other way around. Applying a dead zone with the mean of the historical reliability data as the center of the zone was recommended in [24], [25]. In view of this strategy, the dead zone size is two times the standard division with the end goal that the 'mean + SD' is the reward point and the 'mean - S.D.' is the penalty point. Applying this strategy may locate many data in the dead zone. A wide dead zone may lose the primary idea behind the RPS execution with the end goal that a large number of the information is situated in this zone and there is no any inspiration for distribution company to enhance the reliability.

This paper considers the midpoint of the dead zone(MDZ) as the mean of historical data. The penalty and reward points are defined by 'mean - SD/2' and 'mean + SD/2', respectively. This model prompts to a narrower dead zone than the one proposed in [24], [25] and normally reduced data are situated in this zone. A regulator can utilize this model when the performance-based reliability index is near the average of historical reliability data. Additionally, we proposed one standard deviation as DZW when contrasted with Billinton and Pan [24], [25], who proposed two standard deviations. This delineates that the regulator needs distribution companies to keep up their future performance reliability in view of the average values. This procedure presumes that the information has been gathered in the past and is promptly accessible furthermore that the historical performance was satisfactory. Utilizing these methodologies, the regulator can ensure that service reliability has not been weakened after privatization.

The regulator does not always have impeccable and correct data about customer interruption costs. Thus, a cap value as a rate of the company’s yearly income ought to be considered by the regulator to legitimize the risk of giving high rewards or penalties for improperly high-quality or low-quality reliability levels [62]. In UK and Ireland, maximum reward and maximum penalty are capped and are set at 3 and 4% of price control incomes [62]. In Netherlands, the adjustment in revenues is capped at 5% [62]. The reward and penalty payments are also related to interruption cost. In [5], the maximum cap values are set in light of rate of average yearly earnings by each distribution companies. In [11], CCDF and cap value are utilized to decide the maximum reward. In Norway and Italy[62], the consequences of customer interruption cost surveys are utilized as a part of setting the capping limits. In this paper, a few rates of aggregate revenue of a distribution company is fixed as the maximum reward and maximum penalty caps. The maximum reward cap is same as maximum penalty cap, and it depends on the regulatory goal. Maximum reward and maximum penalty are set as a rate of yearly revenue and is controlled by the regulator. In our method for RPS design, we set the maximum reward and maximum penalty caps for each company as five percentage of their yearly revenue.

We conducted lots of experiments for comparing the proposed ranking outcomes with the existing outcomes. From the results, we made the following observations which shows our proposed scheme does outperforms than others. The inclusion of deadband and capping in our RPS design shows that our ranking results are more reasonable.

- Using limited variables, we can calculate reward/penalty efficiently with less computation time than the existing schemes.
- Without setting the dead band, the quadratic curve acts similarly to a dead band by providing little incentive near the central target (QRPS-NC), thus lessen the complexity happened in existing schemes in designing deadband.
- Ensured a reasonable value for reward-penalty by setting the capping(QRPS-C) than other RPS's.
- By setting the dead band, the proposed scheme considered vulnerability in regards to the ideal performance level, and additionally took into account certain performance variations in light of elements outside of the distribution company's control (QRPS-C)
- The simulation results of QRPS model show that those companies with very low reliability received the maximum penalty.

- When compared to the existing algorithms, this quadratic algorithm is more favorable to power distribution companies.

Table 6.8-2 Comparative study

Properties	[25]	[24]	[4]	[80]	[81]	[11]	QRPS Algorithm
MDZ	Historical average Reliability Index	Historical average Reliability Index	Equivalent Probability Distribution	DEA efficiency scores after a clustering process	Historical average Reliability Index, density area, and improvement target	Historical average Reliability Index, DEA efficiency score, and the maximum reliability improvement	Historical Average Reliability Index (SAIDI)
DZW	Standard Deviation	Standard Deviation	Standard Deviation	-	5% of MDZ	Average standard deviation for each cluster	Standard Deviation of the Historical Reliability index(SAIDI)
PP	MDZ-Half of Standard Deviation	MDZ-Half of Standard Deviation	MDZ-Half of Standard Deviation	-	-	MDZ+Half of Standard Deviation	MDZ+Half of Standard Deviation of the Historical Reliability index(SAIDI)
RP	MDZ+Half of Standard Deviation	MDZ+Half of Standard Deviation	MDZ+Half of Standard Deviation	-	-	MDZ-Half of Standard Deviation	MDZ-Half of Standard Deviation of the Historical Reliability index(SAIDI)
RCP	MDZ+Standard Deviation	MDZ+Standard Deviation	MDZ+Standard Deviation	-	-	MDZ-Standard Deviation and Slack Analysis	MDZ-Standard Deviation of the Historical Reliability index(SAIDI)
PCP	MDZ-Standard Deviation	MDZ-Standard Deviation	MDZ-Standard Deviation	-	-	PP+Max.Penalty/Penalty Ramp	MDZ+Standard Deviation of the Historical Reliability index(SAIDI)
RR	-	Max.Reward/Sloping area width	Max.Reward/Sloping area width	-	Varies according to the density and reliability level score	Max.Reward/Sloping area width	Maximum Reward/(Reward Point-Reward Cap Point)
PR	-	Max.Penalty/Sloping area width	Max.Penalty/Sloping area width	-	Varies according to the density and reliability level score	Depends on DEA Score	Maximum Penalty/(Penalty Cap Point-penalty Point)

Max.Rew	-	1M$	% of average income of utilities in each cluster	-	-	CCDF and Cap value	5% of average income of distribution companies
Max.Pen	-	1M$	% of average income of utilities in each cluster	-	-	% of average income of utilities	5% of average income of distribution companies

In the first scenario (QRPS-NC) presented from the experiments conducted, we created the following advantages and disadvantages:

Advantages:

- The quadratic function is designed to provide increasing rewards or penalties as performance-based reliability deviates from the target, but the rewards or penalties increase more slowly.
- While the linear formula has the advantage of simplicity, this non-linear formula(Quadratic formula), provides a strong link between performance and reliability.
- Without providing the dead band, the quadratic curve acts similarly to a dead band by providing a littleincentive near the central target.
- Limited parameters for finding reward/penalty
- It is more favourable to distribution companies.

Disadvantages:

- Does not ensure a reasonable value for reward/penalty
- Does not take into accountthe uncertainty about the optimal performance level and those performance related components that are outside of the distribution company's control.

In the second case (QRPS-C), from the experiments that we conducted, we observed the following advantages and disadvantages:

Advantages:

- The quadratic function also designed to provide increasing rewards or penalties, as performance-based reliability deviates from the target, but the rewards or penalties increase more slowly.

- While linear formula has the advantage of simplicity, this non-linear formula(Quadratic Formula), provides a strong link between performance and reliability.
- In addition to the dead band provided, the quadratic curve acts similarly to a dead band by providing no incentive ,near the central target.
- Limited parameters for finding reward/penalty.
- Ensures a reasonable magnitude for reward/penalty, by applying maximum reward/penalty capping.
- By providing dead band, it considered the uncertainty related to those performance related component,s that are outside of the distribution company's control and the optimal performance level. When compared to the existing algorithms, it is more favourable to distribution companies.
- Curve reaches maximum reward/ penalty slowly. I.e., increasing slope demonstrates that this algorithm provides little reward or penalty around the dead band.

Disadvantages:

- It is not favorable to regulatory authorities.

6.9 CONCLUSION

In this chapter, we introduced and formulated the problem of QRPS. We proposed a novel QRPS scheme for power distribution companies. The fundamental advantage of our approach, is that it provides little reward or penalty around the dead band, thus ensures a reasonable value for reward/penalty and has also removed the vulnerability ofthe variations from optimal performance level, caused by those performance related factors that are outside of the distribution company's control. A comparative study of our technique, with previously proposed techniques, demonstrates that our technique is superior and can work in the best interests of the copyright holder.

CHAPTER 7

CUBIC REWARD PENALTY STRUCTURE

This chapter provides:

- Requirements and the design rationale of the proposed cubic reward penalty structure,
- The theoretical foundation and the prototype implementation
- Experimental settings
- Results and observations
- Validation
- Comparative analysis and discussion for cubic reward penalty structure

7.1 INTRODUCTION

In this chapter, we describe how regulators can guide the Power Distribution Company's performance through the use of performance reward penalty mechanisms using the cubic function by considering the disadvantages that have been mentioned in the previous chapter. We specifically consider the effect of quality regulation on continuity of supply (reliability). We present a novel cubic model that is based on a cost of service remuneration[11] towards creating an economical way of regulating quality [10]that is based on rewards and penalties. It encourages Power Distribution Companies to maintain the appropriate reliability levels. The novelty of this reward penalty scheme, lies in the use of cubic reward penalty formula where rewards and penalties increase in a cubic fashion,that defines by what means the curve reaches the maximum reward or penalty as quickly as the performance-based reliability moves away from the benchmark(or the ends of the dead band, in the case of the cubic dead band structure); hence this scheme is termed the Cubic Reward-Penalty Scheme (CRPS). The proposed CRPS implements rewards and penalties for exceeding or failing to achieve the targeted performance levels, respectively. The chapter provides a detailed theoretical foundation for the CRPS. By considering all of the requirements laid out in this section, it also clarifies the algorithm design. A flowchart is given to bolster the clarification. It clarifies how the algorithm is applied for completing the various analyses. It also tests to validate the performance-based reliability and contrast the proposal and existing Reward-Penalty Schemes [4], [5], [10], [11], [28], [66], [76], [77].We also compare the proposed scheme with the other two Reward-Penalty Schemes that have been described in the last two chapters ,in order to demonstrate the power of CRPS, for practical incentive calculations. This chapter formerly concludes with a validation of results. Now we sketch the fundamental prerequisites and the design rationale for CRPS.

7.2 PROPOSED CUBIC REWARD PENALTY STRUCTURE (CRPS)

This section gives an overall outline of CRPS and then explains the requirements to address the issue of cubic reward penalty structure. It is then followed by the design rationale, where we examine the vital design decisions for CRPS.

We now provide a general overview of CRPS.

7.2.1 GENERAL OVERVIEW OF CRPS

Power System Distribution Company Regulators, have utilized reward penalty methods for a long time to address traditional performance areas, for example, reliability, energy efficiency, interruption duration, and safety. Lately, these methods have gotten greater consideration because of regulatory concerns over flexibility and the power distribution company's capability to respond to technological change[78]. Many RPS models previously proposed, were surveyed in Chapter 2. However, most of the existing RPS mechanisms, cannot simultaneously address the following issues:

The proposed CRPS scheme addresses all of these issues

- By using limited variables, we can calculate reward/penalty.
- Ensured a reasonable value for reward /penalty
- Considered the uncertainty concerning the best performance based reliability level and the performance inconsistency factors, that are out of the regulator's control.
- As compared to the linear and quadratic algorithm, described in the previous chapters, this cubic algorithm is more favourable to the power distribution companies.

The main objective of this proposed scheme is to:

1. Introduce a set of well-defined goals for the CRPS scheme
2. Present two novel cubic reward penalty schemes which provide an efficient way for improving the performance, based on reliability for Power Distribution Companies.
3. Demonstrate a cubic RPS scheme, without applying any dead band and without capping the maximum reward and the maximum penalty. Demonstrate a cubic RPS scheme, with a dead band, to control the normal fluctuations in performance and with a capping of maximum reward and maximum penalty.
4. Provide a comparative study of the strengths and limitations of both the proposed approach, with other existing approaches proposed in the literature.

7.2.2 REQUIREMENTS

In order to address the issues of reward penalty schemes, the following prerequisites are set down for the proposed CRPS algorithm. These requirements are follows:

1. Define a specific performance metric that measures reliability
2. Set a realistic target that should be able to support and monitor company's performance behavior.
3. The Reward-Penalty formula, which defines the shape and slope of the curve, should be simple to understand and administer and as well as consistent with the desired outcome.

4. The algorithm should be able to control typical performance fluctuations because of the external elements which cannot be managed by the power distribution company regulator.
5. The algorithm should ensure a reasonable magnitude for reward/penalty that is the magnitude of the reward/penalty should remain in the reasonable bound.
6. Presentation of financial rewards/penalties- should be administratively simple

7.2.3 DESIGN RATIONALE

To fulfill the requirements laid out in 7.2.2, the hypothetical foundation for CRPS is proposed and has addressed all of the prerequisites by settling the design decisions. The design decisions proposed in this framework, are as follows:

1. To assess the Power Distribution Company's performance, to indicate the extent to which the service is reliable and to measure how fast interruptionsare resolved quickly. The parameter performance reliability index, plays a central role in enabling regulators. In the proposed approach, the calculated, System Average Interruption Duration Index (SAIDI)[79], is used for measuring this performance reliability. It indicates the sustained interruptions, experienced by customers. The data required for calculating this sum includes the average number of customers and the number of sustained interruptions[78].
2. The minimum standard (performance target), defined should be made possible by a well-managed distribution company. If the performance of the company is now acceptable, then the performance target could be fixed to maintain with the best performance in the future. On the off chance that they need a higher standard of performance, a sensible target can be set, in consideration of past recorded performance levels. In this proposed model, the minimum standard (performance target) , is fixed, taking into account the shifting average of historical performance. Doing so assists in the measurement of the company's' performance and decides whether the company will be potentially rewarded or receive a penalty.
3. The Reward-Penalty formula which portrays the shape and slope of the curves, decides how rapidly the curve achieves the maximum reward or penalty as performance goes off course from the performance target. Here we have introduced

a cubic reward penalty formula, that increases rewards and penalties, in a cubic fashion as the performance moves away from the normal, on either side of the target. Without applying the dead band, due to the nature of the cubic curve, it acts as a dead band structure, thus considering the uncertainties that are due to external factors and provide very limited amounts of rewards or penalties as compared to the quadratic curve, around the central target.

4. We have introduced a dead band called the neutral zone around the target performance level, where the company does not get a reward or penalty. It presents a vulnerability in regards to the ideal performance level and additionally considers certain performance variations, in light of elements outside of the distribution company's control. Thus, ensures no reward or penalty within the dead band. Also, due to nature of cubic curve, it ensures a little gap around the dead band.
5. We have introduced a capping (thresholding) on the maximum reward and penalties, that allow companies to abstain from paying a critical penalty or getting a huge reward.
6. During the reward-penalty calculation process, it is valuable to display financial rewards or penalties in numerous units. Be that as it may, management of these rewards/penalties calculations, are in the most part simplest when done as dollars than as different units like pennies per share, basis points of return on equity(ROE), percent of base incomes, percent of aggregate income, and so on. Consequently, here we utilized dollars for demonstrating financial rewards or penalties.

The above design decisions should be considered by any RPS scheme, when developing a new RPS algorithm. All these design decisions are incorporated in the CRPS approach, to improvethe accuracy of the proposed scheme, which in turn significantly regulates and improves the performance-based reliability, of power distribution companies. We now discuss the theoretical foundation for CRPS.

7.3 THEORETICAL FOUNDATION FOR CRPS

The theoretical foundation for CRPS is proposed in this section. The proposed scheme offers performance-based regulation based on reliability. In contrast to the scheme proposed in [25], [24], [4], [80], [81], [11]., which favors the power distribution company whilst implementing the reward-penalty scheme, our proposed scheme is described after carefully analyzing the design decisions and is most favorable to power distribution companies. A novel feature of our scheme, is the use of the cubic reward/penalty formula, which varies in a cubic fashion based on the behavior of the performance-based reliability.

Our CRPS scheme comprises two methods:

- CRPS with no dead band and no reward/penalty capping(CRPS-NC)
- CRPS with dead band and reward/penalty capping(CRPS-C)

In this section, we explain the two algorithms of CRPS.

7.3.1 ALGORITHM FOR CRPS NC

Firstly, we explain the algorithm to determine the parameters for CRPS-NC.

Input:

Multiyear historical SAIDI values (4 years)

Current actual SAIDI value

Output:

Reward or Penalties in Dollars

Step 5: Evaluate the reliability index, SAIDI

To calculate SAIDI, each interruption during the period is multiplied by the duration of the interruption, to find the customer minutes of interruption. The customer minutes of all interruptions are calculated to determine the total customer minutes. To find the SAIDI value, the customer minutes are divided by the total customers.

SAIDI=$\sum_{i=1}^{N}(ri \times Ni \div N)$

Where, ri is the duration of each interruption

Step 6: Establish Performance targets

In this step, the company's previous performance reliability index (SAIDI) over a set period of time (for example, the past five years) is used to set the target. This process presumes that the data has been collected in the past and is readily available and that the historical performance was satisfactory.

Step 7: Designing the Cubic RPS curve, without dead band and capping for each distribution companies is based on the SAIDI value

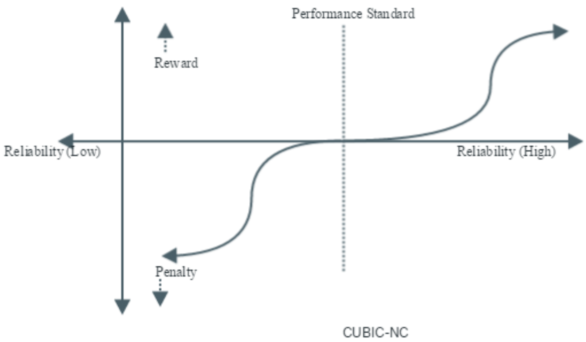

Figure 7.3-1 CRPS C Structure

Step 4: Evaluate the rewards and penalties for each distribution company based on its reliability level as needed. Equation 1 is the functional form of the curve in Fig.23.

$$Reward\ or\ Penalty = \begin{cases} \left(\frac{\text{Max.Reward}}{Target^3}\right) * (\text{Target } - \text{SAIDI})^3\,, & x < Target \\ 0, & x = Target \\ -\left(\frac{\text{Max.Penalty}}{Target^3}\right) * (\text{Target } - \text{SAIDI})^3, & x > Target \end{cases}$$ Equation

23

Where x=Reliability Index SAIDI, *SD*=standard deviation of a set of 4 historical SAIDI values, $Reward/Penalty(x, Target)$ is the reward/penalty payment of the distribution company for x.

When x is smaller than the target, a reward payment is awarded to the distribution company. Similarly, when x is larger than the target, a penalty payment is charged to the distribution company. The reward payment increases as x decreases.

7.3.2 ALGORITHM FOR CRPS C

Secondly, we explain the algorithm of CRPS-C.

Input:

- Historical (Multi-year) SAIDI values (eg: 4 years)
- Current actual reliability index based on SAIDI value
- Annual Revenue

Output:

- Reward or Penalties in Dollars

Step 11: Assess the current year SAIDI, i.e., the company's actual performance score

Step 12: Establish Performance targets

In this step, the company's previous performance reliability index (SAIDI), over a set period (for example, the past five years) is used to set the target. This process presumes that the data has been collected in the past and is readily available and that the historical performance was satisfactory.

Step 13: Establish the Dead Zone

Step 14: Establish Midpoint of the Dead Zone(MDZ)

MDZ=Historical Average SAIDI Values for the past seven years

Step 15: Establish the Dead Zone width

Standard Deviation(SD) of the past seven years SAIDI values

Step 16: Establish the Reward Point (RP) and Penalty Point(PP)

RP=MDZ-SD/2

PP=MDZ+SD/2

Step 17: Establish the Reward Cap point (RCP) and the Penalty Cap point (PCP)

RCP=MDZ-SD

PCP=MDZ+SD

Step 18: Establish the Max. Reward (Max. R) cap and the Max. Penalty (Max. P) cap

Capping is introduced in the proposed scheme, in a manner that the aggregate reward or penalty, based on reliability indices, would be lower than fivepercent of the yearly income of each distribution company. Here we consider that both the reward cap value and penalty cap value are the same. Consequently, it is defined as

*Max.reward=0.05*Rev*

*Max.Penalty=0.05*Rev*

where *Rev*is the annual revenue of thedistribution company.

Step 19: Establish Reward Ramp (RR) and Penalty Ramp (PR)

RR=Max.Reward/ (RP-RCP)

PR=Max.Penalty/ (PCP-PP)

Step 10: Designing the Cubic RPS curve with dead band and capping for each distribution companies based on the SAIDI

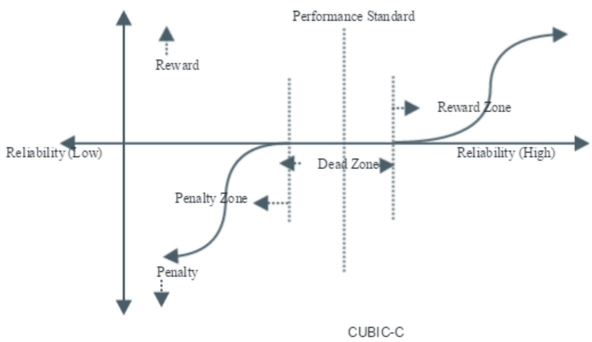

Figure 7.3-2 C RPS C Structure

Step 20: Evaluate rewards and penalties based on the current performance score

$$\textit{Reward/Penalty(x,Target)} = \begin{cases} Max.Reward & x \leq RCP \\ \frac{Max.Reward}{MDZ^3}(x - Target)^3 & RCP < x < RP \\ 0 & RP \leq x \leq PP \\ \frac{Max.Penalty}{MDZ^3}(x - Target)^3 & PP < x < PCP \\ Max.Penalty & PCP \leq x \end{cases} \quad \text{Equation 24}$$

The RPS is explained using a flowchart for easier understanding. This is given in the next section.

7.3.3 FLOWCHART FOR CRPS

In this section, we explain the RPS process using a flowchart. The flowchart is shown in the figures below.

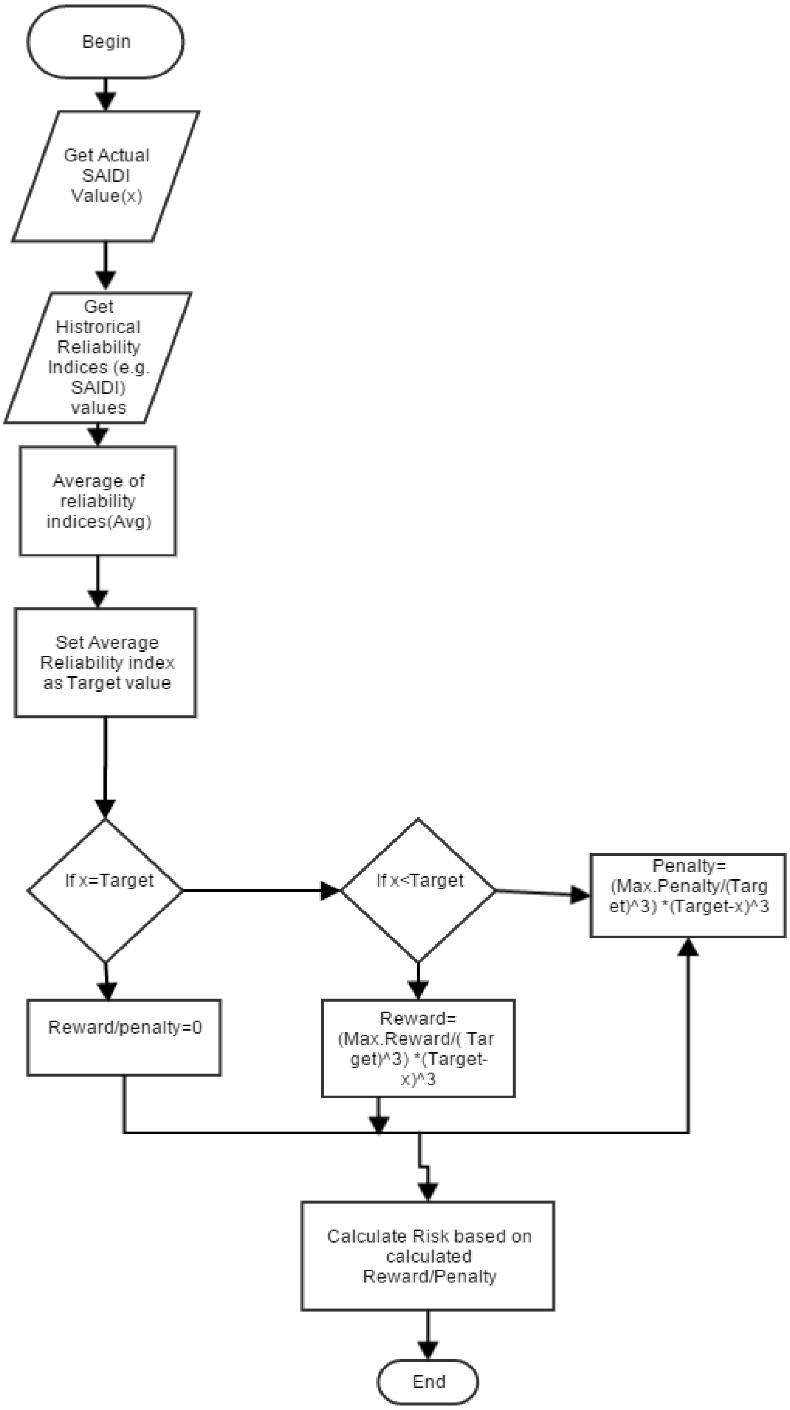

Figure 7.3-3 Flow Chart for CRPS NC

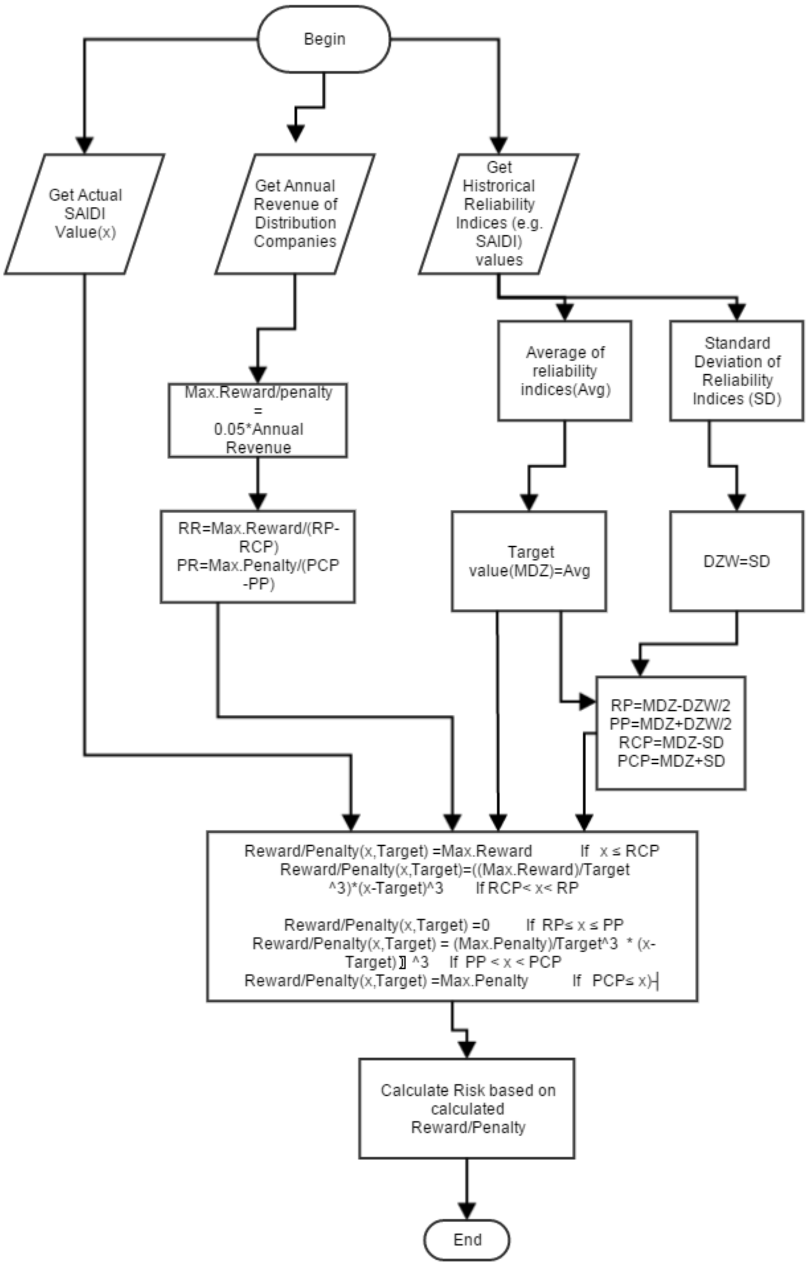

Figure 7.3-4 Flow Chart for CRPS C

7.4 PROTOTYPE IMPLEMENTATION

To test the feasibility of the proposed algorithm, we implemented the algorithm in section 7.3 using the given pseudo code in Appendix 1.

7.5 EXPERIMENTAL SETTINGS

In the experiments that we conducted, we used the following parameter specification. The description of all parameters with values and their results and observations are discussed in this sections.

7.5.1 PARAMETER SPECIFICATION

All the parameters and their associated specification used for gathering the results from the algorithm are listed in Table 7.5-1.

Table 7.5-1 Parameter Specification

Parameter	Description
X	Actual SAIDI value
SD	Standard Deviation of a set of Historical (Past 5 years) Reliability Indices (SAIDI values)
Mean, A	Average of a set of Historical (Past 5 years) Reliability Indices (SAIDI values)
MDZ	Middle point of Dead Zone
DZW	Width of Dead Zone
PP	Penalty Point
RP	Reward Point
RCP	Reward Cap Point
PCP	Penalty Cap Point
RR	Reward Ramp
PR	Penalty Ramp
Max.R	Maximum Reward Cap
Max.P	Maximum Penalty Cap
Rev	Annual Revenue of Distribution Companies

7.6 RESULTS AND OBSERVATIONS

In this section, we examine the experiments that we conducted and the outcomes that we observed, in the wake of operating our model. Perceptions are made by examining the outcomes accumulated from the model. Table 7.6-1 shows the the summary statistics of the 42 Iranian distribution companies' variables which is available at : www. tavanir.org. Applying these parameters to CRPS NC algorithm and CRPS C algorithm helps to identify the inefficient companies that need to improve their service reliability to maintain the target performance reliability level. It also contributes to estimate the corresponding reward or penalty payment based on their performance based reliability index.

For example, consider the case of applying CRPS-NC algorithm on a power distribution company D16 which has an average SAIDI of 712 min, which is set as the minimum target performance reliability level. It can be seen from the Table 7.6.1 that current reliability index for D16 using SAIDI is found as 820min, which is higher than the target performance reliability level, as this company is inefficient. Since there is no dead-zone or capping in CRPS NC, it can expect to receive a penalty payment of 0.004M$ from the regulator. Consider the case of applying CRPS-C on the same company D16 which has an average SAIDI of 712 min. In CRPS C structure, target performance reliability level(712 min) is set as MDZ. The average SD of historical reliability index for D16 is 106 min, and so it shall be fixed as the width of the dead zone(DZW). The penalty and reward points for D16 are set as 765 and 606 respectively which are defined by 'mean - SD/2' and 'mean + SD/2', respectively. It can be seen from Table 7.6.1 that current reliability index using SAIDI is found as 820 min which is higher than the target performance reliability level, as this company is inefficient. Since it is greater than the penalty cap point, it can expect to receive a penalty payment of 1.021M$, which is set as the maximum penalty cap for D16, from the regulator.

The simulation results of the first CRPS in Table 7.6.1 shows that 47.6% of 42 power distribution companies has no penalty, 52.4% has a penalty, the maximum penalty was 0.024 million dollars, and the minimum penalty was 0.001 million dollars. The simulation of the second CRPS in Table 7.6.1 shows that 66.7% of 42 power distribution companies has no penalty, 33.3% has a penalty, the maximum penalty was 4.83 million dollars, and the minimum penalty was 0.001 million dollars. Generally, when observed, we found that those companies with very low reliability received the maximum penalty.

Table 7.6-2 Results of CRPS

Distribution Companies	MAX Reward Cap M$	Reward Ramp Slope ab	RCP(a)	RP (b)	Width of Dead Zone	MDZ	Pp©	PCP(d)	Penalty Ramp Slope cd	MAX. Penalty Cap M$	SAIDI(RI)	CRPS-NC(M$)	CRPS-C(M$)
D1	1.37	0.02	208	287	158	366	445	524	0.02	-1.82	410	-0.003	0
D2	2.87	0.04	218	297	158	376	455	534	0.08	-5.93	376	0	0
D3	0.14	0	46	125	158	204	283	362	0.01	-0.85	224	-0.001	0
D4	1.5	0.02	414	493	158	572	651	730	0.02	-1.5	657	-0.005	-0.005
D5	2.27	0.03	2457	2536	158	2615	2694	2773	0.03	-2.28	3077	-0.013	-2.28
D6	1.97	0.02	470	549	158	628	707	786	0.05	-3.88	653	0	0
D7	1.76	0.02	209	288	158	367	446	525	0.03	-2.75	392	-0.001	0
D8	0.27	0	285	364	158	443	522	601	0.04	-2.85	460	0	0
D9	3.88	0.05	1571	1650	158	1729	1808	1887	0.05	-3.88	1954	-0.009	-3.88
D10	2.79	0.04	307	386	158	465	544	623	0.04	-2.79	518	-0.004	0
D11	3.27	0.04	234	313	158	392	471	550	0.06	-4.54	426	-0.003	0
D12	5.35	0.07	697	776	158	855	934	1013	0.1	-7.77	889	0	0
D13	2.61	0.03	960	1039	158	1118	1197	1276	0.03	-2.61	1267	-0.006	-0.006
D14	2.35	0.04	743	797	108	851	905	959	0.04	-2.35	986	-0.009	-2.345
D15	0.97	0.02	399	453	108	507	561	615	0.02	-0.97	551	-0.001	0
D16	1.02	0.02	606	659	106	712	765	818	0.02	-1.02	820	-0.004	-1.021
D17	2.85	0.05	589	643	108	697	751	805	0.06	-2.97	735	0	0
D18	1.02	0.02	409	462	106	515	568	621	0.04	-2.31	527	0	0
D19	1.49	0.03	685	738	106	791	844	897	0.03	-1.49	886	-0.003	-0.003
D20	0.17	0	135	188	106	241	294	347	0.02	-0.91	243	0	0
D21	0.72	0.01	587	641	108	695	749	803	0.01	-0.72	812	-0.003	-0.718
D22	0.94	0.02	216	270	108	324	378	432	0.03	-1.42	324	0	0
D23	1.38	0.03	441	495	108	549	603	657	0.05	-2.52	575	0	0
D24	1.95	0.04	663	716	106	769	822	875	0.04	-1.95	846	-0.002	-0.002
D25	0.86	0.02	464	517	106	570	623	676	0.02	-1.32	618	-0.001	0
D26	0.68	0.01	527	581	108	635	689	743	0.01	-0.68	742	-0.003	-0.003
D27	2.93	0.05	896	950	108	1004	1058	1112	0.05	-2.93	1078	-0.001	-0.001
D28	1.68	0.03	451	504	106	557	610	663	0.06	-3.14	557	0	0
D29	1.08	0.02	959	1012	106	1065	1118	1171	0.02	-1.08	1253	-0.006	-1.08
D30	1.73	0.03	473	527	108	581	635	689	0.03	-1.73	639	-0.002	-0.002
D31	1.68	0.05	414	446	64	478	510	542	0.08	-2.68	507	-0.001	0
D32	0.72	0.02	349	381	64	413	445	477	0.05	-1.71	438	0	0
D33	0.8	0.02	309	341	64	373	405	437	0.16	-5.17	384	0	0
D34	1.09	0.03	90	122	64	154	186	218	0.11	-3.55	156	0	0
D35	1.72	0.05	101	133	64	165	197	229	0.16	-4.98	165	0	0
D36	0.91	0.03	142	174	64	206	238	270	0.11	-3.36	207	0	0
D37	1.38	0.04	95	127	64	159	191	223	0.13	-4.19	159	0	0
D38	1.66	0.05	161	193	64	225	257	289	0.14	-4.38	225	0	0

D39	3.78	0.12	428	460	64	492	524	556	0.13	-4.28	579	-0.024	-4.283
D40	0.87	0.03	127	159	64	191	223	255	0.11	-3.53	192	0	0
D41	0.83	0.03	443	475	64	507	539	571	0.17	-5.51	507	0	0
D42	1.04	0.03	314	346	64	378	410	442	0.1	-3.29	378	0	0

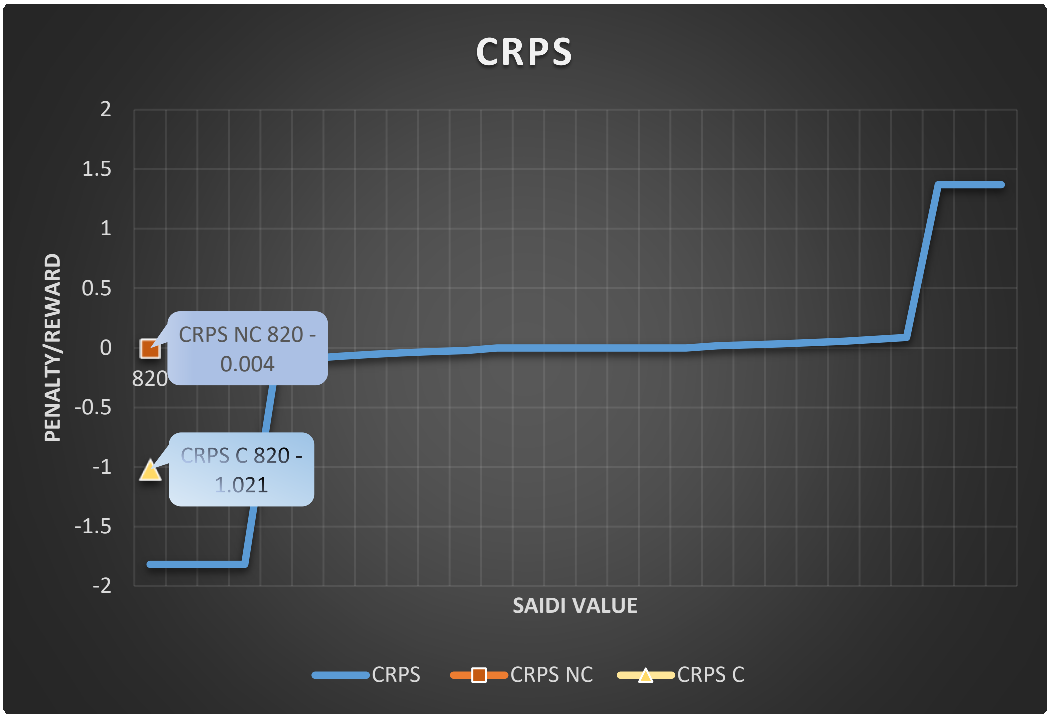

Figure 7.6-1 CRPS Structure

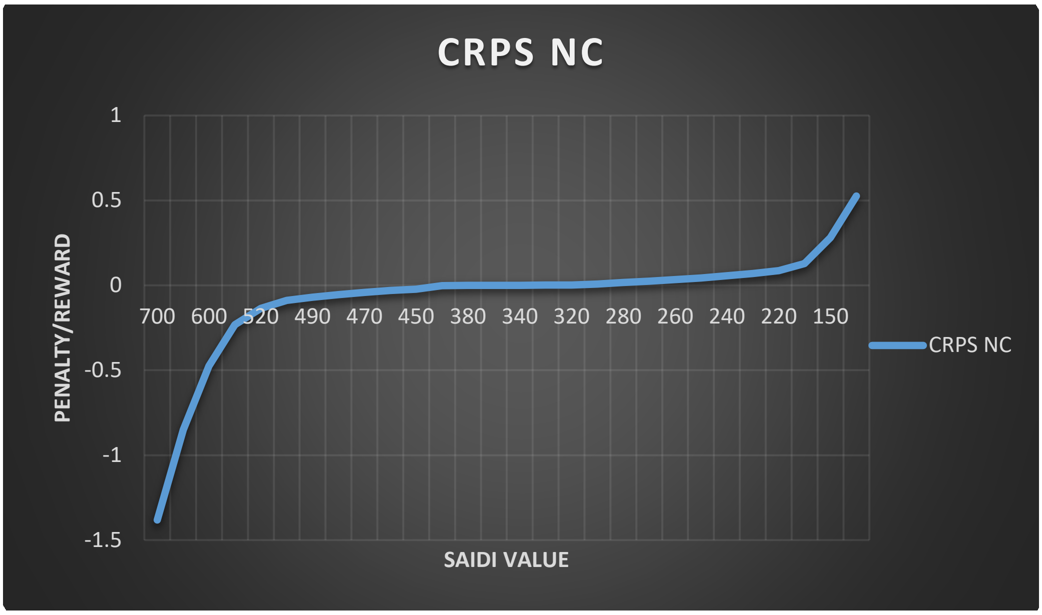

Figure 7.6-2 CRPS NC Structure

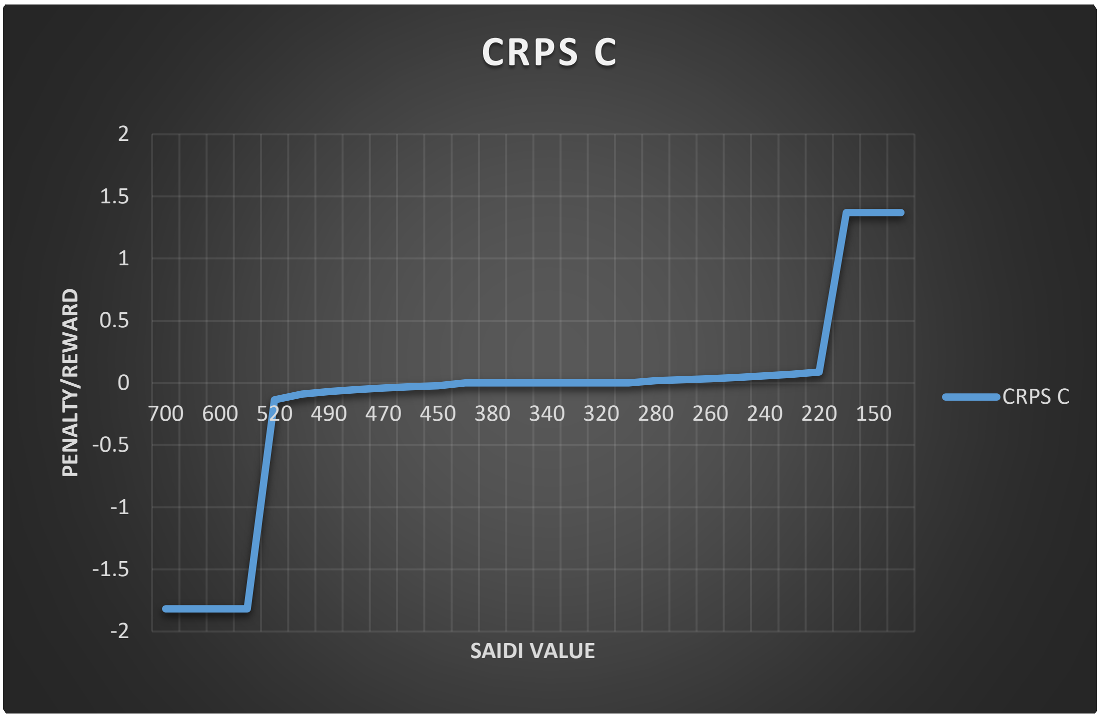

Figure 7.6-3 CRPS C Structure

7.7 VALIDATION

In this Chapter, we proposed a Quadratic Reward-Penalty Scheme term QRPS in two different ways- without a dead band and cappingand with the dead band and capping.

From the experiments that we conducted, we made the following observations:

- By using limited variables, we can calculate reward/penalty.
- Without setting the dead band, the cubic curve acts similarly to a dead band by providing a little incentive near the central target (CRPS-NC)
- Ensured a reasonable value for the reward /penalty after setting the capping (CRPS-C)
- By setting the dead band the proposed scheme considered the vulnerability related to the ideal performance level, and additionally took into account certain performance variations, in light of elements outside of the distribution company's control (CRPS-C)
- When compared to the existing algorithms, this cubic algorithm is most favourable to distribution companies.

7.8 COMPARATIVE ANALYSIS AND DISCUSSION

In this section, the proposed solution is compared with the existing schemes. A comparative study is depicted in the table below, which shows our algorithm (CRPS) and its comparison with the existing schemes in [25], [24], [4], [80], [81], [11]. The parameters for CRPS design implementation largely affect the financial risk of electric distribution companies and in this way setting these parameters is a basic issue in the reward and penalty payment. It is very reliant on the goal of the regulator. There are various elements that ought to be considered which influence the reliability and the behavior of individual companies when setting the parameters of CRPS. The nature and assortment of customer effects, coming about because of duration and recurrence of interruptions, ought to be considered while selecting the characteristic parameters for CRPS outline.

The reward–penalty schemes do not have a steady structure in all conditions and change as per necessities. Structures of these models rely upon the scope of data, kind of reliability index, the objective of system regulators, RPS execution time and so forth. If RPS is mainly designed using performance-based reliability, then the type of reliability index used in designing RPS has a significant impact on the reward and penalty payment. There are distinctive structures of RPS, be that as it may, Dead-Band RPS for reliability is the most proficient one since it incorporates the uncertainty about the optimal performance level and the performance related components that are outside of the distribution company's control. We implemented two approaches mainly intended for those regulators who concern more to customers that are affected by outage duration factor, the first approach is for those regulators who want to apply RPS for the first time, and they can apply RPS for money making. In the second method, we designed a dead-band RPS, which achieve an effective RPS for enhancing service reliability. The performance of the proposed approach is illustrated by reliability data of various electric distribution companies. A comparison between existing algorithms is provided in Table 3.

Mid-Point of Dead-Zone is the point where we set the performance target on an RPS curve which determines whether a company gets reward or penalty, so it has a vital importance in designing RPS curve. Billinton and Pan[24], [25] utilized both reliability indices SAIDI and SAIFI, with every index is weighted in light of the customer's concern, for determining this point. In [4], they utilized an Equivalent Probability Distribution of reliability indices for designing the RPS. A mix of cluster analysis and DEA is utilized by[80] for ascertaining MDZ while [81] utilized a mix of Historical Average Reliability Index, density area, and improvement target. In [11], MDZ is computed in light of the estimations of Historical Average Reliability Index, DEA efficiency score and the maximum reliability improvement. Even though the results have demonstrated to be better, it used too many parameters and took longer computation time. In the proposed CRPS approach, we set MDZ as the average of the last five years' reliability indices. Since the characteristic of the customers who are more concern towards the outage duration is taken into account in the CRPS design, so we applied SAIDI as the reliability index for determining the performance target (MDZ). In our design, only one parameter, SAIDI, is used, the results have proven to be fairly robust and took lesser computation time.

The parameter width of the dead zone(DZW) is highly subject to parameters of probability distribution measures, for example, mode, mean, range, variance, standard deviation, and skewness. Picking a bigger dead zone size estimate makes the CRPS design inadequate as many data might be situated in this fair-minded zone. Then again, a smaller dead zone size estimate brings about a high hazard for a distribution company as little change in the reliability index may shift the incentive payment from the reward zone to the penalty one or the other way around. Applying a dead zone with the mean of the historical reliability data as the center of the zone was recommended in [25,45]. In view of this strategy, the dead zone size is two times the standard division with the end goal that the 'mean + SD' is the reward point and the 'mean - S.D.' is the penalty point. Applying this strategy may locate many data in the dead zone. A wide dead zone may lose the primary idea behind the RPS execution with the end goal that a large number of information is situated in this zone and it does not make any inspiration for the distribution company to enhance the reliability.

Table 7.8-1 A comparative study of CRPS with the existing RPS schemes

Proper-ties	*[25]*	*[24]*	*[4]*	*[80]*	*[81]*	*[11]*	***CRPS***
MDZ	Historical average Reliability Index	Historical average Relia-bility Index	Equivalent Probability Distribution	DEA effi-ciency scores after a clustering process	Historical aver-age Reliability Index, density area, and im-provement target	Historical average Reliability Index, DEA efficiency score, and the maximum reliability improve-ment	Historical Average Relia-bility Index (SAIDI)
DZW	Standard Deviation	Standard Deviation	Standard Deviation	-	5% of MDZ	Average standard deviation for each cluster	Standard Deviation of the Historical Reliability index(SAIDI)
PP	MDZ-Half of Standard Deviation	MDZ-Half of Standard Deviation	MDZ-Half of Standard Deviation	-	-	MDZ+Half of Stand-ard Deviation	MDZ+Half of Standard Deviation of the Historical Reliability index(SAIDI)
RP	MDZ+Half of Standard Deviation	MDZ+Half of Standard Deviation	MDZ+Half of Standard Deviation	-	-	MDZ-Half of Stand-ard Deviation	MDZ-Half of Standard Deviation of the Historical Reliability index(SAIDI)
RCP	MDZ+Standa rd Deviation	MDZ+Standard Deviation	MDZ+Standard Deviation	-	-	MDZ-Standard Devia-tion and Slack Analy-sis	MDZ-Standard Deviation of the Historical Reliability index(SAIDI)
PCP	MDZ-Standard Deviation	MDZ-Standard Deviation	MDZ-Standard Deviation	-	-	PP+Max.Penalty/Pen alty Ramp	MDZ+Standard Deviation of the Historical Reliability index(SAIDI)
RR	-	Max.Reward/S loping area width	Max.Reward/S loping area width	-	Varies according to the density and reliability level score	Max.Reward/Sloping area width	Maximum Re-ward/(Reward Point-Reward Cap Point)
PR	-	Max.Penalty/Sl oping area width	Max.Penalty/Sl oping area width	-	Varies according to the density and reliability level score	Depends on DEA Score	Maximum Penalty/ (Pen-alty Cap Point-penalty Point)
Max. Rew	-	1M$	% of average income of utilities in each cluster	-	-	CCDF and Cap value	5% of average income of distribution companies

Max. Pen	-	1M$	% of average income of utilities in each cluster	-	-	% of average earnings of utilities	5% of average income of distribution companies

This thesis considers the midpoint of the dead zone (MDZ) as the mean of historical data. The penalty and reward points are defined by 'mean - SD/2' and 'mean + SD/2', respectively. This model prompts to a narrower dead zone than the one proposed in [24], [25] and normally reduced data are situated in this zone. A regulator can utilize this model when the performance-based reliability index is near the average of historical reliability data. Additionally, we proposed one standard deviation as DZW when contrasted with Billinton and Pan [24] and [39], who proposed two standard deviations. This delineates that the regulator needs distribution companies to keep up their future performance reliability in view of the average values. This procedure presumes that the information has been gathered in the past and is promptly accessible furthermore that the historical performance was satisfactory. Utilizing these methodologies, the regulator can ensure that service reliability has not been weakened after privatization.

The regulator does not always have impeccable and correct data about customer interruption costs. Thus, a cap value as a rate of the company's yearly income ought to be considered by the regulator to legitimize the risk of giving high rewards or penalties for improperly high-quality or low-quality reliability levels [62]. In the UK and Ireland [62], [82], maximum reward and maximum penalty are capped and are set at 3 and 4% of price control incomes [42]. In Netherlands [42], the adjustment in revenues is capped at 5%. The reward and penalty payments are also related to interruption cost. In [4], the cap values are set based on the yearly income of power distribution companies. In[11], CCDF and cap value are utilized to decide the maximum reward. In Norway and Italy, the consequences of customer interruption cost surveys are utilized as a part of setting the capping limits. In this paper, a few rate of aggregate revenue of the distribution company shall be fixed as the maximum reward and maximum penalty caps [4], [11]. The maximum reward cap is same as maximum penalty cap, and it depends on the regulatory goal. Max reward and Max penalty are set as a rate of yearly revenue and is controlled by the regulator. In our method for CRPS design, we set the maximum reward and maximum penalty caps for each distribution company as 5% of their yearly revenue.

From the experiments that we conducted on CRPS, we made the following observations:

1. Using limited variables, we can calculate reward/penalty efficiently with less computation time.
2. Without setting the dead band, the cubic curve acts similar to a dead band by providing a little incentive near the central target (CRPS-NC).
3. Ensured a reasonable magnitude for reward /penalty after setting the capping(CRPS-C).
4. By setting the dead band the proposed scheme considered vulnerability in regards to the ideal performance level, and additionally taken into account certain performance variations in light of elements outside of the distribution company's control (CRPS-C).
5. The simulation results of CRPS model show that those companies with very low reliability received the maximum penalty.
6. When compared to the existing algorithms, this cubic algorithm favors most to distribution companies and regulators than others.

In the first instance(CRPS-NC), from the experiments that we conducted, we observed the following advantages and disadvantages:

Advantages:

- The cubic function is also designed to provide increasing rewards or penalties as performance-based reliability strays away from the target, but the rewards or penalties increase most slowly.
- While linear formula has the advantage of simplicity, this non-linear formula(cubic formula), provides a strong link between performance and reliability.
- Without providing the dead band, this cubic curve acts similarly to a dead band by providing a little incentive near the central target.
- Limited parameters for finding reward/penalty.
- It is more favourable to distribution companies.

Disadvantages:

- Does not ensure a reasonable value for reward/penalty because of no capping.
- Does not consider the uncertainty in performance variance factors outside of the regulator's control.

In the second instance (CRPS-C), from the experiments that we conducted, we observed the following advantages and disadvantages:

Advantages:

- The cubic function is designed to provide increasing rewards or penalties as performance-based reliability strays away from the target, but the rewards or penalties increase most slowly.
- While linear formula has the advantage of simplicity, this non-linear formula (cubic Formula), provides the strongest link between performance and reliability.
- In addition to the dead band provided, the quadratic curve acts similarly to a dead band by providing no incentive near the central target.
- Limited parameters for finding reward/penalty
- Ensures a reasonable value for reward/penalty by applying maximum reward/penalty capping.
- By providing dead band, this approach has taken into account the uncertainty concerning the optimal performance level and some performance variance factors, outside of the regulator's control.
- Even though the same value of dead band is applied to linear, quadratic and cubic, this structure shows the largest dead band width, as compared to other structures. So it is most favourable to distribution companies, by considering that most of the uncertainties happened internally and externally, in the distribution companies.
- Curve reaches the maximum reward/ penalty more slowly in comparison to the quadratic curve and linear curve. I.e., increasingly most of theslope shows this algorithm provides a little reward or penalty around the dead band.

Disadvantages:

- It is not simple and is difficult to administer, because of the cubic calculations.

7.9 CONCLUSION

In this chapter, we introduced and formulated the problem of CRPS. We proposed a novel CRPS scheme most favorable to power distribution companies. The fundamental advantage of our approach is that it provides no reward or penalty around the dead band, thus ensures a reasonable value for reward/penalty and has also taken out the vulnerability on the variations from the optimal performance levels caused by those performance related factors that are outside of the distribution company's control. A comparative study of our technique, with previously proposed techniques, demonstrates that our technique is superior and can work in the best interests of the copyright holder.

CHAPTER 8

DISCUSSION AND RECOMMENDATION

This chapter provides the discussion and recommendations on

- Regulatory Index selection
- Factors affecting regulatory indices calculation
- Target Determination
- Tariff regulation methods

8.1 INTRODUCTION

A critical significance of deregulation in the power industry is the arrival of service quality regulation, in the distribution network. The Reward/Penalty Scheme (RPS) is managed to guarantee the service reliability. RPS is a financial strategy developed by the regulator to avoid the service reliability deterioration. RPS rewards the utility which is giving great reliability and penalizes the utility, which is giving poor reliability. This paper explores the principle necessities for the development and implementation of an efficient RPS. It discusses the national conditions for RPS implementations such as the choice of regulatory index, external and internal factors affecting regulatory indices calculation, target determination, tariff regulation methods, and other different aspects that drive the regulator to set an exclusive strategy for RPS. The objective of this chapter is to broadly discuss the principal aspects that should be considered for developing an RPS. This chapter also providesrecommendations based on the discussions that are relevant for implementing an effective Reward-Penalty Structure for power distribution companies

8.2 DISCUSSION

This section discusses four principal aspects of implementing RPS.

8.2.1 REGULATORY INDEX SELECTION

The first aspect is gathering and verifying data for calculating reliability, efficiency, and interruption cost indices. This process consumes a lot of time and money [48]. Regulators can apply just one regulatory index to improve performance but selecting two or more indices can satisfy industrial and rural customers concerns'.

8.2.1.1 RELIABILITY INDICES

Reliability indices such asSAIDI and SAIFI are more generally used in Australia [46]and internationally. In fact, SAIDI is more popular than SAIFI (Table 6.8-1). Results in [10] show that the number of interruptions (SAIFI) is less important than the duration of interruption (SAIDI). For example, customers residing in the rural areas, may live with frequent outages but may be concerned with the duration of the outage[6][47]. Similarly, for industrial customers frequent outages are a big concern because each interruption, may result in expensive start-up costs (e.g. restarting machines), furthermore, losing production time resulting in significant losses [6]. When applying multiple reliability indices, weighting individual indexes based on the customer's type is very important to closely follows customers' interest [4]. According to Canadian Energy Research Institute (CERI)[51], CAIDI is typically preferable to SAIDI, because it shows the duration of single (average) customer interruptions. It usually proves most intuitive and useful to evaluate the cost effectiveness of restoration and automation functions[51]. However, as CAIDI is the ratio of SAIDI/SAIFI, a disproportionate improvement in one measure, may lead to a misleading CAIDI result.

8.2.1.2 LOAD INDICES

Load indices have a relatively weak relationship to the economic value of reliability, because they measure the durations of interruptions, and do not capture the scale of the interruption. EENS measures are specifically designed for capacity planning, because of this, they inherently provide a statistical measure of reliability that customers can use.

However, many stakeholders prefer actual reliability measurement (SAIFI/SAIDI) over EENS for reasons such as capacity planning. Thus, we can state that SAIDI and SAIFI are the most commonly used reliability indices, that can be used as parameters for RPS implementation.

8.2.1.3 INTERRUPTION COST INDICES

This index is difficult for regulators to estimate, because of the uncertainties with the customer survey method, frequency, and type of power quality events, experienced by customers, as well as on the vulnerability of customers' equipment to these events. Another challenge is the limited information available, so, not all regulators want to use customer interruption costs as an input, when designing an RPS [19]. However, many regulators have still used customer interruption costs, while developing RPS[1], [4], [8], [15], [5], [9], [35], [27].

8.2.1.4 DEA ANALYSIS

This process can also be used by regulators to improve the service reliability by creating competition amongst different distribution companies, thereby improving the efficiency of inefficient companies.

8.2.2 FACTORS AFFECTING REGULATORY INDICES CALCULATION

Interruption (either internal or external) is a significant aspect that should be considered while calculating regulatory indices. Examples of internal interruptions are distribution equipment's failure, human failures, equipment maintenance and external interruptions such as generation and transmission failures, due to weather conditions, etc. Some countries do not consider interruptions in the process of indices calculation, because they want to take it as an important long-term reliability improvement task (i.e. long-term restoration time), whilst others consider it in indices calculation to perform the short time maintenance actions [6] (i.e. short term restoration time). Even though restoration time (long-term and short-term) is extremely dependent on the distribution company's disaster management, it also depends upon the indirect indices calculation.

8.2.3 TARGET DETERMINATION

The Target indicates the point at which the reward or penalty will start. Regulators can use three methods to determine the target [4], [14]. The *Historical performance method,* averages historic performance of the past three years [4], to determine the target, this ensures distribution companies can maintain the same level of performance. *Initially, targeted value method* fixes the target based on an initial value followed with yearly improvement [14]. *Competition method* fixes the target based on the average performance of distribution companies, grouped in one cluster, and the reliability is compared to companies within the same cluster.

8.2.4 TARIFF REGULATION METHODS

Five methods can be used. In the *distribution company's tariff regulation method,* the electricity rate varies for each distribution company based on their performance reliability. With the *country tariff regulation* method, all distribution companies apply the same tariff. However, with the *direct reward and penalty tariff method,* well-performing companies are rewarded from the regulator's fund and weak companies receive a penalty. Using the *balanced reward and penalty tariff method*, the regulator sets a balance amongst the rewards granted, and the penalty received, such that the net difference tends to be zero [15]. With the *budget,regulated tariff method,* government sets a fixed budget for RPS.

8.3 RECOMMENDATIONS

This section provides recommendations for implementing RPS.

- When selecting regulatory indicators, we recommend selecting factors that are quantifiable, independent and consider the customer type (industrial or residential), so that it can easily be managed by the regulators[48]. Multiple indicators (e.g. SAIFI and

SAIDI) can be used together, but it can give varying outputs where one index may penalize a company, but another index may reward the same company. For example, if each customer experiences two interruptions (1min & 20 mins), then from SAIFI's perspective, each customer is interrupted twice a year, but from SAIDI's perspective, customers are affected 20 times more in the second interruption. Hence we recommend assigning weights when using a combination of SAIDI and SAIFI. Regulators can decide the weights for each index, based on the customer type. It is suggested to include energy based reliability indices such as EENS, only if capacity planning is concerned, while designing RPS. Even though Interruption Cost Indices, are difficult to estimate and only limited information is available, it is still used widely used [1], [4], [8], [15], [5], [9], [35], [27]for developing RPS. Thus, it is recommended that the Interruption cost index be taken into consideration. We also recommend using the DEA score to compare the efficiencies of different distribution companies, to create competition between distribution systems to improve the service reliability. Furthermore, when defining a model of DEA, we recommend input-oriented DEA, where the outputs are fixed and the efficiency scores depend upon input.

- It is recommended that more consideration should be given to interruptions in the calculation of indices, so as to take maintenance actions within a short period (to avoid long-term restoration time).

- Depending on the scenario, one of these methods can be used. If performance should be consistent, we recommended using a combination of historical performance methods and competition methods, thus ensuring the maintenance of the same level of performance-based methods within the cluster.

- To consider a relationship between income and performance; to guarantee a better network reliability, it is recommended to consider the *balanced reward and penalty tariff method,* since it can establish a balance between reward and penalty, such that the net difference turns to zero within a specified period. Thus, it can avoid the doubt amongst distribution companies, that regulators apply RPS for money making.

8.4 COMPARATIVE ANALYSIS OF THE PROPOSED SCHEMES

The comparative analyses of the proposed schemes in terms of advantages and disadvantages are discussed in chapter 5, 6 and 7. Even though the pros and cons are inherited from each scheme, applicability of each scheme depends on the requirement of the user. A comprehensive numerical study is accomplished in chapter 5, 6 and 7 to examine the applicability of the proposed schemes. This numerical study shows that when compared to the results of Linear Reward-Penalty Scheme, Quadratic Reward-Penalty Scheme is more favorable to power distribution companies, by considering the performance inconsistency factors that are out of the regulator's control. By providing dead band, each scheme has taken into account the uncertainty concerning the optimal performance level and some performance variance factors, outside of the regulator's control. Even though the same value of dead band is applied to linear, quadratic and cubic, cubic structure shows the largest dead band width, as compared to other structures. Also, cubic curve reaches the maximum reward/ penalty more slowly in comparison to the quadratic curve and linear curve. by considering most of the uncertainties happened internally and externally in the distribution companies, cubic algorithm provides little penalty around the dead band. Hence, financially, cubic reward penalty scheme is the most favourable scheme for distribution companies.

In some cases, regulator can make money by adopting linear RPS inorder to improve the reliability of inefficient power distribution companies. In linear RPS, curve reaches the maximum reward/penalty more quickly in comparison to the quadratic curve and cubic. Because of this linear nature, reward or penalty values of Linear RPS a more around the dead band. Thus, Linear Reward-Penalty schemes helps the regulators financially.

Since the proposed schemes(linear, quadratic and cubic) have increased power exponentiation, we have done their comparative analysis in terms of accuracy, flexibility, complexity and scalability. The running time of the proposed Linear RPS is directly proportional to number of parameters, N, involved. When N doubles, so does the running time cost and complexity of computation. The proposed Quadratic RPS running time is proportional to the square of number of parameters involved. When N doubles, the running time increases by N * N. Thus complexity and cost of computation of the proposed quadratic function is more than the linear function. Also, the running time of the proposed Cubic RPS is proportional to the triple the number of parameters involved. When N doubles, the running time increases by N * N * N. Thus time complexity of Linear RPS, Quadratic RPS and Cubic RPS are $O(n)$, $O(n^2)$, $O(n^3)$ respectively. Even though time complexity of nonlinear functions are more than linear as the parameters vary, lots of performance enhancing techniques are there in MATLAB which can compute nonlinear functions very efficiently in less complexity and running time. So, high computational cost (running time) of nonlinear schemes does not affect the efficiency of RPS evaluation.

The complexity as well as accuracy of the proposed nonlinear functions can be controlled by setting the required number of iterations in evaluating the reward/penalty values. The proposed non-linear schemes, Quadratic RPS and Cubic RPS, provides the most flexible curve-fitting functionality because of their nonlinear nature of curve. Even though the scalability of linear RPS would have linear growth, we can achieve linear scalability in non-linear RPS by naturally setting the iterations to a limit.

It should be noted that in the proposed RPS schemes, RPS parameters must be recalculated each year. This may result in a small increase in the operational cost of regulator. However, the cost of updating RPS parameters, which can be easily calculated using a computer-based program, can be ignored compared to the other cost of implementing RPS such as data gathering, data auditing and supervision of companies. On the one hand, the recalculation of RPS parameters may increase the company in risk, since regulation can change from year to year. On the other hand, the method proposed also intends to simulate the competition between distribution companies. Competition may naturally increase the risk but insures the improvement of the service quality.

8.5 CONCLUSION

This chapter explained most of the principal aspects that should be considered while designing RPS. Based on the generic RPS framework developed in Chapter 4, we identified the relevant parameters used for computing the reward and penalty. This chapter also provided guidelines that should be considered, based on the parameters that are relevant for implementing an effective Reward-Penalty Structure, for power distribution companies.

CHAPTER 9

FUTUREWORKS AND CONCLUSION

This chapter provides:

- An introduction to current issues and problems with managing power distribution companies in the form of RPS
- Solutions proposed by this dissertation to address the problems
- Future works
- Conclusion

9.1 INTRODUCTION

In the literature, the notion of performance-based regulation and reliable power distribution has been widely discussed and various methods have been d eveloped to address different challenges associated with it. At the same time, the notion of managing power distribution companies has not been comprehensively investigated; moreover, only a scant amount of research studies are available on developing RPS to manage power distribution companies. Although managing power distribution companies, in the form of RPS, has been acknowledged as an important factor to be considered in recent literature, comprehensive approaches to address the issues associated with it, have not been proposed and developed.

To overcome this disadvantage,and to improve the reliability of power distribution, in this thesis, we identified different key issues in developing RPS, to manage power distribution companies and address them.

In the next section, we will recapitulate the different issues that we have identified and discussed in this thesis. In Section10.3, we highlight the contributions, which have been made by the thesis to the literature, as a result of addressing the different issues. In Section10.4, we identify some areas for future work and in Section 10.5 we conclude the chapter.

9.2 PROBLEMS ADDRESSED BY THIS THESIS

Although there are approaches proposed by different researchers in the literature made, to investigate the concepts of performance-based regulation through reliability, we noted that none of them have developed comprehensive frameworks to address the research problems that we address in this thesis. In this dissertation, the main problems, associated with developing RPS to manage power distribution companies, have been addressed. As mentioned in Chapter 3, the common issues in RPS implementation areas are as follows:

1. How to define and characterize most vital parameters for designing and implementing RPS?
2. How to set a realistic target that should be able to support and monitor the company's performance behavior?
3. How to ensure a reasonable value for reward or penalty?
4. How to reduce the complexity of adopting reward penalty formulas?
5. How to maintain the consistency of the reward penalty formula with the desired outcome?
6. How to include certain external factors in RPS implementation, that affect the performance of power distribution companies, that cannot be controlled by the regulators?
7. How to motivate the efficient and inefficient power distribution companies within the power market?
8. How to improve the power distribution company's reliability of power supply?
9. How to develop an effective RPS scheme, that is more favorable to the regulatory agency than the power distribution companies?

10. How to develop an effective RPS scheme, that is more favorable to power distribution companies than regulatory agencies?
11. How to develop an effective RPS scheme, that is most favorable to power distribution companies?
12. How to present financial rewards/penalties that are administratively simple?

These problems are solved by finding solutions to the specific problems that this thesis focuses on. The specific problems associated with managing performance based on reliability, in the form of RPS are:

1. Problems with identifying the most vital parameters for designing and implementing RPS, focusing on PBR that is based on reliability.
2. Problems with developing an effective RPS scheme that is simple and easy to understand and administer; that increases rewards and penalties, in a linear fashion, as the performance fluctuates from the normal; and should considers certain performance variations, in light of elements outside of the distribution company's control.
3. Problems with developing an effective RPS scheme that reaches the maximum reward/ penalty slowly, that providesvery little incentive near the central target and should consider the uncertainty related to those performance related components, that are outside of the distribution company's control.
4. Problems with developing an effective RPS scheme that should acts like a dead band RPS structure but considers the uncertainties which are due to external factors and provide no reward or penalty around the central target.

For each of these issues, the discussion is carried out from two alternate perspectives: the existing solutions and the technical problems innate in these solutions. The specialized concerns connected with the issues that will frame the research issues for the development of the new solution.

As discussed in Chapter 2, it is clear that current research studies on RPS are still susceptible to the issues above. Thus, these issues are the drivers for this research and the subsequent development of innovative algorithms.

9.3 DISSERTATION CONTRIBUTIONS

General problems for RPS implementation are namely:

- Problems with defining and characterizing the RPSs,
- setting.a realistic target that should be able to support and monitor the company's performance behavior,
- ensuring a reasonable value for reward or penalty,
- reducing the complexity in adopting reward penalty formulas,
- maintaining the consistency of reward penalty formula with the desired outcome,
- inclusion of certain external factors in RPS implementation that affect the performance of power distribution companies that cannot be controlled by the regulators,
- motivation of inefficient power distribution companies in power market,
- improvingthe power distribution companiesreliability in power supply,
- developing an effectiveRPS scheme,
- presenting financial rewards/penalties administratively simple.

These problems are solved by finding solutions to the specific problems that this thesis focuses on. The solution to the specific research problemsare associated with managing performance based reliability in the form of RPS implementation, from the dissertation contributions. The research problems are:

1. How to Identify the most vital parameters for designing and implementing RPS, focusing on PBR based on reliability?

In Chapter2, we discussed the survey of existing approaches for PBR based reliability and problem definitions along with the characterization of the most vital parameters for designing and implementing RPS. Based on thissurve, it is clear that the concepts of defining and characterizing the most vital parameters, are not well understood. Moreover, the literature contains no approaches, that particularly address the vital parameter definitions and characterizations. Additionally, the approaches discussed in other contexts, such as the PBR based on data envelopment analysis and the PBR based on customer interruption cost, are difficult to adapt to RPSs and may require major revision. To address this problem with defining and characterizing, the most vital parameters, we design a framework, which is extensively presented in Chapter 5.

2. **How to develop an effective RPS scheme that is simple and easy to understand and administer, that increases rewards and penalties as the performance fluctuates from the normal and should considers certain performance variations, in light of elements outside of the distribution company's control?**

According to the survey in Chapter 2, the literature has heavily overlooked the aspects of setting a target to analyze the company's behavior. In Chapter 3, the problem definitions for setting a realistic target and the associated technical issues, are discussed. Those technical problems result in some research questions which include:

- How to implement an RPS scheme, without any dead band and capping of the maximum reward and the maximum penalty ,for the improvement of the performance, based on reliability, for Power Distribution Companies?,
- How to implement an RPS scheme with a dead band, to control the normal fluctuations in performance, whilst also capping the maximum reward and the maximum penalty?".

To overcome the second research problem, the following research questions need to be answered. The answer to these questions has been well presented in Chapter 5, with the development of a linear reward-penalty structure.

3. **How to develop an effective RPS scheme, that reaches maximum reward/ penalty slowly, providing very little incentive near the central target and considers the**

uncertainty related to those performance related components, that are outside of the distribution companys' control.

As mentioned in Research Problem 3,the existing literature has not focused on managing diverse performance goals, based on reliability in the power distribution market, thus defining an effective RPS scheme that reaches maximum reward/ penalty slowly, that provides very little incentive, near the central target and has considered the uncertainty related to those performance related components, that are outside of the distribution company's control, to achieve the performance goals based on reliability.To address this problem of managing performance goals, based on reliability within thepower distribution market, the following research questions needed to be answered:
How to calculate the reward/penalty by using limited variables? How to ensure a resealable value for reward/penalty? How can we efficiently achieve performance goals based on reliability, within the power distribution market? What are the factors affecting the performance reliability of power distribution companies? How can we develop an approach that is more favorable to power distribution companies, by considering the performance inconsistency factors that are out of the regulator's control?
How can we accommodate the uncertainty factors that deviate the distribution companies performance-based reliability levels, in achieving the defined performance goal? We comprehensively illustrated a solution to all of these questions by the an algorithm proposed in Chapter 6, which implemented a new RPS, called the Quadratic Reward-Penalty Scheme.

4. **How to develop an effective RPS scheme that will act as a dead band RPS structure, by considering the uncertainties due to external factors and provide no reward or penalty around the central target?**

The Reward-Penalty formula which portrays the shape and slope of the curves, decides how rapidly the curve achieves the maximum reward or penalty, as performance strays from the performance target. To address this issue, the following research questions needed to be answered:

- How to define an RPS that increases rewards and penalties in a fashion that the performance shifts away from the norm, without applying the dead band; that acts as a dead band structure, by considering the uncertainties due to external factors?
- How to introduce a capping (thresholding) on the maximum reward and penalties that allow companies to abstain from paying a critically significant penalty or getting a huge reward?
- How can we evaluate the reward/ penalty based on performance-based reliability, by including a neutral zone around the target, which represents the vulnerability, in regards to the ideal performance level?

In order to answer theses questions, we developed a new structure for RPS, called Cubic reward-penalty scheme, which was discussed in Chapter 7.

9.4 FUTURE WORKS

Although a significant amount of effort has been invested in this research, there is still scope for future work, which is illustrated in this section. Initial work on demand response programs [64], utilization of capital and non-capital resources to meet regulatory targets[63] and distribution network reconfigurations[20], has been carried out recently within the power distribution system operations field. Integration of such potential works, into the present RPS framework, can improve the characteristics of the load profile, the customer satisfactionand the customer behavior simulation, for different prices, incentives, and penalties. This extension could be a striking idea to be considered shortly by distribution companies and regulatory authorities, in the electric power sector. We discuss each of these potential works in detail in the following sections.

9.4.1 DEMAND RESPONSE PROGRAMS

Demand response programs[64], [4]–[9]forpower distribution system operations, have risen. This situation has created a vital chance for customers to show an important part in the functioning of the smart grid, by lessening or changing their power use to within peak periods or different types of monetary incentives. It is used, for adjusting supply and demand and could bring down the expense of power in wholesale markets, and thus, prompt lower retail rates. Strategies for drawing in customer's demand response programs, incorporate offering time-based rates.

The electric power industry contemplates demand response programs(DSP)[83]as an inexorably great asset alternative, whose capacities and potential effects, are extended by grid modernization efforts. demand response Management programs use rates, motivations, and different techniques aimed to improve the management of power use during times of peak customer request[64], [4]–[9]. Those Demand Side Management activities, including direct cooperation from the customer side, can cut critical reductions in electricpower costs, as demand driven movements of interest during peaks, could lessen marginal costs [1], [4]–[9]. There is a scope for future work that can offer a reward-penalty mechanism, for the customers, by encouraging DSP programs. The goal of this future work, can be implemented as an RPS, in a manner that relatively penalizes non-active customers.

9.4.2 UTILIZATION OF INPUT AND OUTPUT (CAPITAL AND NON-CAPITAL) RESOURCES

Incentive regulation in electricity distribution, is relied upon to grow its extension, from an input oriented instrument, to one that incorporates output based motivating forces. This createsa potential clash with more conventional concerns regarding productive efficiency. In this thesis, we implemented an output based reward penalty incentive scheme. Applying an output based quality indicator for reward penalty scheme implementation,. Iit is found that there is no indication of a contention between cost effectiveness and social cost productivity. So as a future extension of this research, it will be more efficient in measuring distribution companies performance, if we apply both input and output based quality indicators, in our developed reward penalty scheme,in order to use social costs.

9.4.3 DISTRIBUTION NETWORK RECONFIGURATION

It has been assessed that the greater part of the interruptions to the power supply to customers is because of distribution network systems failures[89]. Subsequently, in resource supervision of a distribution system, expanding consideration is being made to enhance the customer service reliability[90]. Besides, most of the distribution network systems have the major problem of power failure, due to interruptions. A standout amongst the best strategies for reducing interferences in power supply, is to consider distribution network reconfiguration [91]–[96]. The majority of the research papers based on reducing the power system failures used network reconfiguration concepts but give less consideration on their system reliability. Some researchers have who have used reliability as a goal as a part of the network reconfiguration issue, simply attempt to maximize the reliability index or minimize the interruption cost. Because of the presentation of the reward and penalty scheme (RPS), within the distribution network system, the significance of quality level has improved, but has severely affected network reconfiguration. As a future expansion to our research, it will be beneficial for power distribution companies, to implement a distribution network reconfiguration in the presence of RPS, with the objective of considering both reliability and power system loss reduction, as an important problem.

The extension of RPS, based on demand response programs, utilization of capital and non-capital resources to meet regulatory target and distribution network reconfiguration, will be a striking idea for distribution companies and regulatory authorities in the electric power sector.

9.4.4 DYNAMIC GAME MODEL

The power distribution systems conservative political environment conceivably empowers better distribution quality over higher profit and added savings, nonetheless it causes energy loss. In order to analyze their relationship with the political environment, , it is necessary to develop a model that includes both features. Our work recommends an interesting future direction of developing the dynamic game model, a direct expansion of this research is to evaluate time irregularity and political philosophy, in imposing monopoly regulation of electricity distribution, to catch the interactions amongst customers and the electric power suppliers, over a specific timeframe.

9.4.5 PROSPECT HYPOTHESIS

Other exciting future work based on our research, is to apply a behavioral economic theory, such as a prospect hypothesis, on our implemented RPS models. Thus, it could be able to assess the subjectivebehavior amongst the electric power supplier and the customers. Thus, this will assist in the development of power distribution company's' new strategies, based on customer behavior psychology, the individual customer becoming the central focus. Application of a prospect hypothesis on RPS, helps power distribution companies to acquire the perfect knowledge of each customer requirements, requests, and favorites, thus providing reliable power supply. Additionally, they could plan to improve the customer service loyalty levels, through prospect theory.

9.4.6 INTEGRATING MORE HETEROGENEITY IN BOTH DEMAND AND SUPPLY

Requirement variations for the electric power supply system on the supply and demand side, have brought about a critical moment in its development. The enhancing of conventional general quality of service in the modern age, adds burdens that might be superfluously expensive. The demand side changes, resulting from our apparently voracious hunger for electric power in a rising computerized age, has tightened our performance-based reliability requirements. However, on the supply-side of the market, limitations on framework development, and the vulnerabilities of power markets, has encouraged us to stick to current standards. The administration of such electric power distribution, turns out to be difficult and will require the modernization of the control and distribution of power systems based upon the demand requisites of the cost-effective ,high-qualit and reliable power supply. The trends rising in the electric power framewor,k recommend that the centralized model that has ruled electric power systems, needs to be changed, by an option in which control is more scattered, and in which the general nature of the quality of service needs to be replaced by a heterogeneous service, based on end user requirements. Based on our research, we suggest an intriguing future direction, that could enhance our RPS model, by including more heterogeneity in the supply of power on the demand side, with a mixture of power stations, and small renewable energy sources. The objective of this approach, is to consider the heterogeneity of the reliability advantages over geographic conditions, by separating industrial and residential customers.

9.4.7 IMPLEMENTATION OF OUR MODEL IN OTHER LARGE SECTOR DOMAINS REGULATED BY POLITICAL AGENTS

As indicated by the standard economic hypothesis, higher financial incentives will prompt higher performance and improved effort without depending on work, connection, or people. In numerous large sectors under different domains of regulations, this standard monetary theory is executed. The financial incentives are, for instance, used to improve performance in the work environment or to expand wellbeing related behavior. The expansion of our developed RPS structure to different domains of regulation, such as renewable energy distribution sectors, financial sectors, health insurance and all other large sectors that are subject to control by regulatory agents, could provide an exciting future for this kind of research.

This research could expand into other directions in the future, including the expansion of our RPS models in the context of the changing operating and technical framework of the electricity supply industry. Our models could be applied for use within a smart grid; for increasing the digitalization of the grid and for increasing the greater adoption of smart grids, to facilitate renewable energy integrations and also for reducing the risks of high impact and low frequency interruption events, that the smart grids are exposed to, due to adverse climate change impacts ..

9.5 CONCLUSION

Distribution company's' performance evaluation, based on reliability, efficiency, and interruption costs have a greater significance with the arrival of deregulation. Maintaining the operational strength of their assets, while improving their performance, has become essential to keep customer loyal, lower costs of operation and improve the durability of the distribution company. The reward penalty scheme, is one of the global financial tools, that have been used by regulators, to revise the distribution company's revenues, according to their performance. It rewards those who are perform well and penalizes those who perform poorly, in order to maintain their appropriate performance levels.

In this chapter, we have summarized the work that we have undertaken and documented it, in this dissertation. We first discussed the issues that, we have addressed in the literature that prompted the research study done in this dissertation. We then highlighted the different contributions of this thesis and briefly described the future research work on RPS structure, for loss reduction and reliability improvement, based on demand response programs on power distribution system operations, utilization of capital and non-capital resources to meet regulatory target and distribution network reconfigurations. These future approaches can be used to improve load profile features and customer satisfaction. They can also be used by the regulatory agencies to develop applications that can simulate the customer behavior for different prices, incentives, and penalties. The distribution network reconfiguration method, allows the distribution companies to consider financial risk in the reconfiguration issues and helps to select the best configuration, based on acceptable risk. Thus these forthcoming methods that, we intend to carry out in the future, can contribute to extend the further development of the RPS approaches, developed in this thesis. Most importantly, the thesis concludes on how RPS schemes are future proof of the changing context of the operating and technical frameworks within the Electricity Supply Industry.

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APPENDIX-1

PSEUDO-CODE

1. PSEUDO CODE FOR LRPS

Algorithm 1: Pseudo code for LRPS, with no dead band and no maximum reward/penalty capping, for power distribution companies

Require: Parameter D, such that D= {D1, D2, …} is a collection of all distribution companies, with their current SAIDI values represented by parameter S, such that S= {S1, S2, ……,}.

Parameter X, such that X= {X1, X2, ….}, represents a collection of a set of historical SAIDI values for all distribution companies, where X1= {x1, x2, x3, x4} shows a set of the last 4 years SAIDI values, for each distribution company D1.

Output: Estimating the Reward or Penalty for all distribution companies, based on their performance score (current actual SAIDI value)

```
for all D1 ∊ D do
for all X1 ∈X do
Target ← avg(X1)
SD1←sd(X1)
end for;
end for;
for all D1 ∊ D do
for all R1 ∊ R do
for all value S1 ∊ S do
for all X1 ∊ X do
RwPn ← rwpn (Target, S, X)
end for;
end for;
  end for;
  end for;
```

SUBMODLE: avg(X1)

ASSERTION: To find the average of a set of 4 historical SAIDI values

ALGOROTHM

```
declare the variables
for each X1 ∈ X from 1 to 4 do
sum = sum of all values in X1
return sum / 4
end for;
```

SUBMODLE: sd(X1)

ASSERTION: To find the standard deviation of a set of 4 historical SAIDI values.

ALGOROTHM

```
declare the variables
define the expression and the constraints
for each X1 ∈ X from 1 to 4 do
A ← avg (X1)
sumsq = sumsq + power(x,2)
return sqrt (sumsq / 4 - A * A)
end for;
```

SUBMODLE: rwpn (Target, S, X)

ASSERTION: To estimate the reward or penalty of all distribution companies according to their performance based on reliability.

ALGOROTHM

```
for each D1 ∈ D do
for each R1 ∈ R do
for each value S1 ∈ S do
for each X1 ∈ X do
if 0 < S1 < D1. Target then
set RwPn ← (D1. Target - S1)/D1. sd(X1)
  else if S1 > D1. Target then
  set RwPn ← -(D1. Target - S1)/D1. sd(X1)
  else if S1 = D1. Target then
```

```
    set RwPn ← 0
    end for;
    end for;
    end for;
```

Algorithm 2: Pseudo code for LRPS with the dead band and maximum reward capping and maximum penalty capping, for power distribution companies.

Require: Parameter D, such that D= {D1, D2, ….}, is a collection of all power distribution companies with their current SAIDI values represented by a parameter S, such that S= {S1, S2, …} and their annual revenue is represented by a parameter R, such that R= {R1, R2, …}

Parameter X, such that X= {X1, X2, ….} represents a collection of a set of historical SAIDI values for all distribution companies, where X1= {x1, x2, x3, x4} shows a set of the last 4 years SAIDI values, for each distribution company D1.

Output: Estimating the Reward or Penalty for all distribution companies, based on their performance score (current actual SAIDI value) **for all** D1 ∊ D **do**

```
for all X1 ∈X do
A1← avg(X1)
SD1←sd(X1)
end for;
for all R1 ∊ R do
MaxR ← mxrw(R1)
MaxP ← mxpn(R1)
end for;
end for;
for all D1 ∊ D do
for all X1 ∈X do
DZW ← ddzw (X1)
MDZ ← mpdz(X1)
end for;
end for;
```

```
for all D1 ∈ D do
for all X1 ∈ X do
RP ← rwpt(X1)
RCP ← rwcpt(X1)
end for;
end for;
for all D1 ∈ D do
for all X1 ∈X do
PP ← pnpt(X1)
PCP ← pncpt(X1)
end for;
end for;
for all D1 ∈ D do
for all R1 ∈ R do
for all X1 ∈X do
RR ← rwrmp(X1)
PR ← pnrmp(X1)
end for;
end for;
end for;
for all D1 ∈ D do
for all R1 ∈ R do
for all value S1 ∈ S do
for all X1 ∈ X do
RwPn ← rwpn (R, S, X)
end for;
end for;
end for;
end for;
```

SUBMODLE: avg (X1)

ASSERTION: To find the average of a set of 4 historical SAIDI values.

ALGOROTHM

```
declare the variables
for each X1 ∊ X from 1 to 4 do
sum = sum of all values in X1
return sum / 4
end for;
```

SUBMODLE: sd(X1)

ASSERTION: To find the standard deviation of a set of 4 historical SAIDI values.

ALGOROTHM

```
declare the variables
define the expression and the constraints
for each X1 ∊ X from 1 to 4 do
A ← avg (X1)
sumsq = sumsq + power(x,2)
return sqrt (sumsq / 4 - A * A)
end for;
```

SUBMODLE: mxrw(R1)

ASSERTION: To find the Maximum Reward cap for each of the distribution companies

ALGOROTHM

```
for each revenue R1 ∊ R do
MaxR ← 0.05*R
end for;
```

SUBMODLE: mxpn(R1)

ASSERTION: To find the Maximum Penalty cap for each of the distribution companies

ALGOROTHM

```
for each revenue R1 ∊ R do
MaxP ← 0.05*R
end for;
```

SUBMODLE: ddzw (X1)

ASSERTION: To find the dead zone width for each of the distribution companies

ALGOROTHM

```
for each D1 ∊ D do
for each X1∈X do
DZW ← D1.sd (X1,4)
end for;
end for;
```

SUBMODLE: mpdz (X1)

ASSERTION: To find the mid-point of dead zone for each of the distribution companies

ALGOROTHM

```
for each D1 ∊ D do
for each X1∈X do
MDZ ← D1. avg (X1, 4)
end for;
end for;
```

SUBMODLE: rwpt (X1)

ASSERTION: To find the reward point for each of the distribution companies

ALGOROTHM

```
for each D1 ∊ D do
for each X1∈X do
RP ← D1. mpdz(X1) - (D1. ddzw(X1,4) / 2)
end for;
end for;
```

SUBMODLE: rwcpt (X1)

ASSERTION: To find the reward cap point for each of the distribution companies

ALGOROTHM

```
for each D1 ∊ D do
  for each X1∈X do
  RCP ← D1. mpdz(X1) + D1. ddzw(X1,4)
  end for;
  end for;
```

SUBMODLE: pnpt (X1)

ASSERTION: To find the penalty point for each of the distribution companies

ALGOROTHM

```
for each D1 ∊ D do
for each X1∈X do
PP ← D1. mpdz(X1) + D1. ddzw(X1,4)
end for;
end for;
```

SUBMODLE: pncpt (X1)

ASSERTION: To find the penalty cap point for each of the distribution companies

ALGOROTHM

```
for each D1 ∊ D do
for each X1∈X do
PCP ← D1. mpdz(X1) + D1. ddzw(X1,4)
end for;
end for;
```

SUBMODLE: rwrmp (X1)

ASSERTION: To find the reward ramp

ALGOROTHM

```
for each D1 ∊ D do
for each X1∈X do
RR ← D1.Max.rew(X1) / (D1. rwpt (X1)-D1. rwcpt (X1))
end for;
end for;
```

SUBMODLE: pnrmp (X1)

ASSERTION: To find the penalty ramp for each of the distribution companies

ALGOROTHM

```
for each D1 ∊ D do
for each X1∈X do
PR ← D1.Max.pen(X1) / (D1. pncpt (X1)-D1. pnpt (X1))
end for;
end for;
```

SUBMODLE: rwpn (R, S, X)

ASSERTION: To estimate the reward or penalty of each distribution company

ALGOROTHM

```
for each D1 ∊ D do
for all R1 ∊ R do
for all value S1 ∊ S do
for all X1 ∊ X do
if S1 <= D1. rwcpt(X1) then
return RwPn ← D1. mxrw(R1)
else if D1. rwcpt(X1) < S1< D1. rwpt(X1) then
return RwPn ← [D1. mxrw(R1)/ (D1. rwpt(X1)-D1.
rwcpt(X1))] × (D1. mpdz(X1)-S1)
else if D1. rwpt(X1) ≤ S1 ≤ D1. pnpt(X1) then
return RwPn ← 0
else if D1. pnpt(X1) < S1< D1. pncpt(X1) then
return RwPn ← [D1. mxpn(R1)/ (D1. pncpt(X1)-D1.
pnpt(X1))] × (S1-D1. mpdz(X1))
else if D1. pncpt(X1) <= S1 then
return RwPn ← D1. mxpn(R1)
end for;
end for;
end for;
end for;
```

2. PSEUDO CODE FOR QRPS

Algorithm 1: Pseudocode for QRPS with no dead band and no maximum reward/penalty capping for all distribution companies

Require: Parameter D, such that D= {D1, D2, …}, is a collection of all distribution companies with their current SAIDI values, represented by a parameter S, such that S= {S1, S2, ….} and their annual revenue represented by a parameter R, such that R= {R1, R2, …}

Parameter X, such that X= {X1, X2, ….} represents a collection of a set of historical SAIDI values for alldistribution companies, where X1= {x1, x2, x3, x4} shows a set of the last 4 years SAIDI values for each distribution company D1.

Output: Estimating the Reward or Penalty for all distribution companies based on their performance score (current actual SAIDI value)

```
1. for all D1 ∈ D do
2. for all X1 ∈X do
3. Target← avg(X1)
4. SD1←sd(X1)
5. end for;
6. end for;
7. for all D1 ∈ D do
8. for all R1 ∈ R do
9. for all value S1 ∈ S do
10.     for all X1 ∈ X do
11.     RwPn ← rwpn (Target, S, X)
12.     end for;
13.end for;
14. end for;
15. end for;
```

SUBMODLE: avg(X1)

ASSERTION: To find the average of a set of 4 historical SAIDI values

ALGOROTHM

```
1.    declare the variables
2.    foreach X1 ∈ X from 1 to 4 do
3.    sum = sum of all values in X1
4.    return sum / 4
5.    end for;
```

SUBMODLE: sd(X1)

ASSERTION: To find the standarddeviationof a set of 4 historical SAIDI values

ALGOROTHM

```
declare the variables
define the expression and the constraints
foreach X1 ∊ X from 1 to 4 do
A ← avg (X1)
sumsq = sumsq + power(x,2)
return sqrt (sumsq / 4 - A * A)
end for;
```

SUBMODLE: rwpn (Target, S, X)

ASSERTION: To estimate the reward or penalty of each distribution company

ALGOROTHM

```
for each D1 ∊ D do
for each R1 ∊ R do
for each value S1 ∊ S do
for each X1 ∊ X do
if 0 < S1 < D1. Target then
set RwPn ← power ((D1. Target - S1)/D1. sd(X1), 2)
else if S1 > D1. Target then
set RwPn ← -power ((D1. Target - S1)/D1. sd(X1),2)
else if S1 = D1. Target then
set RwPn ← 0
end for;
end for;
end for;
end for;
```

Algorithm 2: Pseudocode for QRPS with dead band and maximum reward capping and maximum penalty capping for all distribution companies.

Require: Parameter D, such that D= {D1, D2, …} is a collection of 43 distribution companies with their currentSAIDI values represented by a parameter S, such that S=

{S1, S2, ……} and their annual revenue represented by a parameter R, such that R={R1, R2, …}.

Parameter X, such that X= {X1, X2, …} represents a collection of a set of historical SAIDI values for alldistribution companies, where X1= {x1, x2, x3, x4} shows a set of last 4 years SAIDI values, for each distribution company D1.

Output: Reward or Penalty values of all distribution companies according to their performance based on reliability

```
for all D1 ∊ D do
for all X1 ∈X do
A1← avg(X1)
SD1←sd(X1)
end for;
end for;
for all D1 ∊ D do
for all R1 ∊ R
MaxR ← mxrw(R1)
MaxP ← mxpn(R1)
end for;
end for;
for all D1 ∊ D do
for all X1 ∈X do
DZW ← ddzw (X1)
MDZ ← mpdz(X1)
end for;
end for;
for all D1 ∊ D do
for all X1 ∈ X do
RP ← rwpt(X1)
RCP ← rwcpt(X1)
end for;
end for;
```

```
for all D1 ∊ D do
for all X1 ∈X do
PP ← pnpt(X1)
PCP ← pncpt(X1)
end for;
end for;
for all D1 ∊ D do
for all R1 ∊ R do
for all X1 ∈X do
RR ← rwrmp(X1)
PR ← pnrmp(X1)
end for;
end for;
end for;
for all D1 ∊ D do
for all R1 ∊ R do
for all value S1 ∊ S do
for all X1 ∊ X do
RwPn ← rwpn (R, S, X)
end for;
end for;
end for;
end for;
```

SUBMODLE: avg(X1)

ASSERTION: Finding the average of all historical SAIDI values for all distribution companies

ALGOROTHM

```
declare the variables
for each X1 ∊ X from 1 to 4 do
sum = sum of all values in X1
return sum / 4
```

5. **end for**

SUBMODLE: sd(X1)

ASSERTION: Finding the standard deviation of all historical SAIDI values for all distribution companies

ALGOROTHM

8. **declare** the variables
9. **define** the expression and the constraints
10. **for each** X1 ∊ X from 1 to 4 **do**
11. A ← avg (X1)
12. sumsq = sumsq + power(x,2)
13. return sqrt (sumsq / 4 - A * A)
14. **end for**

SUBMODLE: mxrw(R1)

ASSERTION: To find the Maximum Reward cap for all distribution companies

ALGOROTHM

1. **for each** revenue R1 ∊ R **do**
2. MaxR ← 0.05*R
3. **end for;**

SUBMODLE: mxpn(R1)

ASSERTION: To find the Maximum Penalty cap for all distribution companies

ALGOROTHM

1. **for each** revenue R1 ∊ R **do**
2. MaxP ← 0.05*R
3. **end for;**

SUBMODLE: ddzw (X1)

ASSERTION: To find the dead zone width for all distribution companies

ALGOROTHM

1. **for each** D1 ∊ D **do**
2. **for each** X1∈X **do**
3. DZW ← D1.sd (X1)
4. **end for;**

5. **end for;**

SUBMODLE: mpdz (X1)

ASSERTION: To find the mid-point of dead zone for all distribution companies

ALGOROTHM

1. **for each** D1 ∈ D **do**
2. **for each** X1∈X **do**
3. MDZ ← D1.avg (X1)
4. **end for;**
5. **end for;**

SUBMODLE: rwpt (X1)

ASSERTION: To find the reward point for all distribution companies

ALGOROTHM

1. **for each** D1 ∈ D **do**
2. **for each** X1∈X **do**
3. RP ← D1. mpdz(X1) - (D1. ddzw(X1,4) / 2)
4. **end for;**
5. **end for;**

SUBMODLE: rwcpt (X1)

ASSERTION: To find the reward cap point for all distribution companies

ALGOROTHM

1. **for each** D1 ∈ D **do**
2. **for each** X1∈X **do**
3. RCP ← D1. mpdz(X1) + D1. ddzw(X1,4)
4. **end for;**
5. **end for;**

SUBMODLE: pnpt (X1)

ASSERTION: To find the penalty point for all distribution companies

ALGOROTHM

1. **for each** D1 ∈ D **do**
2. **for each** X1∈X **do**
3. PP ← D1. mpdz(X1) + D1. ddzw(X1,4)

```
4.    end for;
5.    end for;
```

SUBMODLE: pncpt (X1)

ASSERTION: To find the penalty cap point for all distribution companies

ALGOROTHM

```
1.    for each D1 ∊ D do
2.    for each X1∈X do
3.    PCP ← D1. mpdz(X1) + D1. ddzw(X1,4)
4.    end for;
5.    end for;
```

SUBMODLE: rwrmp (X1)

ASSERTION: To find the reward ramp for all distribution companies

ALGOROTHM

```
1.    for each D1 ∊ D do
2.    for each X1∈X do
3.    RR ← D1.Max.rew(X1) / (D1. rwpt (X1)-D1. rwcpt (X1))
4.    end for;
5.    end for;
```

SUBMODLE: pnrmp (X1)

ASSERTION: To find the penalty ramp for all distribution companies

ALGOROTHM

```
1.    for each D1 ∊ D do
2.    for each X1∈X do
3.    PR ← D1.Max.pen(X1) / (D1. pncpt (X1)-D1. pnpt (X1))
4.    end for;
5.    end for;
```

SUBMODLE: rwpn (R, S, X)

ASSERTION: Estimating the Reward or Penalty for all distribution companies according to their performance, based on reliability

ALGOROTHM

```
1.    for each D1 ∊ D do
```

```
for all R1 ∊ R do
for all value S1 ∊ S do
for all X1 ∊ X do
if S1 <= D1. rwcpt(X1) then
return RwPn ← D1. mxrw(R1)
else if D1. rwcpt(X1) < S1< D1. rwpt(X1) then
return RwPn ← (D1. mxrw(R1)/power (D1. mpdz(X1),2))
×power (S1-D1. mpdz(X1),2)
else if D1. rwpt(X1) ≤ S1 ≤ D1. pnpt(X1) then
return RwPn ← 0
else if D1. pnpt(X1) < S1< D1. pncpt(X1) then
return RwPn ← (D1. mxpn(R1)/power (D1. mpdz(X1),2)) ×power
(S1-D1. mpdz(X1),2)
else if D1. pncpt(X1) <= S1 then
return RwPn ← D1. mxpn(R1)
end for;
end for;
end for;
  end for;
```

3. PSEUDO CODE FOR CRPS

Algorithm 1: Pseudocode for CRPS with no dead band and no maximum reward/penalty capping for all distribution companies

Require: Parameter D, such that D= {D1, D2, …} is a collection of all distribution companies with their current SAIDI values, represented by a parameter S, such that S= {S1, S2, ……} and their annual revenue represented by a parameter R, such that R= {R1, R2, ……}

Parameter X, such that X= {X1, X2, …} represents a collection of a set of historical SAIDI values for all distribution company, where X1= {x1, x2, x3, x4} shows a set of last 4 years SAIDI values for each distribution company D1.

Output: Reward or Penalty for all distribution companies according to their performance based reliability (current actual SAIDI value)

```
for all D1 ∈ D do
for all X1 ∈X do
Target← avg(X1)
SD1←sd(X1)
end for;
end for;
for all D1 ∈ D do
for all R1 ∈ R do
for all value S1 ∈ S do
for all X1 ∈ X do
RwPn ← rwpn (Target, S, X)
end for;
end for;
end for;
end for;
```

SUBMODLE: avg(X1)

ASSERTION: Finding average and standard deviation of all historical SAIDI values, for all distribution companies.

ALGOROTHM

```
declare the variables
foreach X1 ∈ X from 1 to 4 do
sum = sum of all values in X1
return sum / 4
end for;
```

SUBMODLE: sd(X1)

ASSERTION: Finding average and standard deviation of all historical SAIDI values, for all distribution companies.

ALGOROTHM

```
declare the variables
define the expression and the constraints
foreach X1 ∊ X from 1 to 4 do
A ← avg (X1)
sumsq = sumsq + power(x,2)
return sqrt (sumsq / 4 - A * A)
end for
```

SUBMODLE: rwpn (Target, S, X)

ASSERTION: Finding Reward or Penalty for all distribution companies

ALGOROTHM

```
for each D1 ∊ D do
for each R1 ∊ R do
for each value S1 ∊ S do
for each X1 ∊ X do
if 0 < S1 < D1. Targetthen
set RwPn ← power ((D1. Target - S1)/D1. sd(X1), 3)
else if S1 > D1. Targetthen
set RwPn ← -power (((D1. Target - S1)/D1. sd(X1)), 3)
else if S1 = D1. Targetthen
set RwPn ← 0
end for;
end for;
end for;
end for;
```

Algorithm 2: Pseudocode for CRPS with dead band and maximum reward capping and maximum penalty capping of 43 distribution companies

Require: Parameter D, such that D= {D1, D2, ...D43} is a collection of all distribution companies with their current SAIDI values represented by a parameter S, such that S= {S1, S2, ……} and their annual revenue represented by a parameter R, such that R= {R1, R2, …}

Parameter X, such that X= {X1, X2, ...} represents a collection of a set of historical SAIDI values for all distribution company, where X1={x1, x2,x3,x4} shows a set of the last 4 years SAIDI values, for each distribution company D1.

Output: Reward or Penalty for all distribution companies according to their performance based on their reliability

```
for all D1 ∈ D do
for all X1 ∈X do
A1← avg(X1)
SD1←sd(X1)
end for;
end for;
for all D1 ∈ D do
for all R1 ∈ R
MaxR ← mxrw(R1)
MaxP ← mxpn(R1)
end for;
end for;
for all D1 ∈ D do
for all X1 ∈X do
DZW ← ddzw (X1)
MDZ ← mpdz(X1)
end for;
end for;
for all D1 ∈ D do
for all X1 ∈ X do
RP ← rwpt(X1)
RCP ← rwcpt(X1)
end for;
end for;
for all D1 ∈ D do
for all X1 ∈X do
```

```
PP ← pnpt(X1)
PCP ← pncpt(X1)
end for;
end for;
for all D1 ∊ D do
for all R1 ∊ R do
for all X1 ∊X do
RR ← rwrmp(X1)
PR ← pnrmp(X1)
end for;
end for;
end for;
for all D1 ∊ D do
for all R1 ∊ R do
for all value S1 ∊ S do
for all X1 ∊ X do
RwPn ← rwpn (R, S, X)
end for;
end for;
end for;
end for;
```

SUBMODLE: avg(X1)

ASSERTION: To find the average of a set of 4 historical SAIDI valuesfor all distribution companies

ALGOROTHM

```
declare the variables
for each X1 ∊ X from 1 to 4 do
sum = sum of all values in X1
return sum / 4
end for;
```

SUBMODLE: sd(X1,4)

ASSERTION: To find the standard deviation of a set of 4 historical SAIDI valuesfor all distribution companies

ALGOROTHM

1. **declare** the variables
2. **define** the expression and the constraints
3. **for each** X1 ∊ X from 1 to 4 **do**
4. A ← avg (X1)
5. sumsq = sumsq + power(x,2)
6. return sqrt (sumsq / 4 - A * A)
7. **end for;**

SUBMODLE: mxrw(R1)

ASSERTION: To find the Maximum Reward cap for all distribution companies

ALGOROTHM

1. **for each** revenue R1 ∊ R **do**
2. MaxR ← 0.05*R
3. **end for;**

SUBMODLE: mxpn(R1)

ASSERTION: To find the Maximum Penalty cap for all distribution companies

ALGOROTHM

1. **for each** revenue R1 ∊ R **do**
2. MaxP ← 0.05*R
3. **end for;**

SUBMODLE: ddzw (X1)

ASSERTION: To find the dead zone widthfor all distribution companies

ALGOROTHM

1. **for each** D1 ∊ D **do**
2. **for each** X1∈X **do**
3. DZW ← D1.sd (X1,4)
4. **end for;**
5. **end for;**

SUBMODLE: mpdz (X1)

ASSERTION: To find the mid-point of dead zone for all distribution companies

ALGOROTHM

1. **for each** D1 ∊ D **do**
2. **for each** X1∈X **do**
3. MDZ ← D1. avg (X1, 4)
4. **end for;**
5. **end for;**

SUBMODLE: rwpt (X1)

ASSERTION: To find the reward point for all distribution companies

ALGOROTHM

1. **for each** D1 ∊ D **do**
2. **for each** X1∈X **do**
3. RP ← D1. mpdz(X1) - (D1. ddzw(X1,4) / 2)
4. **end for;**
5. **end for;**

SUBMODLE: rwcpt (X1)

ASSERTION: To find the reward cap point for all distribution companies

ALGOROTHM

1. **for each** D1 ∊ D **do**
2. **for each** X1∈X **do**
3. RCP ← D1. mpdz(X1) + D1. ddzw(X1,4)
4. **end for;**
5. **end for;**

SUBMODLE: pnpt (X1)

ASSERTION: To find the penalty point for all distribution companies

ALGOROTHM

1. **for each** D1 ∊ D **do**
2. **for each** X1∈X **do**
3. PP ← D1. mpdz(X1) + D1. ddzw(X1,4)
4. **end for;**

```
5.    end for;
```

SUBMODLE: pncpt (X1)

ASSERTION: To find the penalty cap point for all distribution companies

ALGOROTHM

```
1.    for each D1 ∊ D do
2.    for each X1∈X do
3.    PCP ← D1. mpdz(X1) + D1. ddzw(X1,4)
4.    end for;
5.    end for;
```

SUBMODLE: rwrmp (X1)

ASSERTION: To find the reward ramp for all distribution companies

ALGOROTHM

```
1.    for each D1 ∊ D do
2.    for each X1∈X do
3.    RR ← D1.Max.rew(X1) / (D1. rwpt (X1)-D1. rwcpt (X1))
4.    end for;
5.    end for;
```

SUBMODLE: pnrmp (X1)

ASSERTION: To find the penalty ramp for all distribution companies

ALGOROTHM

```
1.    for each D1 ∊ D do
2.    for each X1∈X do
3.    PR ← D1.Max.pen(X1) / (D1. pncpt (X1)-D1. pnpt (X1))
4.    end for;
5.    end for;
```

SUBMODLE: rwpn (R, S, X)

ASSERTION: To estimate the reward or penalty for all distribution companies, according to their performance based on reliability

ALGOROTHM

```
1.    for each D1 ∊ D do
```

```
for all R1 ∊ R do
for all value S1 ∊ S do
for all X1 ∊ X do
if S1 <= D1. rwcpt(X1) then
return RwPn ← D1. mxrw(R1)
else if D1. rwcpt(X1) < S1< D1. rwpt(X1) then
return RwPn ← (D1. mxrw(R1)/power(D1.mpdz(X1),3))
×power (S1-D1.mpdz(X1),3)
else if D1. rwpt(X1) ≤ S1 ≤ D1. pnpt(X1) then
return RwPn ← 0
else if D1. pnpt(X1) < S1< D1. pncpt(X1) then
return RwPn ← (D1. mxpn(R1)/ power (D1.  mpdz(X1),3))
×power (S1-D1. mpdz(X1),3)
else if D1. pncpt(X1) <= S1 then
return RwPn ← D1. mxpn(R1)
end for;
end for;
end for;
end for;
```