Faculty of Engineering and Science

Cloud Computing Strategies for Enhancing Smart Grid Performance in Developing Countries

Naveen Palanichamy

This thesis is presented for the Degree of
Doctor of Philosophy
of
Curtin University

February 2018

Declaration of Originality

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

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

Signature:

Date: 18/1/2018

Acknowledgments

Firstly, I am heartily grateful to my Ph.D. supervisor, **Dr. Wong Kiing Ing** for his priceless research guidance, inspiration, and recommendations all over this exploration. He is an earnest and dedicated supervisor, as well an effective mentor.

It is a great pleasure to thank my chair **Prof. Dr. Michael Kobina Danquah**, and co-supervisors **Asso. Prof. Dr. Ahmed Abu-Siada** and **Asso. Prof. Dr. Amandeep S. Sidhu** for their constructive suggestions, valuable guidance, and moral support throughout my research.

I also wholeheartedly express my gratitude to **Curtin University** for their excellent working environment, management & administrative supports, the state-of-the-art infrastructural facilities, and the full financial support for the successful completion of my Ph.D. research.

Lastly, let me reserve my final indebtedness to my family. Without the attention and love from my parents, I certainly could not have completed my doctoral study. They always offer me a lot but expect nothing from me. Special thanks to my husband, who open-handedly permitted me to carry on my studies, and managed himself lonely with love and patience. I am very proud of my first son who is the inspiration for my continued studies after my marriage, and the new arrival of my family i.e. my second son who is the secret of my energy recovering process whenever I exhaust and lose the spirit of reading.

Dedication

To my beloved sons Shanmuga Priyan and Lokajit Priyan,
lovable husband,
affectionate parents,
and
dedicated teachers.

List of Author's Publications

a) Journal Publications

1. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, "Cloud Associated Smart Grid Admin Dashboard," Engineering, Technology & Applied Science Research Journal, 2017, 8(1), ISSN (e/p): 1792-8036, 2241-4487 (Indexed in Web of Science/Thomson Reuters), http://www.etasr.com/index.php/ETASR
2. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, "Sustainable Economic and Emission Control Strategy for Deregulated Power Systems" International Journal of Energy Economics and Policy, 2017, 7(5), 102-110. (Scopus Indexed, Quartile: Q2), https://www.econjournals.com/
3. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, "Cloud-Based Solid Waste Transportation Optimisation for Energy Conversion," International Journal of Energy Economics and Policy, 2017, 7(4), 291-301 (Scopus Indexed, Quartile: Q2), https://www.econjournals.com/

b) Conference Publications

1. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, "The Implementation Issues of Smart Grid in Developing Countries," One Curtin International Postgraduate Conference, OCPC, Dec.10-12, 2017, reference number: EE8.
2. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, "Cloud Computing for Energy Management in Smart Grid - An Application Survey," IOP Conference Series: Materials Science and Engineering, 2016, 121(1), pp. 012010.
3. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, "Smart Grid Developments Across the Globe," North Borneo Research Colloquium (NBRC) 2016.

c) Papers in Process

1. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, "User-defined PMU Placements for Smart Grid Observability and Maintainability," International Journal of Electrical and Computer Engineering, revised and resubmitted on Dec. 21, 2017, (Scopus Indexed, Quartile: Q2)
2. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, "PMU Optimal Placement with priority for Renewable Energy Systems," IEEE Transactions on Smart Grid, submitted on Dec. 3, 2017.

Abstract

In developing countries, the awareness and development of Smart Grids are still in the introductory stage and their full realisation requires significantly more time and effort. In addition, some developing countries introduced partial Smart Grids, which are inefficient, unreliable, and environmentally unfriendly. The logical tools, control, and optimisation processes necessitate dependable computation servers for self-recovery, fault lenient, demand- management, and optimal power flow features. The engagement of Cloud Computing satisfies the requisite of data management and computing for Smart Grid applications. This research attempts to introduce a cost-effective wireless communication technology suitable for Smart Grids to facilitate data dissemination and querying effectively with the Cloud control. The Cloud is the link between the energy providers and the consumers to exchange data and to deliver the decisions of the energy providers to the consumers through this probable communication technology.

To enhance the performance of a Smart Grid in terms of minimising the unit cost of electricity generation, successful integration of renewable energy resources, energy supplier-consumer two-way communication facilities, and environmental friendliness, this research aims to develop power dispatching algorithms incorporating economic and environmental protocols. The algorithms are based on an analytical approach that provides solutions at a faster rate compared to the time-consuming and laborious iterative techniques. Cloud Computing strategies will be adapted for instantaneous data collection, execution of dispatching algorithms, and provision of two-way communications. The efficacy of the proposed on-line power dispatching algorithms with Cloud services will be determined applying the IEEE test systems and an Indian 62-bus power system incorporating Smart Grid technologies.

Finally, a Smart Grid Admin Dashboard and a Smartphone App will be developed for managing the Smart Grid for end-users. These tools will facilitate the transmission to end-users of all the energy-related information transparently on concurrent basis and allow better planning for any upcoming events in an economical manner, which in turn helps the Smart Grid in generation-demand management.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

ABB	ASEA Brown Boveri
ADC	Analog to Digital Converters
AI	Attribute Index
App	Application
AVL	Attributes Value List
CD	Cluster Descriptor
CI	Child Index
CN	Caching Node
CT	Current Time
DCIM	Distributed Cache Invalidation Mechanism
DR	Demand Response
EMS	Energy Management System
ET	Expiry Time
GHG	Greenhouse Gas
GPS	Global Positioning System
IWO	Invasive Weed Optimisation
LE	Lineage Encoding
MG-node	Modified G-node
PDC	Phasor Data Concentrator
PMU	Phasor Measurement Unit
RES	Renewable Energy Systems
SCADA	Supervisory Control And Data Acquisition
TI	Text Index
TL	Text List
TTL	Time to live
Tons	Metric Tons
UIWO	User-defined Invasive Weed Optimisation
WAMS	Wide Area Measurements System
WAN	Wide-Area Network
XML	eXtensible Markup Language
XPath	XML user queries

List of Symbols

$\mathbf{A}$	Network connectivity matrix
a_i, b_i , c_i	Quadratic cost coefficients
B_{ii}, B_{ij}	Self and mutual transmission loss coefficients
d_i,e_i, f_i	Quadratic emission coefficients
E_i	Emission of generator, *i* (kg/h)
E_T	Total emission (kg),
E_{Ti}	Emission of vehicle, *i* (kg)
F_i	Fuel cost of generator, *i*
F_{Li}	Cost of transmission power loss of generator, *i*
h	Price penalty factor. $/kg.
h_i	Price penalty factor of generator, *i* ($/kg)
h_{PD}	Price penalty factor at part load condition ($/kg)
kWh	Kilowatt-hour
n	Number of units
P_D	Total load demand (MW)
P_i	Generation of plant, *i* (MW)
P_{imax}	Maximum generation limit (MW)
P_{imin}	Minimum generation limit (MW)
P_j	Generation of plant, *j* (MW)
P_L	Transmission power loss (MW)
P_{Limax}	Maximum permissible power losses associated with generator, *i* and its transmission network
TC_i	Operating cost of vehicle, *i* ($)
TC_T	Total operating cost ($)
TWh	Terawatt-hour
W_D	Total load at the transfer station (Tons)
W_{Di}	Load of vehicle, *i* (Ton)
$W_{Di\,max}$	The maximum loading capacity of the vehicle, *i*.
w_i	Cost associated with PMU placement at bus, *i*
W_R	Total waste delivered (or received) at the sorting station (Tons)
W_{Ri}	Solid waste receivable from an individual vehicle, *i* (Tons)
W_{TL}	Solid waste losses during transportation (Tons)

ɤ	The conversion coefficient
Ψ	The optimum amount of emission
λ	The incremental cost of received power ($/MWh)
ϕ	The optimum cost of generation/transportation or fuel cost

Chapter 1
INTRODUCTION

1.1. Energy Challenges

Electrical energy has become a basic requirement for modern day life and a standard for evaluating the economic index of a country. Research on global energy usage [1-3] indicates nearly 1.3 billion people are without access to electricity, which is equivalent to 17 % of the global population and 22 % of those are living in developing countries. In addition to the scarcity of the energy supply, the existing energy systems are further jeopardised by the rapid growth in energy demand, the generation-demand mismatch, the reliability of the system components, the operational strategies, the size and fuel type of the energy sources, and weather conditions [4, 5]. As the global economy depends on energy sustainability, there are persistent economic as well as ecological needs to redesign the existing energy systems, with a more intelligent, reliable and efficient energy system, i.e. the Smart Grid.

Three conference papers have been published ("The Implementation Issues of Smart Grid in Developing Countries", "Cloud Computing for Energy Management in Smart Grid - An Application Survey" and "Smart Grid Developments Across the Globe") based on the concept of the proposed research.

1.2. The Smart Grid

ABB [6] defines a Smart Grid as an advanced grid system that facilitates electricity demand in a supportable, dependable and cost-effective manner, built on innovative infrastructure and regulated to expedite the integration of all involved. It incorporates renewable energy sources, distributed energy sources, and new technologically driven smart machines like plug-in electric vehicles with the existing energy systems as shown in Figure 1.1 [7].

It is self-healing, self-monitoring, digitally controlled and facilitates bilateral communications between suppliers and consumers. As energy demand is of a variable nature and renewable energy generation is intermittent due to weather and time of day, the power generation varies continuously; hence, generation-demand balancing is a significant task.

For the cost-effective, energy-efficient and reliable functioning of Smart Grids, many sensors and smart meters are required at demand site [8]. They produce an enormous quantity of data in real-time, which is compiled and sent to the analytics applications to produce results, i.e. control parameters, to enhance the efficacy and dependability of the Smart Grid [9, 10]. The current estimate is there is an average data generation of 22 gigabytes per day from 2 million customers. For data storage, retrieval, and analytics applications, the preferred source is the Cloud.

Figure 1.1. The Smart Grid Resources and End-users

The performance of Smart Grids is quantifiable through their widespread applications as:

(i) demand response - load management of industrial, commercial and residential consumers at their requirement,

(ii) dynamic pricing - the fixation of unit cost of electrical energy by the electric utilities,

(iii) demand scheduling - synchronizing various power generating sources, so the unit cost of energy generated is minimised without violating the stipulated emissions released from the power stations,

(iv) communication and information management - effective data transferring between utilities and consumers at real-time, updating of utility decisions to consumers on unit cost of energy, service continuity, maintenance scheduling, and probable blackouts due to weather, cyber threats, etc.

(v) optimisation of communication systems in terms of energy use - by appropriate choice of computing devices and working strategy,

(vi) integration of “smart” appliances and consumer devices, and

(vii) deployment and integration of advanced electricity storage and peak-shaving technologies, including plug-in electric and hybrid electric vehicles, and thermal-storage air conditioning.

1.3. Cloud Computing

The Cloud, simply, means software and services that function on the Internet instead of one's computer. This is a network of resources (servers), and each server has unique functions. Cloud Computing uses a linkage of remote servers accommodated on the Internet to preserve, accomplish, and process data instead of using a local server or a personal computer [11-13]. It provides several advantages for its widespread adoption:

- resources are provided as services and can be retrieved from the Internet,
- scalability on request, outgoing and incoming, and load management,
- coordinates resource utilisation according to resource requests hosted in the Cloud,
- users pay for their usage; once their requests are optimised, resulting in minimising costs immediately, and
- Cloud Computing technologies are energy-efficient, environmentally friendly, and cost-effective.

1.4. Need for Smart Grid in Developing Countries

Today Smart Grid has become essential for all countries because of its benefits and its growing global acceptance. Compared to developed countries, the progress of establishing a Smart Grid in developing countries is still in the initial stage. However, developing nations such as Brazil, China, Egypt, India, Iran, Malaysia, and Thailand, are currently investigating the potentials of some pilot projects [14-16]. There are critical reasons why developing countries need Smart Grid:

- *Capacity addition:* Most developing countries such as China and India have abundant renewable energy resources. Energy consumption in China has reached 23 % of global energy consumption. Its coal consumption has exceeded over half of the total world coal consumption [17]. The projected technically exploitable renewable energy generation is estimated as 7260 *TWh* per annum, which is more than 25 % of its current total energy generation. Whereas the estimated exploitable renewable energy generation in India is 5684 *TWh* per annum, which is equal to 17.7 % of the country's total energy generation [18]. If energy harnessed from renewable energy was implemented successfully, the additional capacity of the existing energy systems for these two countries would be significant. Moreover, developing countries can decrease their reliance on fossil fuels, forming energy portfolios less susceptible to volatile international markets. Increasingly today, these renewable energy investments can be less expensive than fossil fuel energy systems.

- *Energy theft and power losses:* Developing countries' have widespread, non-technical losses due to electricity theft. These can arise from errors in meter reading and invoicing but also from illegal connections, meter tampering or corrupt agents. Despite scant information released by energy suppliers, electricity theft frequently amounts to about 10 % of all electricity produced according to the World Bank [19]. In addition, developing countries experience high power losses due to rapid economic growth and expansion, tightly packed urban populations, dispersed rural populations, and inadequate power system management [15, 20-22]. Smart Grids can play an important role in improving systems performance by reducing power losses, and providing adequate security measures to avoid theft of electrical energy.
- *Global Warming:* Greenhouse Gas (GHG) emissions from developing countries will probably exceed those from developed countries before 2050 [23], and the risk of environmental degradation is inevitable. Electricity generation and its associated activities account for about one-quarter of total GHG emissions, the main offender in global warming [23]. For instance, China ranks first in total emission and its energy-related GHG emissions are 25.26 % of the total global emissions resulting in an average per capita emission of 8.13 tons/person, and India ranks fourth with 6.96 % of global emissions with a per capita emission of 2.24 tons/person [24]. As Smart Grids integrate renewable energy sources, environmental issues can be addressed economically and effectively.
- *Quality and reliability of power:* In developing countries like India and Bangladesh, the quality of the grid is very poor with voltage variation, voltage unbalance, harmonic distortion, and equipment failure. India and Bangladesh experience a 16 % deficit in their energy supply. Consequently, stable electricity is available for only certain times of the day [15, 25].

Generation-demand balancing and distribution automation are two features of Smart Grid that can keep the power supply available continuously, through carefully managing the power flow in an intelligent power system [7].

- *Energy Deficiency:* In developing countries, the unit energy cost lies in the range of US$ 0.20-0.50 per *kWh*. This is primarily due to the scarcity of fossil fuels, the frequent volatility in fuel prices, the higher transportation costs of moving fuel from the supplier to the power stations, the aging of the generating plants, inadequate maintenance of equipment, operational deficiencies, and lack of technical expertise in load balancing [15, 19]. Such high electricity costs become a barrier to further development. As the Smart Grid is intelligent, self-healing and energy-efficient, the energy cost could be brought down to a more appealing value by generation scheduling and demand management.

1.5. Research Gap

- Available mechanisms to monitor Smart Grid performance at a real-time basis, including data collection and dissemination are limited.
- In a competitive energy market, an attractive unit cost of electricity generation and environmentally friendly has not been addressed effectively and efficiently, and
- The communication link between the energy providers and the consumers to exchange data and to deliver decisions from the energy providers to the consumers is inadequate.

1.6. Problem Statement

Performance enhancement of Smart Grid on a real-time basis – *mechanisms to obtain attractive energy costs, environmental friendliness, secured system data collection & dissemination and two-way communications between energy suppliers and users are preferable*.

1.7. Research Questions

a) How to enhance the performance of Smart Grid at a real-time basis when data collection and dissemination are limited?

b) How to overcome the security and stability challenges on incorporating renewable energy sources in Smart Grids by an economical manner?

c) What is the best suited generation scheduling strategy to evade convergence issues and slowness in solution time?

d) How to ease the bilateral communication needs of energy suppliers and end-users in a cost-effective way?

1.8. Research Objectives

The primary objectives of this research are:

a) To enhance the performance of the Smart Grid, (i) an algorithm will be developed for the optimal placement of Phasor Measurement Units and (ii) wireless communication tactics for data dissemination and querying,

b) To provide an attractive price for environmentally benign energy, using a non-iterative analytical strategy suitable for Cloud services in a Smart Grid, and

c) To cater to the bilateral communication needs of energy suppliers and end-users, a Smart Grid System Admin Dashboard and a Smartphone App will be developed.

1.9. Research Contributions

The proposed research provides cost-effective optimal locations for the placement of PMUs for real-time monitoring of Smart Grids, also these locations offer complete observability of all the buses; hence, system reliability and security are assured always. The suggested wireless communication strategy, if implemented successfully, could fulfils the communication gap between the energy supplier and the end-users. The proposed non-iterative technique to determine the unit cost of electrical energy is very fast, straightforward, cost-effective, and suitable for real-time applications. The optimisation strategy is subject to environmental constraints; hence, the harmful effects of electricity generation on the environment are reduced and a clean electrical energy system for the society can be provided. The objective functions are assumed to be in quadratic forms (cost and emission equations), and for other forms of representation, the algorithm has to be modified to accommodate few approximations without sacrificing accuracy or to accommodate other polynomial functions. In addition, through the Dashboard and Smartphone App, consumers receive all the energy-related information transparently in a real-time so they can plan their future activities in an economical manner, which in turn helps the grid on demand-side management. Finally, all the research questions will be duly answered and the research objectives will be completely achieved.

1.10. Thesis Outline

This thesis is composed of eight chapters, following Chapter 1’s introduction,

Chapter 2 presents the review of related literature on Smart Grid monitoring, data collection and dissemination, the optimisation strategies to achieve the unit cost of energy incorporating economic and environmental concerns, and the Cloud and the Cloud supported Dashboard and Smartphone Apps for energy supplier and end-user bilateral communications.

In Chapter 3, a modified Invasive Weed Optimisation algorithm has been presented for the employment of Phasor Measurement Units (PMUs) at certain buses mandatorily to accommodate renewable energy and intermittent resources, which introduces unique challenges to the Smart Grid operations.

Chapter 4 introduces a Wireless XML Streaming system as an appropriate technique for broadcasting XML data over a mobile environment for expeditious query processing by clients with extended battery usage.

Chapter 5 proposes a direct dispatching algorithm to perform economic, emission and combined economic and emission dispatches, which is fast, cost-effective, Cloud-based, and does not require switching between individual dispatching tasks.

Chapter 6 of this research introduces a Cloud-based waste-to-energy recovery strategy for Smart Grid capacity enhancement.

Chapter 7 provides a Smart Grid Admin Dashboard and a Smartphone App to facilitate end-users receiving all the energy-related information transparently in a real-time basis to plan their upcoming events in a cost-effective manner, which in turn helps the Smart Grid on demand management.

Finally, Chapter 8 summarises and highlights the principal contributions of this study, and the probable future research directions.

Chapter 2

RESEARCH BACKGROUND AND LITERATURE REVIEW

This chapter discusses the current relevant literature on Smart Grid monitoring, data collection and dissemination, the optimisation strategies to achieve the unit cost of energy incorporating economic and environmental concerns, the Cloud, and the Cloud supported Dashboard and Smartphone Apps for energy supplier and end-user communications.

2.1. Synchrophasor Technology

The modern electric grid, the so-called “Smart Grid”, faces many challenges in its day to day operations with stability, security, reliability, and its primary objective of delivering electric energy at an economically and environmentally acceptable cost [15, 25-27]. To meet all these roles, advanced infrastructural requirements becomes inevitable. Figure 2.1 shows the enhanced performance and diagnostics of a Smart Grid with the advanced metering and control infrastructures including the Phasor Measurement Units (PMUs).

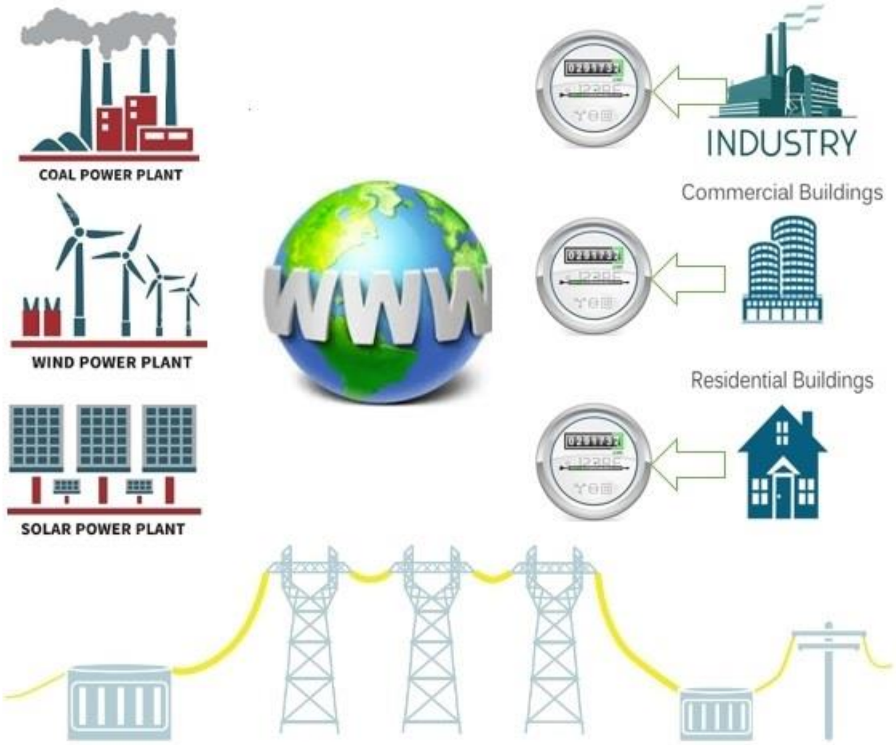


Figure 2.1. Performance & Diagnostics of a Smart Grid

On August 14, 2003 the North-eastern US and Ontario experienced a blackout due to weak situational alertness by electric grid operators (incomplete information and misunderstanding; a short circuit due to inadequate tree trimming; and operators lacked coordination). As a result, utilities progressively installed Synchrophasor (PMUs) to deliver real-time, reliable wide area grid visibility.

2.1.1. Optimal PMU Placements

Grid system planning engineers commonly experience great difficulty in deploying PMUs at the most appropriate locations to achieve complete system observability due to the very high cost of installing PMUs. Such PMU deployment planning can be either for the primary stage or for supplementing new PMUs where the grid system encompasses some existing PMUs [28].

Currently, a substantial amount of research on deciding how many PMUs and their prime locations has been carried out. In [29], a bisecting search method to determine the least number of PMUs required to create a completely observable electric grid was studied. The simulated annealing approach was applied to identify indiscriminately the PMUs for an observability test at every step of the bisecting search. The authors in [30] followed a genetic algorithm approach to determine the optimum PMU positions for complete system observability. A bus-ranking approach has been followed to decide on the required quantity of PMUs for thorough grid observability, and this methodology found limited real-time applications since the optimal solution is not always guaranteed. In [31], a unique perception of the depth of unobservability and its sway on the density of PMU placements was discussed. Mainly, the research was based on using the spanning trees of the power system graph and the tree search procedure to find the best locations for PMU placements. The application of the simulated annealing method has been restricted by enormous computational time required over a vast grid. The researchers [32] made use of the binary integer programming technique and the constraints function obtained from the connectivity matrix as a criterion for optimal placement of PMUs. The ensuing solution, however, is not optimum since the required quantity of PMUs and the associated cost are higher than what has been affirmed by other researchers for a typical test system.

The PMUs having a partial channel capacity and only measure sending end voltage and sending end current are referred to as *branch PMUs*. Although the method developed by the authors [33] has resolved the optimum PMU placement problem with great precision, it has little visibility security during either PMU or transmission line outages. A novel approach based on branch placement for PMU assignment has been presented [34]. In this new approach, the PMUs are of a single-channel category and are connected at the beginning of the branches, which can then measure the bus voltages of the grid system. In this research, the optimisation is accomplished by integrating the costs of the PMUs with respect to the number of channels into the objective function.

2.1.2. Invasive Weed Optimisation Technology

Weeds, the most forceful and vexatious floras in agriculture have resilient properties such as adaptation, heftiness, vigorousness, and invasiveness. Based on those irrepressible properties of weeds, Mehrabian and Lucas [35] have developed Invasive Weed Optimisation (IWO) in 2006 by impersonating the biological activities of weeds in inhabiting and discovering new areas for progress and replication. Since its beginning, IWO has been involved in several exploration efforts, and some stimulating modifications have subsequently resulted. Based on the concept of Taboo search, Ren et al. [36] proposed an improved IWO algorithm. Nikoofard et al. [37] applied the refined IWO technique to the analysis of a Pareto improvement model in the electricity market. Roy et al. [38] suggested a hybrid two-stage optimisation procedure starting with the IWO, and finishing with a modified Group Search Optimiser. Josiński et al. [39] proposed an extended Invasive Weed Optimisation for resolving uninterrupted and distinct optimisation issues. Rama Prabha and Jayabarathi [40] suggested using the IWO method to determine the optimal sizing of multiple Distributed Generators for minimising the loss and operational cost and improving the voltage stability in the radial distribution system under different types of loads. Barisal and Prusty [41] presented an advanced mixed algorithm consisting of an IWO and an oppositional-based learning technique for power system load dispatching. Though the IWO and its derived modifications are widely practiced today [42], the IWO often results in premature convergence as in other evolutionary computation algorithms. In order to encourage the best fit for weeds with greater opportunities of survival and be able to produce more seeds, this research addresses a user-defined PMU placement technique overcoming the premature convergence issue. The proposed algorithm is suitable for renewable energy integrated Smart Grids as well as conventional power systems.

2.2. Wireless Communication and XML

In wireless and mobile environs, data propagation is a functional technique for data broadcasting since it has the advantages of a) many clients sharing the same broadcasting channel improves bandwidth efficiency, b) a substantial number of clients for a server improves scalability and economic viability, and c) the flexibility to receive data without a request message improves energy-efficiency [43-47]. Moreover, mobile clients are able to utilise battery-backup devices, which results in greater energy conservation. The complete query processing time must also be shortened to offer a firm reply to the users i.e. latency-efficiency [46, 48].

2.2.1. eXtensible Markup Language

XML (eXtensible Markup Language) [49] has been widely practised as a customary resource to enable the illustration and distribution of structured data across dissimilar information systems in the wired Internet environment as well in the wireless broadcast environment. HTML, which is ubiquitous in applications for the World Wide Web, is not suitable for wireless applications because: a) Memory of mobile devices is extremely low, b) Most HTML pages simply cannot be displayed on a mobile device, and c) Navigating lengthy HTML pages could be extremely difficult.

The eXtensible Markup Language offers a Web-friendly and easily understandable syntax for data interchange as well as influencing data definition and Web share. XML controls user-defined tags confirming the separation of document content from its presentation and supports web information process automation. This research uses an XML-based set of data management requirements to, for instance, accrue and query XML documents [50-56]. The extensive use of XML necessitates following strict requirements for prototypes and mechanisms acquiring XML documents. While securing XML documents, addressing issues such as authenticity, integrity and confidentiality becomes critical. As business and government adopt XML as a reference for document representation and exchange on the Web, there is a crucial necessity for the safe publishing of XML data over the Web.

2.2.2. XML Query Stream

An XML query stream [57] is a substantial sequence of queries continuously generated from users to query XML data over the Internet. Both XML data and user queries can be modelled as a tree. XML user queries (i.e., XPath [58]) generally state assorted patterns and is based on compound elements with definite tree-structured relationships. Mining frequent XML user query patterns may be utilised to improve the query performance of XML streams [59-66]. Frequent XML query patterns can be used to form an index mechanism or cache the outcomes of these patterns to decrease the unnecessary computation and thus improve the query performance. These query patterns can also be used to support storing a collection of XML data’s fragments, the answers to XML query patterns, into a cache.

This research presents a Wireless XML Stream Generation Algorithm plus Client-side Query Processing Algorithm suitable for data dissemination and querying in a Smart Grid system.

2.3. Energy Cost and Environmental Constraints

The major cost of energy production is the price of fuel for fossil-fuelled power plants; hence, the frequent volatility of fuel costs is a risk for investors on achieving the return on their investments [19, 20, 25]. The utilities suffer from limited/uncertain fuel supplies and price stability from the government and energy sector. Moreover, the availability of intermittent forms of renewable generation, storage, and backup issues, the unattractive energy buyback policies and energy cost, and their high capital investment with limited funding resources are further challenges for the utilities and the consumers in terms of higher energy cost.

Due to significant consumers' demand for clean electrical energy, utilities must now control their power plant emissions as per statutory requirements; hence, wide-ranging operational performance schemes have been developed over time [67, 68]. The integration of renewable energy resources, the implementation of advanced pollution control equipment, adoption of multi-fuel dispatching techniques, up grading of inefficient power generating units, and adopting an emission controlled generation scheduling are a few of the more recent strategies. Among these policies, the emission-controlled generation scheduling option is cost effective and easy to carry out.

To meet consumers' concerns for attractive energy bills, continued availability, and environmentally friendly, multi-period and multi-objectives power dispatching algorithms have been developed [69-74]. These methods optimise the energy costs subject to system equality and inequality constraints and indicate the level of emission due to power generation. Since these approaches are multi-dimensional linear programming based, the computation time becomes longer and the decision-making process is delayed; hence the real-time application of these methods is questionable.

Balza et al. [75], Jiménez et al. [76], and World Bank [19] have discussed the fact electricity losses (technical loss due to power flow, and non-technical loss due to theft, un-metered systems and mismanagement) have an important impact on both the supply and demand side. On the supply side, a reduction in technical losses implies gains in the efficiency of the electricity system, helping to reduce the amount of electricity production required to meet demand, with significant associated environmental benefits. On the demand side, non-technical losses are synonymous with unpaid consumption, potentially fostering over consumption of electricity and hypothetically putting a heavy burden on electricity supply capacity. From a business approach, a reduction of power losses would also lead to increased financial sustainability for the utilities, mainly resulting from increased billing and cost reductions associated with a better match between capacity investment and demand.

All electric utilities face serious challenges of peak demand management even though the peak demand lasts for a short period of a day. This management task involves a high marginal cost to maintain standby power plants (fossil-fuelled) that can quickly respond to an increased demand. Further, additional costs are involved in overcoming the environmental issues caused by the standby units. To overcome these economic and environmental issues associated with peak demand management, a virtual power producing mechanism has been introduced [77, 78] wherein the customers dynamically participate in the supply-demand management. This technology needs to be further explored concerning cost, and environmental issues [79].

As the power system operation and control is a multifaceted challenge, the energy utility seeks to ensure a continuous, economical, reliable, and environmentally acceptable power supply for its consumers. This research proposes a non-iterative analytical algorithm for generation scheduling with economic and emission control strategies subject to line load ability constraints. The above objectives are achieved through changes in operating and control policies without any changes in the system configuration.

2.4. Cloud Computing

Recently, Cloud computing has gained great popularity among consumers due to its impressive computing capacity, communicative ability, and financial affordability with a minimum amount of resources required on the consumer end [13, 80, 81]. The wide-range of choices in Cloud computing is all about where the computing process is located, who are managing the Cloud servers, and how the data is retrieved and paid for. A Cloud set-up utilises hardware simulations to isolate the software from the features of physical servers. Hardware or platform simulations denote the formation of a virtual machine, which functions like a ready to use the physical computer [82, 83].

Researchers [84-86] have pointed out Cloud computing has not been effectively introduced and practised in power systems and Smart Grids though these systems deal with a large amount of data, vast communication requirements, real-time monitoring, security and reliability assessments, and performance optimisation. However there have been a few on-going Cloud computing applications [87-90] such as a) Smart Grid energy management through (i) demand response - load requirement by industrial, commercial and residential consumers at their request, (ii) dynamic pricing - the unit cost of electrical energy fixed by the electric utilities, and (iii) demand scheduling - coordinating various power generating sources, for instance, conventional and renewable energy sources so the unit cost of energy generated is minimised without violating the stipulated emissions released from the power stations. Other Cloud applications include, Smart Grid communication and information management through (i) effective data transferring between utilities and consumers at real-time, (ii) updating of utility decisions to consumers on unit cost of energy, service continuity, maintenance scheduling, and probable blackouts due to weather, cyber threats, etc. and c) optimisation of communication systems in terms of energy use-by proper choice of computing devices and operating strategy.

As a Smart Grid involves a mass of consumers, it has the ability to meet the changing needs of these consumers on day-to-day basis. Modern energy consumers have shown a preference for regulating their energy consumption patterns in their premises and operating energy consuming devises more responsibly and intelligently than what is currently possible [15, 89, 91-93]. For real-time monitoring, to meet these preferences and maintaining system performance, many sensors and smart meters must be employed. These incorporated sensors produce a significant quantity of data instantaneously, which is then gathered and supplied to analytical software and used to control decisions to efficiently and reliably manage the power grid [94, 95]. To manage large numbers of sensors and smart meters in a safe, dependable, and scalable manner, electric utilities must be able to apply the bilateral messaging network management system to a distributed data centre [96-98]. In this respect, Cloud Computing is envisioned to improve the performance significantly in modernising the existing Smart Grid. Cloud Computing is an evolving technology promoted to encourage greater access to various computing sources and then rapidly shared efficiently to service providers [89, 99-102].

As a Smart Grid involves a mass of consumers, it has the ability to meet the changing needs of these consumers on day-to-day basis. Modern energy consumers have shown a preference for regulating their energy consumption patterns in their

premises and operating energy consuming devises more responsibly and intelligently than what is currently possible [15, 89, 91-93]. For real-time monitoring, to meet these preferences and maintaining system performance, many sensors and smart meters must be employed. These incorporated sensors produce a significant quantity of data instantaneously, which is then gathered and supplied to analytical software and used to control decisions to efficiently and reliably manage the power grid [94, 95]. To manage large numbers of sensors and smart meters in a safe, dependable, and scalable manner, electric utilities must be able to apply the bilateral messaging network management system to a distributed data centre [96-98]. In this respect, Cloud Computing is envisioned to improve the performance significantly in modernising the existing Smart Grid. Cloud Computing is an evolving technology promoted to encourage greater access to various computing sources and then rapidly shared efficiently to service providers [89, 99-102].

2.5. Admin Dashboard and Smartphone Apps

Although Cloud computing forms a bridge between the Smart Grid and energy consumers, the information system available to the consumers is technically constrained and provides little data to them [103, 104]. Moreover, such resources are limited in quantity and not user-friendly to those consumers with limited technical abilities. Hence, a simple, technology-enabled utility-consumer interactive information system is preferable to cater to the needs of electric consumers. Electric utilities, business entities, and educational institutions have developed a few service dashboards [105-108] with limited functions and services for the end-users. These dashboards display real-time status conditions of the Smart Grid, intelligent early warning of any grid abnormality, real-time energy costs, and the forecasted demand and generation, as well as additional features, in a user-friendly manner. The respective IT staff can program the dashboard to rapidly identify performance matters with associated services together with the Smart Grid and application server components, cohesive web and Cloud components, in a single view.

The flow of information between the end-users and grid operators is essential. Smartphones and web services are in place to aid in this task. Edison [109] introduced the SCE Demand Response (DR) Alerts mobile application to allow consumers to obtain courtesy custom alerts regarding forthcoming DR events, sent directly to the end-users' smartphone. Another company, Cognizant [110] released both sequential and simultaneous screening Smartphones for Smart Grid energy management information exchanges between customers and energy providers by embracing a mobile-first mind-set concept. This is an established software platform that permits utilities to accomplish all aspects of their demand response (DR) programs through a single, integrated system. The authors [111, 112] designed an energy portal logic to provide users feedback on their energy usage, a prompt by the grid to the users about energy conservation, and to remotely control or automate the devices through existing media, such as Smartphone Apps, websites, or computer software.

In this research, to cater to the bilateral communication needs of energy suppliers and end-users, an energy efficient System Admin Dashboard and Smartphone App will be developed.

2.6. Conclusions

This chapter presented the relevant literature on the Smart Grid concept and a Cloud Computing strategy for efficient computation and communication.

- The issues related to Synchrophasor technology and the need for real-time monitoring of the Smart Grid was deliberated.
- An XML query stream continuously generated for mobile users to query XML data over the Internet has been discussed.
- The various methods of performing economic power dispatch to provide electricity at a competitive cost to consumers were addressed, with their limitations.
- The Cloud computing strategies suitable for Smart Grid applications and their implementation issues were analysed, and finally
- Cloud-based dashboard and smartphone applications for energy supplier and end-user, bilateral communications were examined.

Chapter 3

USER-DEFINED PMU PLACEMENTS FOR SMART GRID OBSERVABILITY

According to the existing literature and data availability, a research gap exists to monitor Smart Grid performance at a real-time basis and there is no solution to the questions: 1.7 (a) how to enhance the performance of Smart Grid at a real-time basis when data collection and dissemination are limited, and 1.7 (b) how to overcome the security and stability challenges on incorporating renewable energy sources in Smart Grids by an economical manner. As Phasor measurement units (PMUs) have been receiving increasing attention as a measuring and monitoring technology offering grid operators situational awareness to avoid power outages; so to fill the research gap, provide solutions for the above research questions, and to achieve the objective target 1.8 a) (i) enhancing the performance of the Smart Grid by an appropriate strategy, this chapter proposes a User-defined Invasive Weed Optimisation (UIWO) strategy for the cost-effective assignment of PMUs in a Smart Grid Cloud platform for complete observability and maintainability.

3.1. Wide Area Measurements System

A Wide Area Measurements System (WAMS) has become one of the state-of-the-art technologies indispensable for improving outmoded electric grids [113]. This development has turned out to be an obligation to revolutionise the electric grid delivery system because of some major power failures around the world [114]. A WAMS was first developed by the Bonneville Power Administration [113, 115] in the 1980s and since then has become the definitive data acquisition technology, and is currently used in several applications [116] such as: angle and frequency monitoring, system disturbance and failure analysis, enhanced state estimation, steady-state benchmarking, and voltage stability monitoring, etc. To operate the grid system effectively and efficiently with environmental safeguards, the role of the grid operator has become increasingly critical and who relies on the data or information available in real-time to make key decisions. The analog and digital information such as voltage, frequency, active and reactive power flow and circuit breaker status are presently obtained through a SCADA or the EMS [117-119]. This digital information is updated every 4-10 seconds at respective Load Dispatch Centres. The data sent through a SCADA and EMS are not time synchronised, gradual, accurate and of high resolution.

The foremost limitation of a regular SCADA system is its slow, asynchronous measurements. Moreover, the SCADA systems deliver imprecise conditions during vigorous events; hence, making a SCADA is impracticable during dynamic disturbances [120]. As a result, the more progressive Smart Grid systems have adopted PMU-dominated WAMS also known as Synchrophasor technology, instead of the SCADA.

The primary aim of the PMUs is '*to constantly sample the analog measured voltage, typically 20, 30 or 60 samples per second, and the current and frequency in synchronicity and time-stamp them using the precise clock of GPS receivers'*. The time-stamped measurements are called Synchrophasor, which leads to synchronising and time-aligning the measurements of different locations of the grid system [120]. Thus, these precise clocks present an informative portrait of the grid operating conditions to the grid operators and Load Dispatch Centres. Phasor measurement units and phasor synchronisation are not necessary when there is only one electric power-generating source in the Smart Grid [121-124]. However, this technology becomes of greater interest when the grid has several generating sources operating in parallel. The power demand is of an endlessly varying nature due to consumers' requirements and the power generation required to meet the demand on a real-time basis. Hence, synchronisation becomes crucial and PMUs are necessary for synchronising the phase and frequency of the parallel-connected generators of the grid system. Any exception to this condition could result in inefficient operations or a blackout. The understanding of what exactly happens at definite times in the diversified geographic locations of the Smart Grid system is a vibrant function of the entire grid operation and the prevention and control measures to overcome serious incidents. To ensure grid security and reliability, the deployment of PMUs becomes essential, and if PMUs are placed at all the buses, this will increase the operating costs, and thus there is a need to minimise the number of PMUs.

3.2. PMU Functional Strategy

Figure 3.1 represents the functioning of PMUs through a block diagram. The current and potential transformers of the grid system observe the grid conditions in analog form and feed those signals to anti-aliasing filters. The anti-alias filters remove unwanted high-frequency signals from the input signals and thus avoid aliasing errors. The frequency response of the anti-aliasing filters is expressed through the sampling rate for the sampling process. Anti-aliasing filters confirm all the analog signals posses

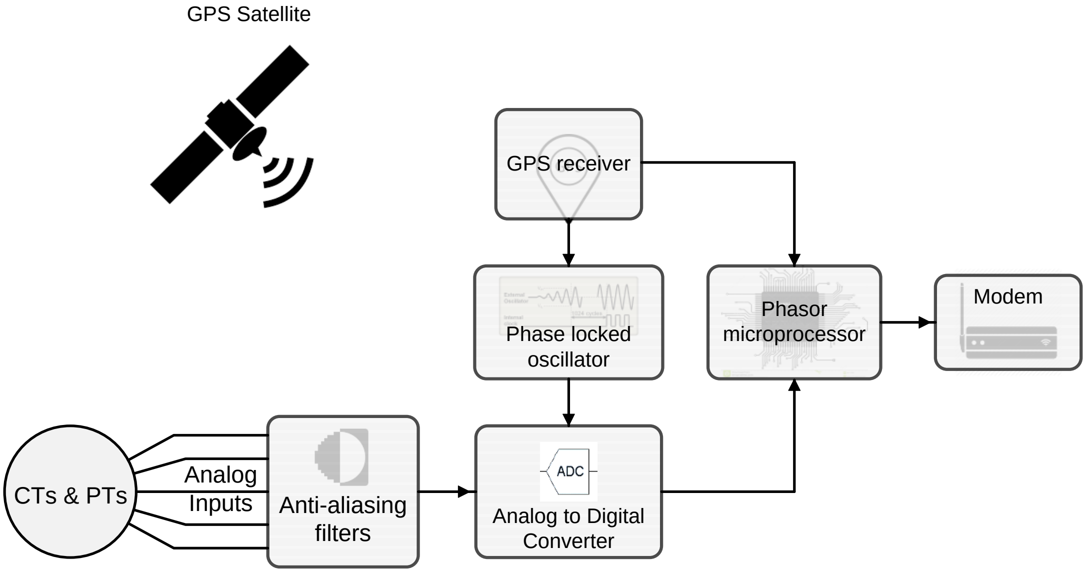


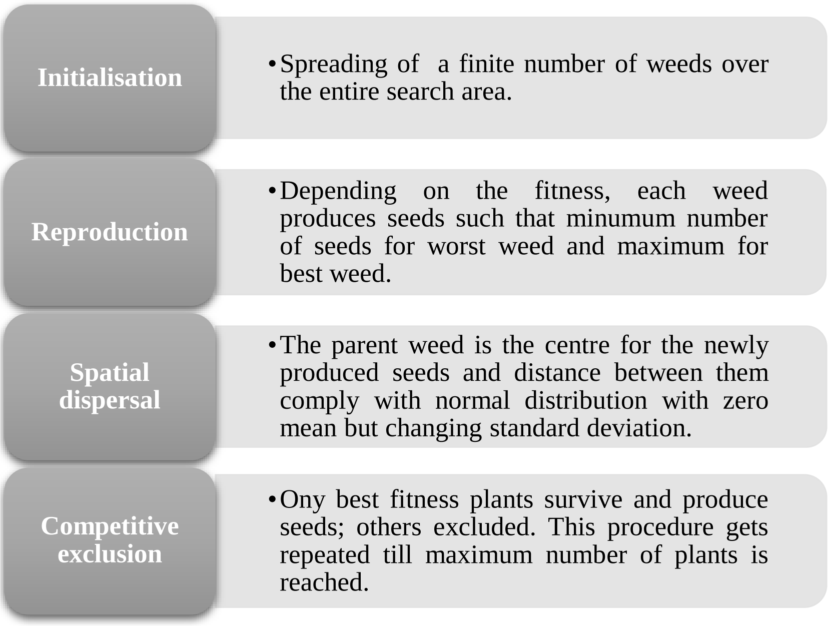
Figure 3.1. Functional block diagram of a PMU

equal phase shifting and attenuation, thus assuring the phase angle differences and relative magnitudes of the dissimilar signals are unchanged. The output analog signals of the anti-aliasing filters are sent to analog to digital converters (ADC), which convert the input analog quantities to a digital form proportional to the magnitude of the input quantities for sampling. The digital output of the ADC is fed to the phase locked oscillator whose output signal is kept locked (i) in phase with a reference signal from GPS receivers and (ii) in phase with another signal whose frequency is the same.

With the use of primary GPS receiver-clocks, PMUs mock-up synchronously at designated locations all over the grid, this offers a system-wide snapshot of the grid. The GPS affords time cataloguing for the measurements as well as confirming all phase angle measurements are synchronised at the same time. The phasor microprocessor computes the value of phasor then the computed phasors are transmitted to the appropriate remote locations over a modem.

3.3. Invasive Weed Optimisation

Weeds, the most forceful and vexatious flora in agriculture have strong properties, for instance, adaptation, heftiness, energetic and incursive. Based on those irrepressible properties of weeds, Mehrabian and Lucas [35] developed Invasive Weed Optimisation (IWO) by impersonating the biological activities of weeds in inhabiting and discovering the opposite abode for progress and replica. Since its beginning, IWO has been subject to several attempts at changes to the original technology, and some stimulating modifications have resulted [36-41]. Figure 3.2 presents the key steps involved in such an IWO technique.



Initialisation	Spreading of a finite number of weeds over the entire search area.
Reproduction	Depending on the fitness, each weed produces seeds such that minumum number of seeds for worst weed and maximum for best weed.
Spatial dispersal	The parent weed is the centre for the newly produced seeds and distance between them comply with normal distribution with zero mean but changing standard deviation.
Competitive exclusion	Ony best fitness plants survive and produce seeds; others excluded. This procedure gets repeated till maximum number of plants is reached.

Figure 3.2. Steps involved in IWO technique

3.4. User-defined Invasive Weed Optimisation

Though the IWO and its various modifications are in wide use today, the IWO process does results in premature convergence as other evolutionary computation algorithms do. To allow the best opportunity for ‘weeds’ to survive and produce more seeds, this research has introduced a user-defined PMU placement technique, [42] significantly overcoming the premature convergence issue. The proposed algorithm is suitable for renewable energy integrated Smart Grids as well as for conventional power systems.

As this research aims for the optimal placement of PMUs for Smart Grid observability, the discussion on system observability is included in section 3.4.1.

3.4.1. System Observability

The phasor measurement units are largely placed throughout the grid system especially at the buses and sub-stations as shown in Figure 3.3. The PMUs placed at these locations enable the measurement of voltage phasors and current phasors of the transmission lines to meet at that point of connection, making the entire grid system observable.

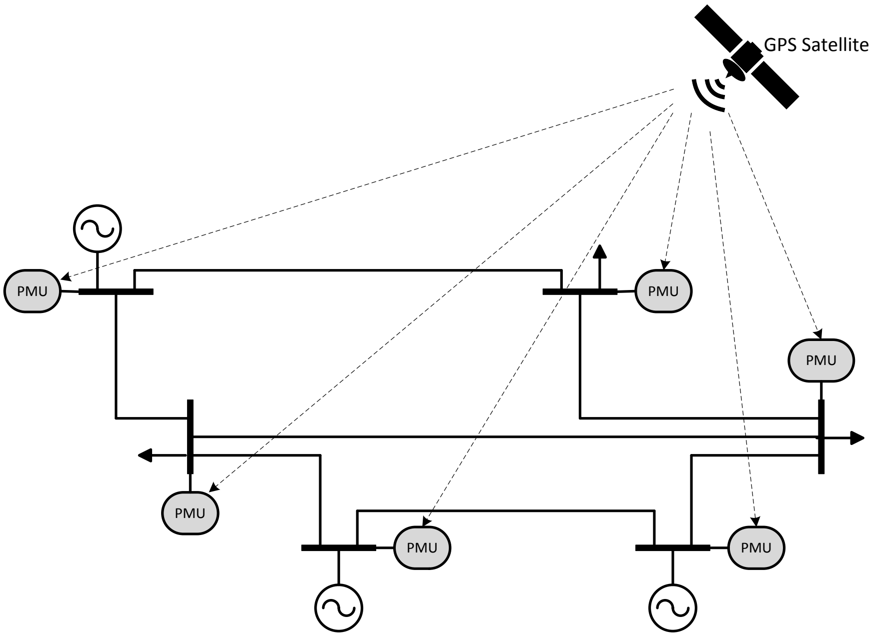


Figure 3.3. A 6-bus system with PMUs at all buses

If the voltage and phase angles are measurable directly at a PMU connected bus, then the bus becomes *directly observable*, whereas if the voltage and phase angles are measurable with the help of other PMUs, then the bus becomes *indirectly observable*. When there is no PMU at a bus and neighbouring buses, then such measurements are not possible on that bus, and the bus is considered *unobservable*.

In Figure 3.4, a single PMU is employed at bus 2 so the voltage magnitude and phase angle at that bus and the current through all the branches (2-1, 2-3, and 2-5) connected to it becomes measurable; hence, the bus 2 is *directly observable*. Voltage magnitude at buses 1, 3 and 5 are predictable using Ohms Law; hence, these buses are *indirectly observable*. Whereas, the voltage phasors at buses 4 and 6 are not assessable using a PMU at bus 2, so the buses 4 and 6 are *unobservable*. If all the buses in a power system are either directly or indirectly observable, then the system becomes *completely observable*. If some buses are directly or indirectly not observable, then the system becomes *partly observable*.

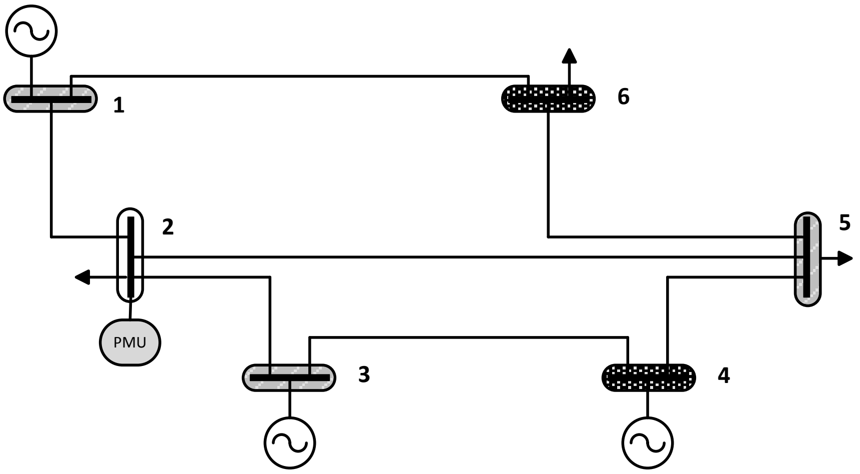


Figure 3.4. A 6-bus system observability with a single PMU

3.4.2. User-defined PMU Locations

The need for User-defined locations is based on the integration of renewable energy resources with a Smart Grid and its associated issues.

- The development of renewable energy technology is well advanced and is also becoming more cost-effective. Concern for the environment necessitates the introduction of green energy technologies in the electricity sector rather than relying on polluting fossil-fuelled energy sources.
- One of the objectives of introducing and developing a Smart Grid is to ease the challenges of incorporating renewable energy sources at a higher level of environmental friendliness, cost-effectiveness, and grid capacity extension with security and stability.
- Though wind and solar energy are abundant and freely available, the power generated from them is intermittent and unpredictable. The fluctuating power generated by a wind farm during a 24-hour period is shown in Figure 3.5 [125]. The variation in power output is found to range from a minimum of 1050 MW to a maximum of 3300 MW in a day. Hence, demand-side management becomes a problem even during normal operating conditions. In the case of a loss in wind power generation due to weather event, technical issue, or cyber-attack, then the stability of the grid becomes a serious issue, and may result in system blackouts. Hence, an effective real-time monitoring of the Smart Grid becomes acutely necessary; otherwise, the purpose of introducing Smart Grid is lost.

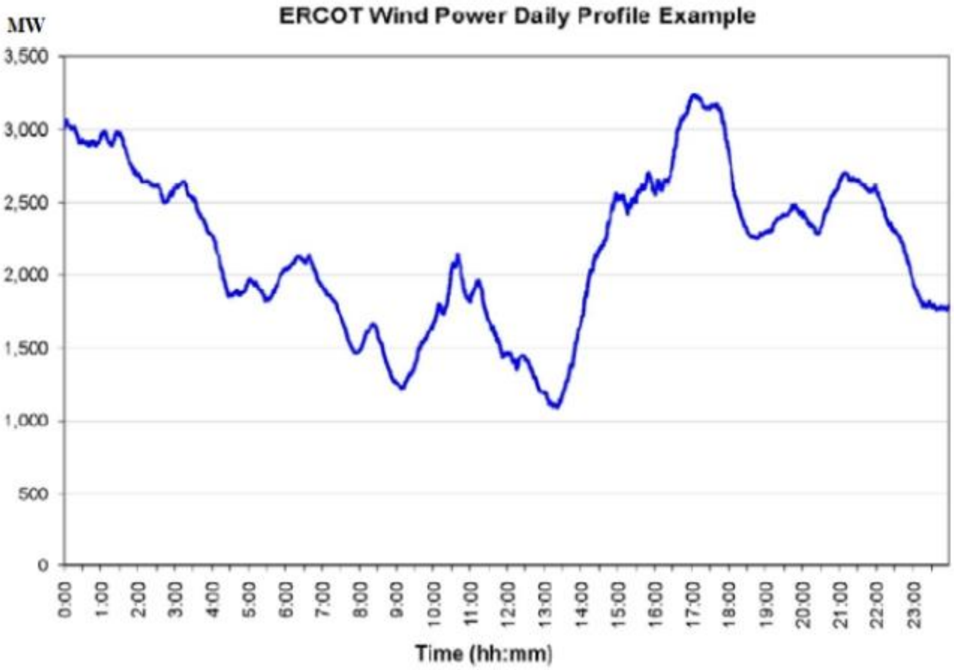


Figure 3.5. Wind power variation in a day [125]

- The distributed nature of the renewable energy systems such as wind is another critical issue. The reliability and the security of the radial lines connecting the RES to the main grid require a higher priority in real-time monitoring to avoid 'power islands', embedded generators and significant power backups.
- The unit cost of renewable energy is determined in a similar way as that of fossil fuels but must also consider the following aspects:

  Economic aspect - production cost, insurance and tax, land cost, the cost associated with transmission and distribution, life span, and payback periods etc.

  Social aspect - social awareness and involvement, employability of the society, and financial support from the society, and

  Technical aspect - type of renewable energy technology, capacity addition, opportunities for expansion, and room for government subsidiary, etc.

Considering all these aspects, the continued operation of renewable energy systems has become essential in order to provide low cost environmentally friendly energy for which real-time monitoring becomes mandatory.

To provide real-time monitoring of renewable energy integrated into a Smart Grid, the invasive weed optimisation algorithm for PMU placement [42] has been redesigned to require employment of PMUs at certain buses, irrespective of any financial burden, to accommodate renewable energy and intermittent resources, which introduce unique challenges to grid operations. While performing optimal placement of PMUs by IWO, the renewable energy and intermittent source connected buses are prioritised for PMU placement. The PMUs should be of a single-channel type to reduce the PMU installation costs. The remaining IWO algorithm is applied to the outstanding buses only, following the same basic sequential steps without the reproduction stage since the PMUs are to be installed at the same time. This new, original algorithm is presented in this research as the User-defined Invasive Weed Optimisation algorithm (UIWO). The proposed approach gives priority to optimal placement of PMUs in the Smart Grid's Cloud platform, which results in faster computing with less computational complexity and memory requirements.

3.4.3. User-defined Optimisation

For the user-defined PMU locations, the user directly identifies the buses with renewable energy and intermittent resources for PMU placements. Mathematically, the objective function is explained as:

$$x(i) = 1, \forall i \in renew\_bus \tag{3.1}$$

For the remaining n-buses, the optimal PMU placement is defined by the following objective function.

$$Min \sum_{i=0}^{n} w_i * x_i \tag{3.2}$$

$$subject\ to\ f(x) = A\,x \geq 1$$

where w_i is the cost associated with PMU placement at bus, i is defined related to the connectivity of buses as

$$w_i = \frac{(Total\ no.of\ buses - Total\ no.of\ connections\ of\ i^{th}\ bus)}{Total\ number\ of\ buses} \tag{3.3}$$

and

$\boldsymbol{f(x)}$ represents the vector whose value is nonzero.

The matrix **A** represents the network connectivity given by

$$a_{ij} = \begin{cases} 1, & if\ either\ i\ and\ j\ are\ adjacent\ buses \\ 0, & otherwise, i.e.\ not\ adjacent\ buses \end{cases} \tag{3.4}$$

and

x_i, the elements of the binary decision variable are given by

$$x_i = \begin{cases} 1, & if\ \ a\ PMU\ is\ connected\ at\ bus, i \\ 0, & if\ no\ PMU\ is\ connected\ at\ bus, i \end{cases} \tag{3.5}$$

3.4.4. Solution Methodology

The User-defined Invasive Weed Optimisation algorithm is presented in Figure 3.6 in the form of a flowchart, which should be easy to implement in large-scale systems. The logical flow for optimal placements of the PMU by the UIWO strategy has been executed through the MATLAB and the generalised coding is given in Appendix – A1.

3.5. Applications to IEEE Test and Indian Utility Systems

The suitability of the suggested User-defined Invasive Weed Optimisation algorithm has been demonstrated through a modified IEEE 14-bus test system and a 62-bus Indian Utility Grid [126]. The outcome of the demonstration has been compared against the results of a reliable algorithm [35, 127] from the literature.

3.5.1. Modified IEEE 14-bus test system

Figure A2.1 shows the modified IEEE 14-bus test system incorporated with wind turbines at bus 8 (Appendix – A2).

The system specifications are shown in Table 3.1.

Table 3.1. Test system specifications

Test system	No. of zero injection buses	Buses with max. no. of lines	Max. no. of lines connected to a bus
IEEE 14 bus	1	4	5
Wind farms connected to bus 8			

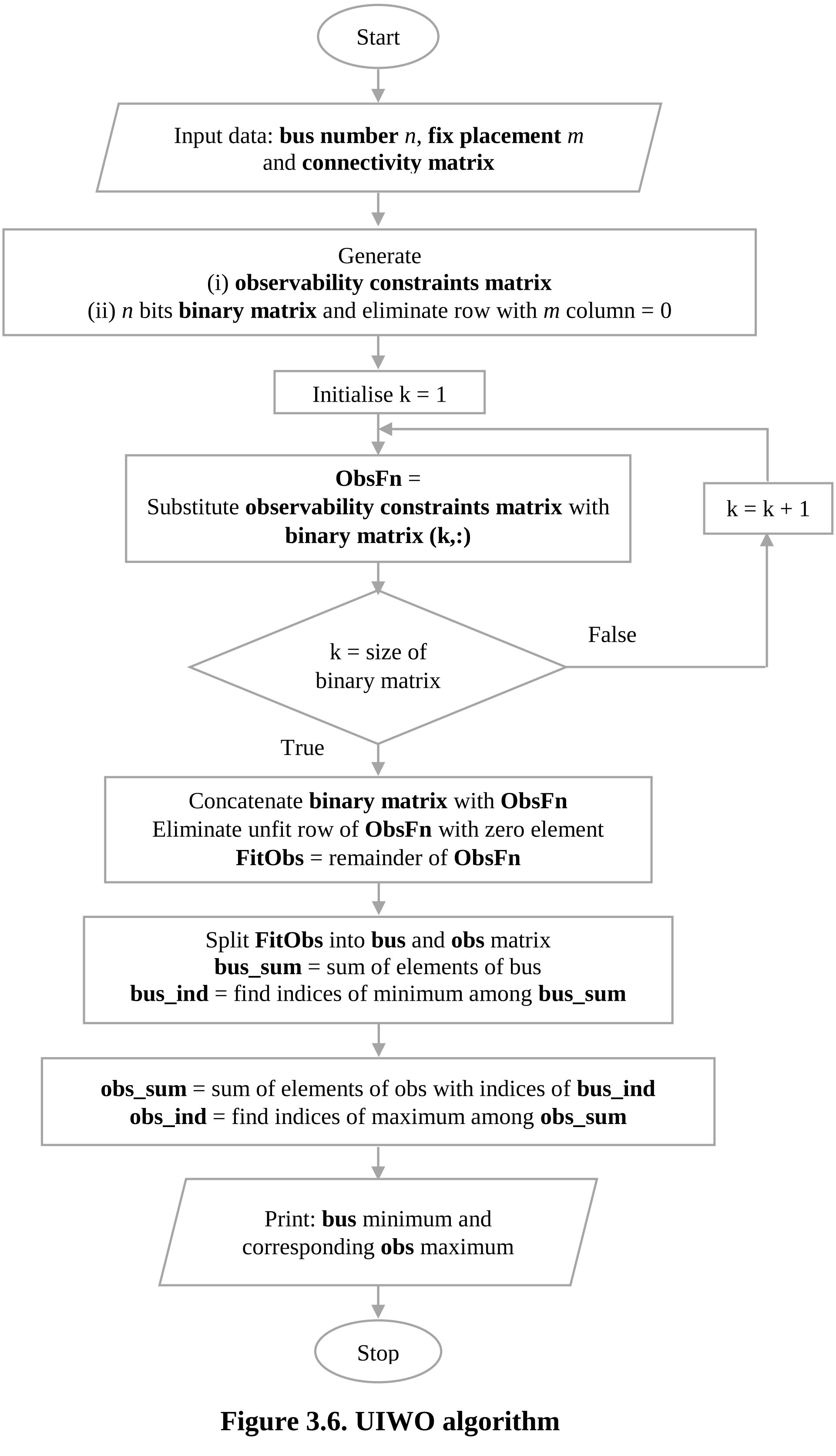


Figure 3.6. UIWO algorithm

The associated connectivity matrix (A) for the test system has been determined as:

$$\boldsymbol{A} = \begin{bmatrix} 1 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 & 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 1 & 0 & 1 & 1 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}$$

The constraints functions are:

$$\boldsymbol{f}(\boldsymbol{x}) = \begin{Bmatrix} x_1 + x_2 + x_5 \\ x_1 + x_2 + x_3 + x_4 + x_5 \\ x_2 + x_3 + x_4 \\ x_2 + x_3 + x_4 + x_5 + x_7 + x_9 \\ x_1 + x_2 + x_4 + x_5 + x_6 \\ x_5 + x_6 + x_{11} + x_{12} + x_{13} \\ x_4 + x_7 + x_8 + x_9 \\ x_7 + x_8 \\ x_4 + x_7 + x_9 + x_{10} + x_{14} \\ x_9 + x_{10} + x_{11} \\ x_6 + x_{10} + x_{11} \\ x_6 + x_{12} + x_{13} \\ x_6 + x_{12} + x_{13} + x_{14} \\ x_9 + x_{13} + x_{14} \end{Bmatrix} \geq 1$$

The MATLAB platform (Version R2014b) was used for the proposed optimisation. There was only one RES connected bus (i.e. bus 8) and it was identified as the user-defined PMU placement location as per the proposed logic. The User-defined Invasive Weed Optimisation strategy was applied to the remaining 13 buses for Phasor Measurement Units placement to achieve complete system observability. The optimal PMU placements are shown in Figure 3.7 and their corresponding bus observabilities are presented in Table 3.2. For comparison purposes, the optimal solution has been obtained without any user-defined bus location and the outcome is shown in Table 3.3 [35, 127]. From the results of Tables 3.2 and 3.3, the buses 2, 6 and 9 were found to be the optimal locations for PMU placement in both cases. Bus 8

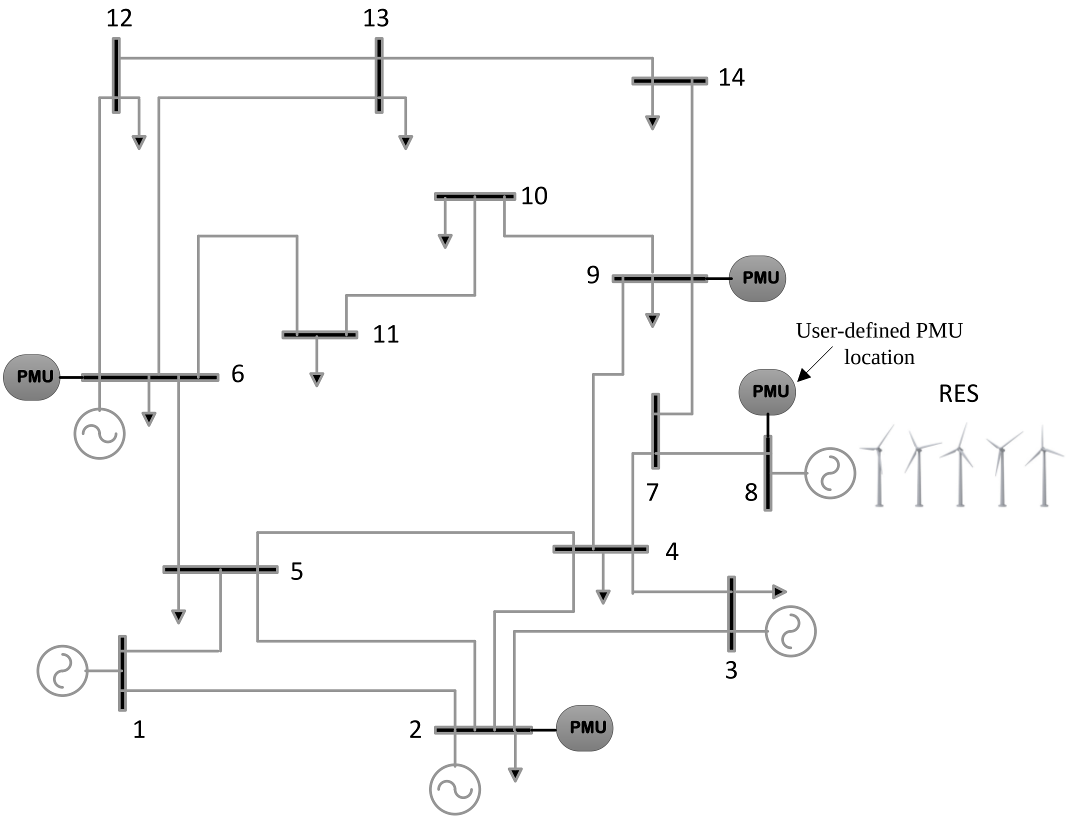


Figure 3.7. Optimal PMU placement by UIWO

was the user-defined one and bus 7 was the optimal location (instead of bus 8) in the nonuser-defined condition. The user-defined location (bus 8) was more appropriate than a PMU at bus 7 since the respective PMU at bus 8 responded to the frequent time-varying data of the intermittent renewable energy sources instantly and met the contractual agreement while integrating a renewable energy system into the Smart Grid. Renewable energy sources are generally in remote areas subject to cyber-attacks and energy theft. A PMU at this type of bus reflects the real-time situation for security, stability, and load balancing tasks with a very high data-reporting rate. As far as observability is concerned, all the buses were found to be fully observable as seen in Tables 3.2 and 3.3. The buses 4, 5 and 7 were observed more than once in the UIWO algorithm whereas buses 4, 5, 7 and 9 were observed more than once in the IWO algorithm. The cost of the PMUs placed at buses 2, 6 and 9, in both conditions, remained the same.

The cost of a PMU at the user-defined location (bus 8) was cheaper by $ 6000 [128] (since it was a single-channel type) than the three-channel type of PMU located at bus 7. The computation time of the UIWO algorithm was 13.304s, whereas for the other IWO algorithm the time was 60.134s. That means the User-defined IWO algorithm was much faster than the original IWO algorithm, and it took only 22.12 % of the time taken by the IWO algorithm. A Cloud computing platform was used for the optimisation.

Table 3.2. User-defined optimal PMU placement and bus observability

Bus No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Solution Time (s)**
PMU placement	0	1	0	0	0	1	0	1	1	0	0	0	0	0	13.304
Bus Observability	1	1	1	2	2	1	2	1	1	1	1	1	1	1	

Table 3.3. Optimal PMU placement and bus observability by IWO [35, 127]

Bus No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**Solution Time (s)**
PMU placement	0	1	0	0	0	1	1	0	1	0	0	0	0	0	60.134
Bus Observability	1	1	1	3	2	1	2	1	2	1	1	1	1	1	

3.5.2. Indian Utility system

As of March 31, 2017, the total installed capacity of wind turbine energy in India was 32380 MW. The cited 62-bus grid [126] is in the southern state of Tamil Nadu, India, which has a total installed energy capacity of 21,701 MW, out of which 7870 MW is produced by wind energy. That means wind power has a significant share of around 36 % in the state grid. Hence, to maintain a reliable power supply the state requires the wind power. The wind farms are scattered throughout the 62-buses and only two locations (buses 9 and 34) were chosen for analysis as the user-defined locations. Bus 9 related to a single transmission line whereas five transmission lines were connected to bus 34. Bus 9 is in an isolated location and it is very remote from the other parts of the grid. Moreover, it is connected to the grid through a single radial line, which necessitates a higher priority in real-time monitoring to avoid the ‘power islands’ effect, embedded generators and significant power backup. The PMU placement optimisation was conducted without the zero-injection bus effect. The specifications of the grid are shown in Table 3.4. The outcome of the UIWO optimisation with the optimum number of PMUs required, the total number of PMU channels required and the solution time are presented in Table 3.5. The proposed method resulted in 17 PMUs with a total number of 52 PMU channels and a solution time of 9.816s. Whereas, the IWO method required only 16 PMUs but with a higher number of total PMU channels. The additional five channels boosted the PMU cost by $ 15,000 in installation costs. The UIWO method's solution time was much faster than the IWO approach and it took only 67 % of the computation time as the IWO approach. The PMU placement for complete system observability by the UIWO and IWO approaches are shown in Figures 3.9 and 3.10.

Table 3.4. 62-bus Indian utility grid specifications

Test system	**No. of zero injection buses**	**Buses with max. no. of lines**	**Max. no. of lines connected to a bus**
62-bus Indian Utility Grid	14	10	7
Wind farms connected buses chosen for testing: Bus 9 & 34			

Table 3.5. 62-bus Indian utility grid optimal PMU placements

Method	**PMU locations**	**Total number of PMU channels required**	**Solution time (s)**
Proposed UIWO	17 PMUs at buses 2, 8, 9,10,14, 20, 21, 25, 30, 34, 36, 42, 45, 48, 53, 58, 59	52	9.816
IWO [35, 127]	16 PMUs at buses 1, 3, 8, 12, 14, 21, 25, 30, 34, 41, 42, 46, 50, 51, 56, 61	57	14.609
Wind farms connected buses chosen for testing: Bus 9 & 34			

While considering the PMU placement at bus 9 using the UIWO approach (Figure 3.8), the real-time monitoring of the RES available at the bus was greatly ensured since the PMU placed at this bus was exclusively dedicated for that purpose. Moreover, there was only one tie line associated with bus 9, a single channel PMU was sufficient; hence, more cost effective. When using the IWO optimisation method (Figure 3.9), there was no PMU placement at bus 9; instead, a PMU was placed at bus 1. The bus 1 is a major node with six transmission lines connected to it. Hence, the PMU had to be a multi-channel type, which was a more expensive affair. The real-time monitoring of the RES at bus 9 had to be done by the PMU placed at bus 1. Under such situations, the measurement redundancy becomes questionable if the PMU at bus 1 fails. A good degree of measurement redundancy improves the system observability and is important for a reliable power system in the state estimations.

As far as the RES connected bus 34 was concerned, both of the methods suggested a PMU placement at this bus. Therefore, the PMU placement cost, inclusive of the multi-channel unit cost, procurement cost, and installation cost remained the same. In this case, the user-defined location (bus 34) had become the optimum location determined by the IWO approach. The solutions of both methods showed buses 8, 14, 21, 25, 30, 34 and 42 as optimal locations for PMU placements. The other PMU locations were unalike in both cases. In this UIWO optimisation strategy, not all of the zero-injection bus effects were considered. If the zero-injection bus effects were considered, then the total number of PMUs required would be reduced.

Cloud computing was used for the optimal placement of PMUs through grid communication and information management, optimisation of the communication systems in terms of energy used by proper choice of computing devices, and performing the optimisation following the UIWO logic provided.

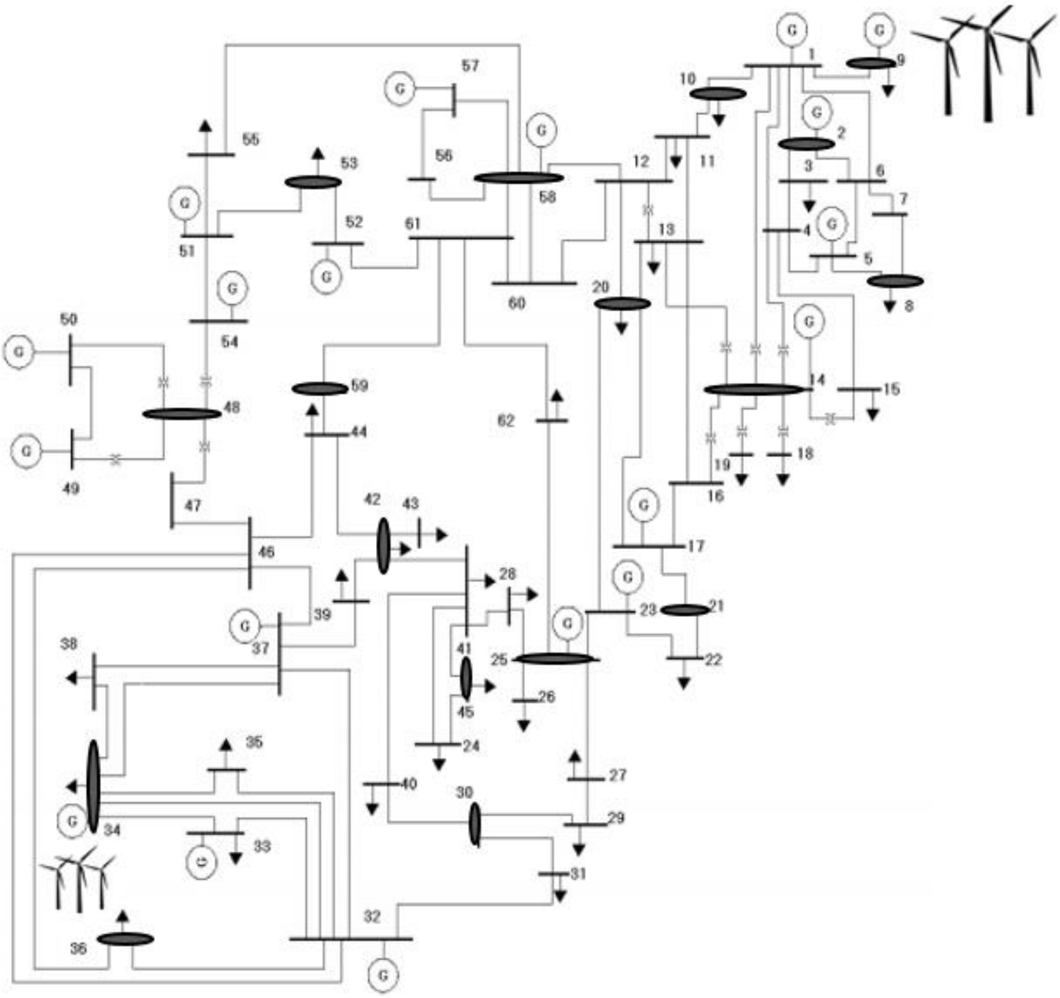


Figure 3.8. 62-bus Indian utility grid optimal PMU placements by UIWO

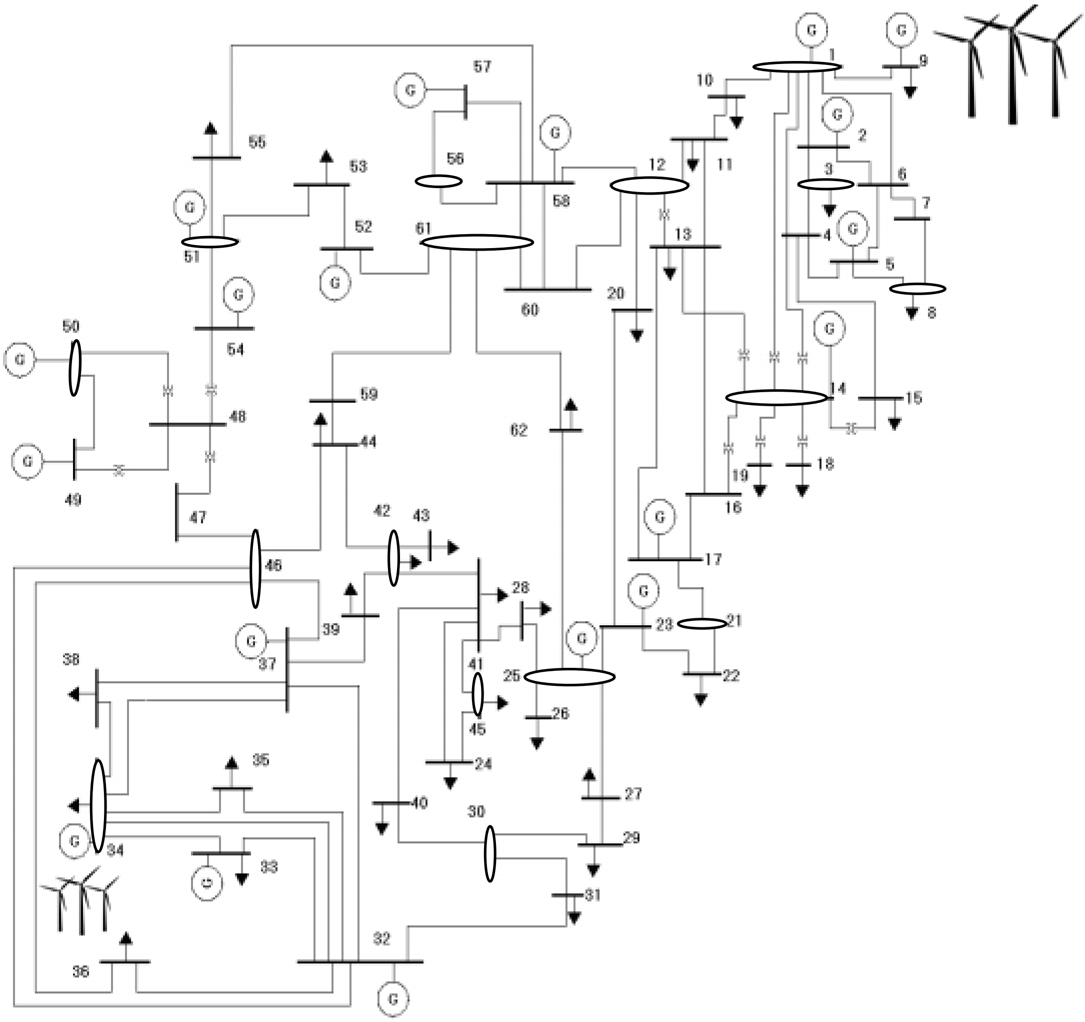


Figure 3.9. 62-bus Indian utility optimal PMU placements by IWO strategy

3.6. Conclusions

As the geographical location of renewable energy resources such as wind and solar power plants are scattered all over the Smart Grid, the real-time monitoring of a Smart Grid has become a significant asset. The existing monitoring and observation systems have technical constraints and are unable to cope with the ever-changing renewable energy systems integrated with the Smart Grid, and they need improvements. Therefore, to ensure the real-time monitoring of the Smart Grid, Phasor Measurements Units should become standard equipment in grid operations. The placement of such PMUs is an expensive undertaking and a cost-effect placement technique becomes critical. This research proposed a new User-defined Invasive Weed Optimisation strategy for the cost-effective placement of Phasor Measurement Units in a Smart Grid for complete observability. Thus by the proposed optimisation strategy, (i) the research gap to monitor Smart Grid performance has been fulfilled, (ii) the question 1.7 (a) how to enhance the performance of Smart Grid at a real-time basis and

(iii) question 1.7 (b) how to overcome the security and stability challenges on incorporating renewable energy sources in Smart Grids by an economical manner have been answered, and (iv) the research objective 1.8 a) (i) enhancing the performance of the Smart Grid by an appropriate PMU placement strategy has been achieved.

To ascertain the appropriateness of the proposed strategy, a modified IEEE 14-bus test system and a 62-bus Indian Utility Grid were identified as the platform for testing. The optimisation outcome has been compared with a proven algorithm. Both of the test results were of comparable values and the proposed method seems to be much faster and more cost-effective. The proposed strategy should be extended to other energy systems to consider the effects of zero-injection buses, single-line outage, and PMU failures in the future.

Chapter 4

WIRELESS COMMUNICATION FOR SMART GRID DATA AND QUERYING

The previous chapter described the primary functions of Phasor Measurement Units in a Smart Grid and subsequently an algorithm for their optimal placement to observe the grid completely. The data gathered by the PMUs deployed over the entire grid would need to be aggregated, stored and disseminated to control centres, utility stakeholders and consumers to enact appropriate measures based on the data. Therefore, to provide an additional solution to the research question 1.7 (a) and to achieve the research objective 1.8 a) (ii) wireless communication tactics for data dissemination and querying, this chapter presents a wireless communication technology suitable for Smart Grids for data dissemination and querying to enhance the performance of Smart Grid at a real-time basis when data collection and dissemination are limited.

4.1. Phasor Data Concentrators

In an electric utility, for effective and reliable functioning, several Phasor Measurement Units can be employed at appropriate buses and from each PMU, rich data such as output voltage, current, their respective phase angles, and frequency rate-of-change are available. The ample data generated by the PMUs are transferred through a Wide-Area Network (WAN) to one or more Phasor Data Concentrators (PDCs) [43-48]. The PDC accumulates the synchronised phasor data and aligns it into a single data packet for each unique time stamp; it then forwards this data to various grid applications as shown in Figure 4.1. The data concentrator may also consist of other functions, such as system event detection and archive, data reprocessing for various applications, and data calibrations.

The PDC is unique in the sense that it collects data and synchronises it irrespective of the receiving time. Further, this technology helps in time alignment, translating, error checking, and modifying the data rate of multiple PMUs through minimum operating time and computing requirements. The PDC time should be coordinated to avoid inaccuracies initiated by the PMU, PDC, additional networks remoteness, and other communication timing concerns. After processing the measurement frames, the PDC forwards it to a SCADA for further observation and control purposes as well to supplement PDCs in other utility locations.

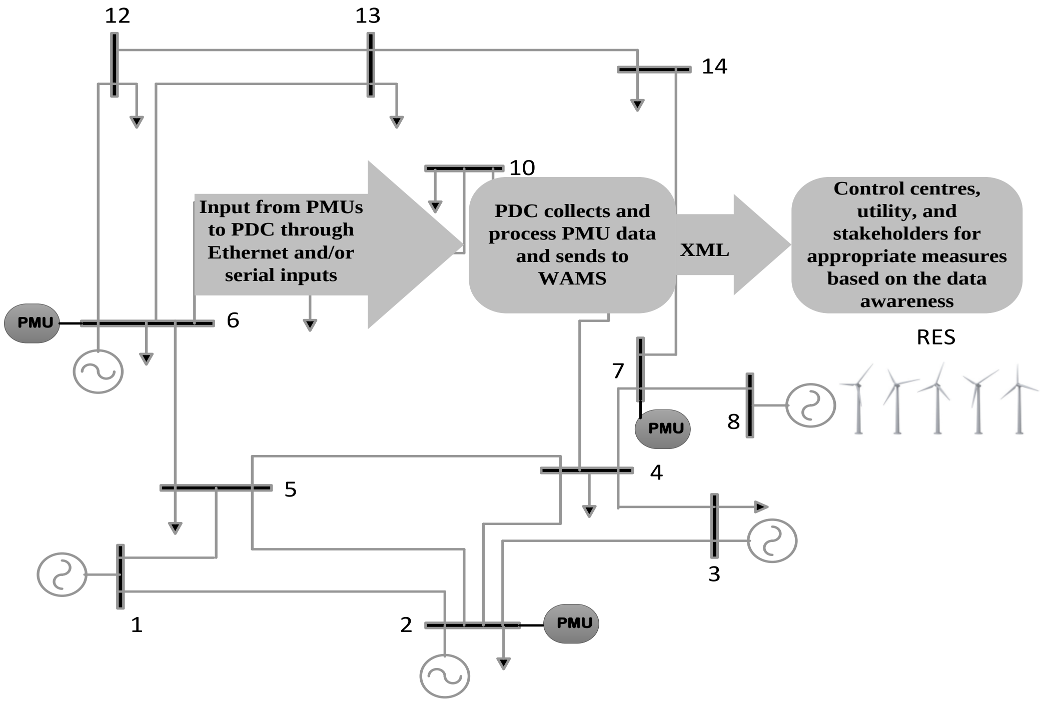


Figure 4.1. Phasor Data Concentrator Functions

4.2. eXtensible Markup Language (XML)

The output of the Phasor Data Concentrator travels to control centres, utilities, and stakeholders for appropriate actions for which a communication scheme becomes essential. The eXtensible Markup Language (XML) is a potential wireless broadcasting system for mobile devices [49]. It permits the mechanisms (both hardware and software) to communicate among themselves by eliminating the differences of registered codes of behaviour between networking, operating systems, and platforms. XML provides a responsive and easily explicable syntax for data interchange and can influence data definition and Web share. XML controls user-defined tags reassuring the separation of document content from its presentation and supports web information process and automation [50-53]. The extensive use of XML necessitates the firm requirement for prototypes and mechanisms for acquiring XML documents. While securing XML documents, addressing issues such as authenticity, integrity and confidentiality become mandatory.

As businesses and governmental administrations use XML effusively as a reference for document depiction and interaction on the Web, there is an essential need for the safe publishing of XML data over the Web [54, 55]. Publish/subscribe (pub/sub) has been a popular communication paradigm which provides customised notifications to users in a distributed environment [56]. The published messages in the XML format is an XML pub/sub system with supple document structures and queries on language-based XPath [57] or XQuery [58]. Two illustrations of XML data are presented in Figure B.1 (Appendix - B) to assist concept understanding. Most recent Internet applications use XML as an inter-application communication exchange format despite its heavy network bandwidth requirement [59, 60].

4.3. Wireless XML Stream

Energy management of the mobile clients is critical to maximise battery function while disseminating XML data. Wireless XML Streaming is an appropriate technique for broadcasting XML data over mobile environments for expeditious query processing by the client [61, 62].

A Wireless XML Streaming (XS) broadcast server parses the XML document and generates a MG-node (Modified G-node) for each element, which eliminates framework outlays of XML documents and permits mobile clients to download relevant data while query processing. The generated nodes are then combined to form an XML Stream. An active coding system known as Lineage Encoding [63] together with MG-node helps facilitate the assessment of predicates and twig patterns, complex search conditions, and queries over the stream.

To facilitate an effective communication in a safe, dependable, and improved manner, electric utilities need to understand the bilateral messaging network handling scheme to a dispersed data centre. In this respect, Cloud Computing is envisioned to perform in significant ways to promote the modernisation process of the existing Smart Grid. Moreover, Cloud Computing as an expertise platform promoted for empowering trustworthy and critical access to various computing resources has been identified as the environment for Wireless XML Streaming (XS) broadcast server installation.

4.3.1. MG-node

An MG-node, a streaming unit, makes use of the advantages of the structure indexing and attributes summarisation to assimilate appropriate XML elements as a group. It offers a means for the judicious contact of their attributes and text content during query processing. It consists of a Cluster Descriptor, Attributes Value List (AVL) and Text List (TL). The Cluster Descriptor (CD) is an array of indices intended for discerning access of a wireless XML stream. To identify the MG-nodes, the Node name and the Location path must be identified first. For retrieval of the subsequent

MG-nodes, their attribute values, text contents, the Child Index (CI), Attribute Index (AI), and Text Index (TI) are also required.

The time information such as the Stream Created Time and Expiry Time are used to calculate and indicate the expiration of the stream. Lastly, the Lineage Code (V, H) is applied to deal with axis and predicate conditions in the user's query. Figure 4.2 shows an example of the Cluster Descriptor of MG-node$_{cost}$.

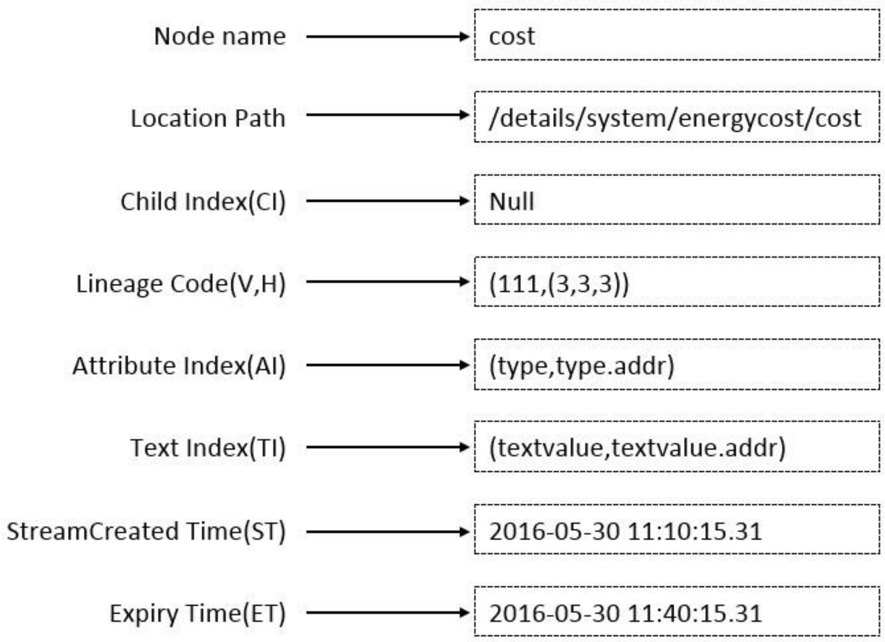


Figure 4.2. Cluster Descriptor

4.3.2. Attribute Value List and Text List

A structural characteristic exists in the elements of XML data with an identical tag name and location path frequently comprising the attributes of the same name. To make XML stream concise, attribute summarisation avoids repeated attribute names in a group of elements while producing a stream of MG-nodes. Figure 4.3 illustrates summarised Attribute for MG-node$_{system}$. The attribute summarisation generates the AVL, and then the AVL and TL stockpile the values of attributes and text contents of the elements denoted by the respective MG-node. The values of attributes and text are preserved in the documented order of elements.

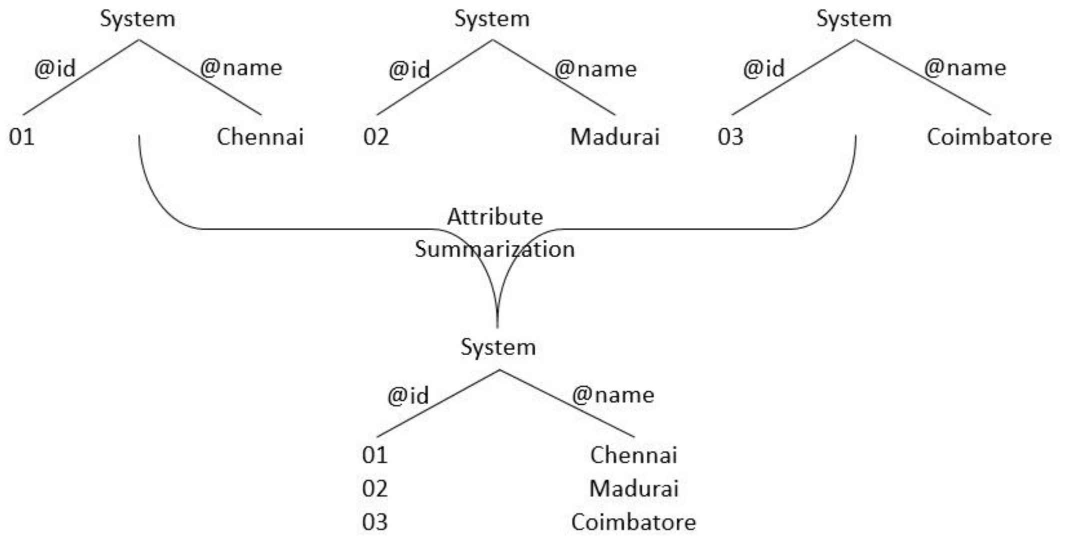


Figure 4.3. Attribute Summarisation

4.3.3. Wireless XML Stream Generation Algorithm

The server generates a wireless XML stream with the help of a SAX (Simple API for XML) parser, which calls appropriate content handlers while parsing an XML document. At the beginning of document parsing, related parameters are initialised by the stream generator. It then creates a new MG-node when a start tag of an element is identified, provided the MG-node is not available in the MG-node queue. Otherwise, the current element's attributes are inserted in the existing MG-node. If a text is detected in the element, then the stream generator inserts the TL of the relevant MG-node with text. At the end of the parsing, the stream generator produces the indices CI, AI and TI and the Lineage Codes (V, H), and subsequently inserts them into the respective MG-nodes, for dequeuing to form a wireless XML stream. Figure 4.4 shows the XML stream generation process.

4.4. Query Processing

For query processing, the mobile client must tune the broadcasting channel and retrieve the appropriate XML stream. To provide an economical and fast query processing, lineage code-based operators and functions such as SelectChildren, Shrink&Mask, Unpack, SelectParents, Pack, Expand&Mask, and GetSelectionBitStringOf must be provided. A counter-based algorithm along with the Distributed Cache Invalidation Mechanism (DCIM) [64] must be incorporated to deliver a high-speed response to the client which in turn decreases the complete query dispensation time.

Instead of caching all data items, the frequently accessed data items [65, 66] are cached in the Client Cache. The frequent access or queries are identified by a Counter-based algorithm, which tracks a subset of items from the inputs and observes counts related to them. For every new entrance, the algorithms resolve whether to preserve this item or not by comparing the item with the threshold value. Items that exceed the threshold value are considered frequent items and are cached in the caching node. To circumvent the maintenance of old data items in the client cache, only the active data items are retained and expired data items are discarded from the cache using DCIM.

Figure 4.5 shows the flow of query processing by the client. First, when a new query is submitted, it initialises *n* total of access count, as zero, T stored item, as Φ and CT as current system time. The overview of the Counter-based algorithm is to increase gradually the new item's counter, C if it is among the stored items T (comparing each new item against items in T). Otherwise, if there is some counter with a zero value, it is allocated to the new item, and the counter is set to 1. If there exists a counter with a zero value, the new item is merged with T, and the counter is assigned with a 1 value. The algorithm upon termination stores any item occurring more frequently than the threshold, K (round down of n/k times, where *k* stores values in a pair form (item, counter)). The items stored by the algorithm are the frequent items (queries). The frequent items are cached in CN, the caching node, until the current time, CT, exceeds the expiry time, ET. If the current time exceeds the expiry time, then the items in the caching node are grouped for invalidation and will be deleted. Otherwise, items will be retained in CN and return the result to the client either by processing the query or by fetching it from CN.

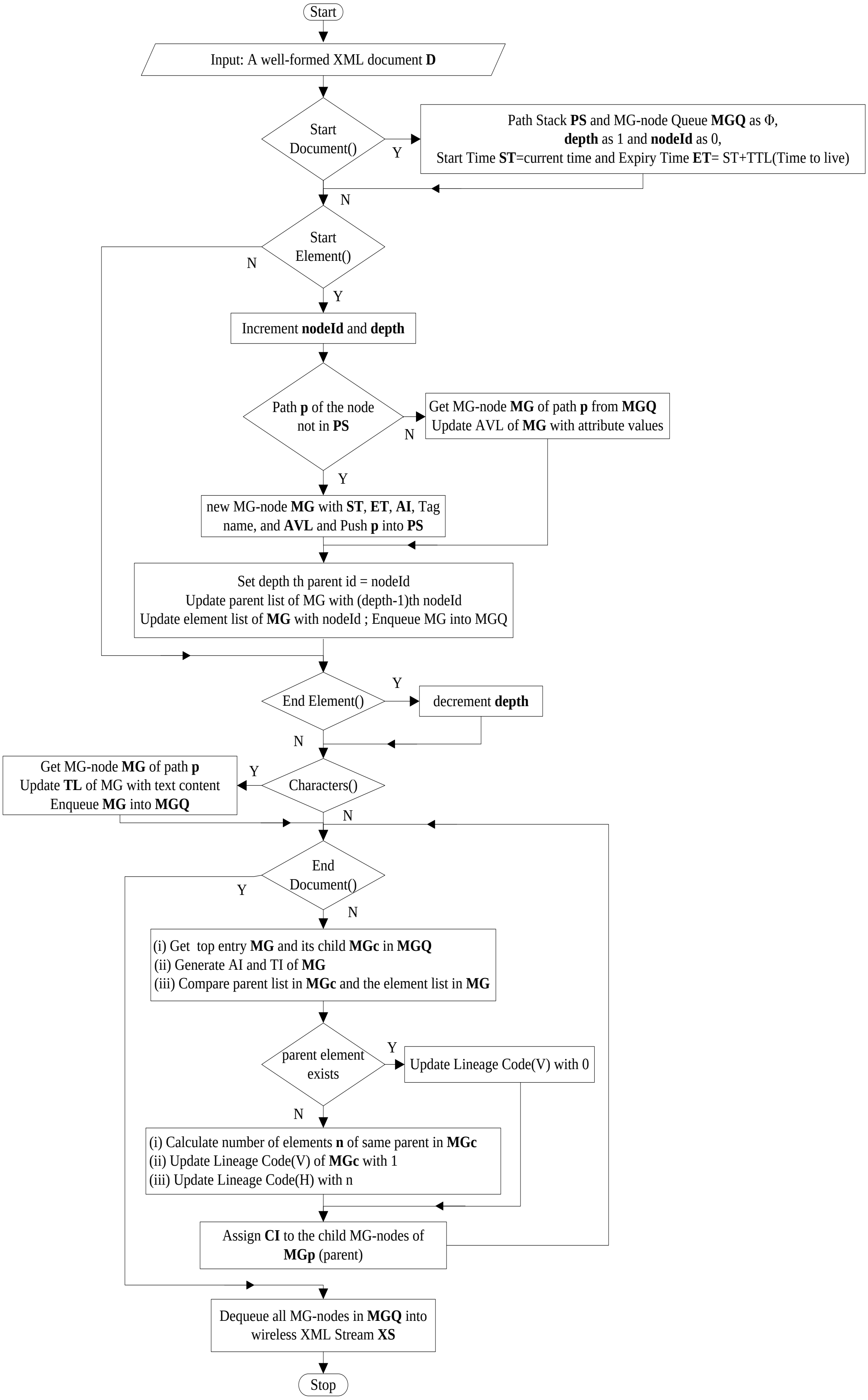


Figure 4.4. Algorithm for Wireless XML Stream Generation

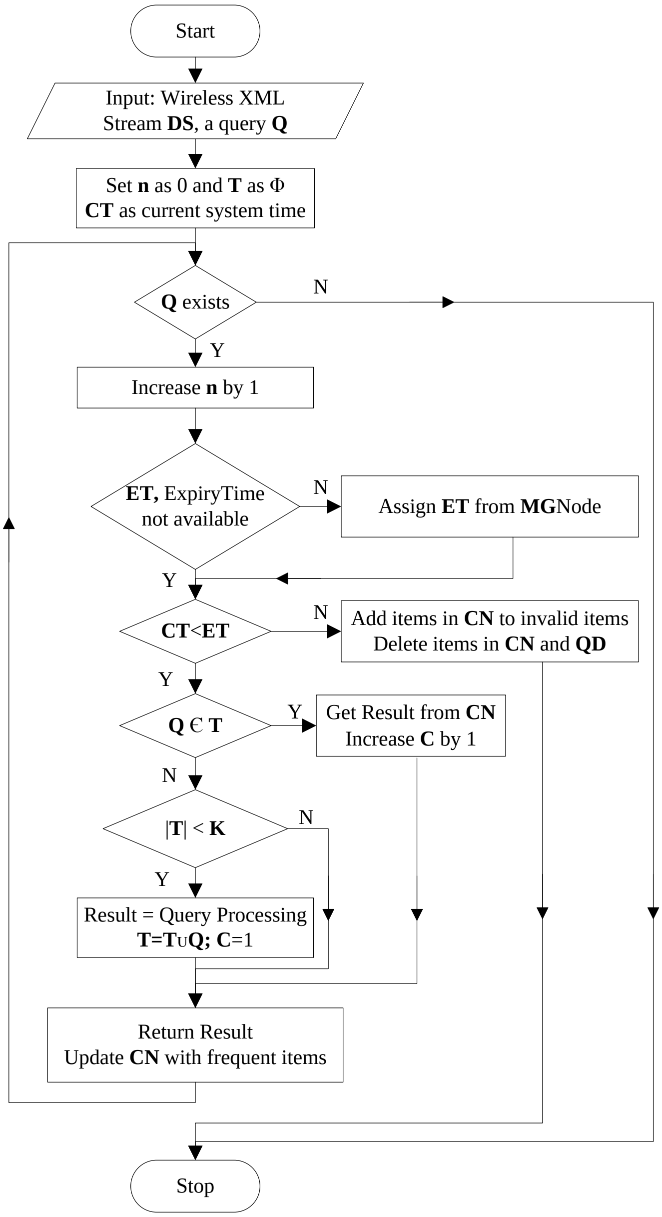


Figure 4.5. Query Processing

4.5. Experimental Evaluation

To assess the effectiveness of the suggested scheme, an experimental analysis on a system with features as:

an AMD FX-7500Radeon R7,

10 Compute cores 4C+6C

a 2.10 GHz processor, and

2 GB of main memory running on Windows 8,

has been conducted in Java using jre (Java runtime environment) 1.8.9_91 requiring system details as a real data set (Table 4.1). In this experiment, the objective was to determine how much time was needed to process and respond to user's queries.

Table 4.1. Data Set Used in the Experiment

Dataset	Elements	Attributes	Texts	Size	Max depth
System details	41	14	31	2.13 KB	5

4.5.1. Experimental Results on Real Data Set

Table 4.2 displays the features of streams produced by the proposed approach. The generation time signifies the necessary duration for producing a single broadcast stream for the specified XML documents, typically relying on the time consumed by index formation. The Lineage Encoding (LE) requires a more extensive production interval than PS and S-node approaches do since it involves a two-pass generation, i.e., one pass for MG-node creation and a second for the Lineage Code computation. As the broadcast server dispenses only the pre-generated XML stream, the generation cost is independent of the access time and tuning time.

The generation time depends on the Processor and RAM used for the program run. In addition, the generation time also hinges on the efficacy of the program developed and the time consumed by the index formation. Lesser computation time is preferred in query processing. Following the query processing logic developed (Figure 4.5) and executing the program on AMD FX-7500Radeon R7, 10 Compute cores 4C+6C, with 2.10 GHz processor, and 2 GB of main memory running on Windows 8, an attractive generation time of 2 ms as in Table 4.2 is achieved.

Table 4.3 illustrates the XPath queries used in this experimental analysis. Q1, Q2 and Q3 are the queries for examining a simple path query processing performance. Likewise, Q4, Q5 and Q6 are examples of twig pattern query processing. Q2, Q3, Q4, Q5 and Q6 are simple path queries concerning predicate and twig pattern query.

When a query is placed for processing, whether the query is present in the caching node or in the query directory, it is checked first. If not present in either, it then checks whether it is a simple path or a twig pattern query. It then executes the corresponding algorithm. A LE exhibits the best performance, access time and tuning time, since it produces the smallest data stream by removing laid-off tag names, attribute names, and dismisses query processing quicker as it circumvents tuning of needless data in the stream.

Table 4.2. System Details Data Streams Generated by the Considered Methods

Features	**LE**	
	No	**Size (Bytes)**
Tag names	15	121
Attribute names	14	159
Attribute values	41	303
Texts	31	264
Indexes		83
Total size		930
Generation time		2ms

Table 4.3. Test XPath Queries on the System Details Data Set

#	**Test Query**
Q1	/details/system/name
Q2	/details/system[@name="Chennai"]/schedule
Q3	/details/system/weather/temperature [@value="35"]/value
Q4	/details/system[name]/weather/wind
Q5	/details/system[name]/weather/temperature[@value="35"]/value
Q6	/details/system[demand]/weather[humidity]/wind

Figure 4.6 displays the query response time gain as compared to query processing without DCIM. The contribution of the Counter-based algorithm has a significant function here in identifying frequent queries. The frequency threshold considered was very quick and did not affect the update throughput. The space required by the algorithm was less than 1MB. The cost involved was almost the same cost as executing data of one kilobyte. This approximate size is small enough to fit within a modern second level cache. The query response time-gain is the time required to obtain the query response (measured from the time of issuing the query). In a DCIM, the frequently accessed queries are continually updated and can respond directly from the caching nodes (CN) whereas, in the absence of a DCIM, the client processes the queries by downloading the relevant information.

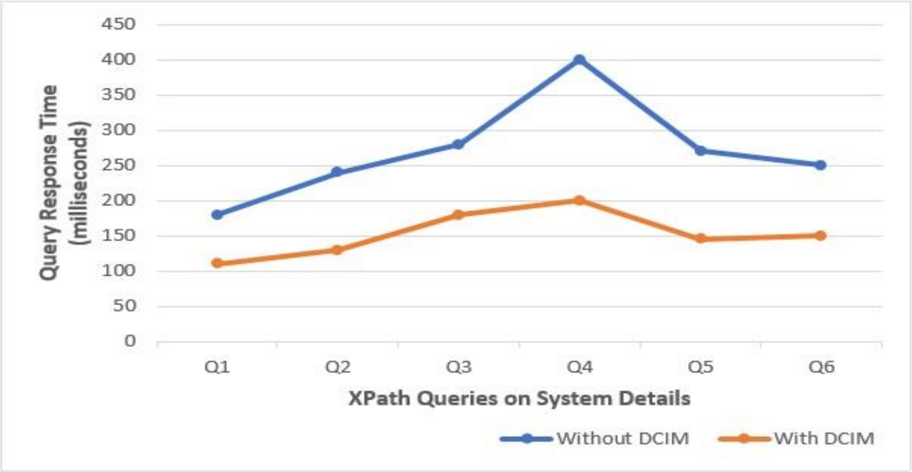


Figure 4.6. Query Response Time Gain on the System Details data set

4.6. Conclusions

A Smart Grid is an intelligent grid with bilateral interaction capabilities between the administrators and the end-users. One method for effective interaction is through communication; hence, this chapter presented a wireless communication technology for data dispensing and querying. The chapter began by explaining briefly the need for a PDC in a Smart Grid, its mechanisms and main tasks. Then a potential wireless broadcasting system suitable for mobile devices, XML was introduced. The XML involves both hardware and software for communication by eradicating the variances of registered codes of behaviour between networking, operating systems, and platforms. Subsequently, the MG-node recognised as an XML streaming unit, which has structure indexing and attributes summarisation tactics can assimilate appropriate XML elements as a group. To accommodate the mobile clients' query request, a fast and cost-effective Lineage code-based operators and functions have been incorporated. An efficient query processing logic has been presented in the form of flowcharts. To ascertain the efficacy of the schemes suggested, an experimental analysis was carried out and the outcome of this research confirmed the suitability of the proposed schemes for Smart Grid wireless communication. Thus, by the presented wireless communication tactics, the research question 1.7 (a) has been answered further and the research objective 1.8 a) (ii) wireless communication tactics for data dissemination and querying, has been achieved.

Chapter 5

ECONOMIC AND EMISSION CONTROL STRATEGY FOR SMART GRID

In a competitive energy market, an attractive unit cost of electricity generation and environmentally friendly has not been addressed effectively and efficiently, which is a research gap identified from the existing literature and available data. Also, the question 1.7 (c) - What is the best suited generation scheduling strategy to evade convergence issues and slowness in solution time, has not been answered yet.

To fill up the research gap (an attractive unit cost of electricity generation and environmentally friendly) and to provide a solution to the research question 1.7 (c), this research offers a direct optimisation technique [139] (to evade convergence issues and slowness in solution time) for power generation dispatching subject to system equality and inequality constraints. This research work achieves the research objective 1.8 (b) by providing an attractive price for environmentally benign energy, using the proposed non-iterative analytical strategy suitable for Cloud services in a Smart Grid.

A journal paper has been published (“Sustainable Economic and Emission Control Strategy for Deregulated Power Systems" International Journal of Energy Economics and Policy, 2017, 7(5), 102-110, Scopus Indexed, Quartile: Q2) based on the outcome of this part of research.

5.1. Introduction

The increasing awareness of the ecological impact and carbon footprint of electric power generation has provided the reasoning for the development and promotion of renewable energy. The emergence of electric power system deregulation [129, 130] and the move away from the vertically integrated utility business model are additional significant advancements in the electric power industry. The advent of the Smart Grid [131] is an improvement not only to humanity but also to all who are acquainted with the electric power industry, its end-users, and various stakeholders. The introduction of a Smart Grid has added benefits in energy production costs through work force optimisation, refurbished maintenance strategies and tactical scheduling fuel procurement, to mention the most obvious.

Due to substantial consumer receptiveness for clean electrical energy, power suppliers must now regulate their emissions in order to meet the stipulated ecological requirements; hence, a few operating schemes have been industrialised over time. The incorporation of renewable energy sources, installation of effective GHG controllers, implementation of fuel-switching generation strategies, revamping of inefficient power producing plants, and emission constrained power dispatch are some of the tactics in practice today [132-137]. Among the list of strategies above, the emission constrained generation scheduling option is one of the most economical and energy efficient [138].

This research offers a direct optimisation technique [139] for power generation dispatching of Smart Grids to enhance performance in terms of costs and environmental credits subject to system equality and inequality constraints. Additionally, this technology considers power losses a crucial factor in operating costs due to its considerable magnitude and the difficulty in identifying the share of the generating plants power demand needed for network losses. Hence, this section of the research introduces a first-hand approach [139] to address transmission losses in a practical way while generation dispatching on the Cloud platform. This is a unique approach of pricing the power losses considering fuel prices escalating.

5.2. Problem Formulation

5.2.1. Transmission Loss Constraints

The major constituent of power generation costs is the input fuel cost and following closely is the costs related with incurred power losses. The power losses increase generation costs by 6.8 % and the energy costs delivered to the consumers' terminals by 25 % [136]. These losses are inevitable but controllable to exploit the increase in production as well as energy delivered costs.

Fewer power transmission losses decrease the power generating costs with a progressive impact on company finances and an improved lifespan of the Smart Grid. This strategy to lower transmission losses diminishes the grid's peak power demand and the energy requirement of the grid when the unit cost of energy production is normally the greatest. The losses during these periods additionally have a notable financial effect since peaking power plants are required to meet the rise in demand, which is usually very expensive compared to base-load power plants. A slight decrease in network losses adds substantial monetary benefits to energy producers as well as to energy consumers. The influence of power losses on the merit order loading of the generating units is also substantial. In addition, while achieving economic power dispatch, a decrease in power losses affects the generation costs of associated generators; hence, their economic ranking becomes more attractive.

The sharing of transmission losses amongst different loads and generating units is a complicated task. It is challenging to resolve which generator or load is responsible for the power loss in a particular transmission line and the cross-term associated with the quadratic loss function will not allow allocating straight losses to generators and end-users. To evaluate the influence of grid power losses, these losses must have a significant cost on the energy supply and must be tackled like other supplementary costs, and considered in the Smart Grid energy production cost fixation on a time-of-use pricing basis. Thus, the need of an effective mechanism for the allotment of power loss is apparent. This section of the paper targets the evaluation of each generator share on the incurred network losses. A practical way of accomplishing this is assigning a cost to the power losses in terms of a variable conversion factor, ɣ depending on the energy operating costs or the fuel costs. For instance, if ɣ equals 1.0 then this means the losses are charged at the same rate as the production costs (i.e. fuel cost).

5.2.2. Individual Plant Generation

For a specified arrangement of prevailing as well as newly incorporated generators, if neglecting transmission losses, the optimisation strategy for economic power dispatch is stated as

$$\phi = Min \sum_{i=1}^{n} F_i \quad \$/h \tag{5.1}$$

The fuel costs or the generation costs (\$/hr.) of a generator, i is specified by a quadratic function in terms of its power generation, P_i as:

$$F_i = a_i\, P_i^2 + b_i\, P_i + c_i \qquad \$/h \tag{5.2}$$

The power transmission losses are usually expressed through transmission loss B-coefficients [137].

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i\, B_{ij} P_j \qquad MW \tag{5.3}$$

The allied power loss, P_{Li} with generator i, and its associated link is specified by

$$P_{Li} = {P_i}^2 \left(B_{ii} + \sum_{i \neq j} B_{ij} \alpha_{ij} \right) + P_i \left(\sum_{i \neq j} B_{ij} \beta_{ij} \right) \quad MW \tag{5.4}$$

where $\alpha_{ij} = \frac{a_i}{a_j}$; $\beta_{ij} = \frac{b_i - b_j}{2a_j}$

The power loss can be converted to a cost factor through the newly defined variable conversion factor, ɣ. For generator, *i* the general form of power loss (F_{Li}) is

$$F_{Li} = \Upsilon {P_i}^2 \left(B_{ii} + \sum_{i \neq j} B_{ij}\alpha_{ij} \right) + \Upsilon P_i \left(\sum_{i \neq j} B_{ij}\beta_{ij} \right) \$/hr \tag{5.5}$$

To determine the fixed price of the competitive energy market, transmission losses are charged at the production cost of energy (or the rising fuel cost on the day of dispatch) in this study; hence, Υ equals 1.0. Therefore, (5.5) takes the form

$$F_{Li} = {P_i}^2 \left(B_{ii} + \sum_{i \neq j} B_{ij}\alpha_{ij} \right) + P_i \left(\sum_{i \neq j} B_{ij}\beta_{ij} \right) \$/hr \tag{5.6}$$

Combining (5.2) and (5.6) results in the power production cost of generator i, (F_{it}) as in (5.8).

$$F_{it} = F_i + F_{Li} \tag{5.7}$$

$$F_{it} = \left(a_i + B_{ii} + \sum_{i \neq j} B_{ij}\alpha_{ij} \right) {P_i}^2 + \left(b_i + \sum_{i \neq j} B_{ij}\beta_{ij} \right) P_i + c_i \quad \frac{\$}{hr} \tag{5.8}$$

Then

$$\frac{dF_{it}}{dP_i} = 2\left(a_i + B_{ii} + \sum_{i \neq j} B_{ij}\alpha_{ij} \right) P_i + \left(b_i + \sum_{i \neq j} B_{ij}\beta_{ij} \right) = \lambda \quad \$/MWh \tag{5.9}$$

From (5.9), the individual plant generation, P_i(MW) in terms of λ($/MWh) is achieved as

$$P_i = \left[\lambda - \left(b_i + \sum_{i \neq j} B_{ij}\beta_{ij} \right) \right] \Big/ 2\left(a_i + B_{ii} + \sum_{i \neq j} B_{ij}\alpha_{ij} \right) \quad MW \tag{5.10}$$

5.2.3. Economic Control

This approach aims at decreasing the energy production costs of the contributing generators (prevailing and new additions). There are several traditional tactics [69-74, 134, 136] currently to solve economic dispatch problems. As the demand changes (commonly, every 20 minutes), the dispatching outcome should be sufficiently fast to implement the generation schedule. However, the existing methods suffer from delivering output slowly since they need to replicate the vast time-consuming dispatching. Hence, this research proposes a fast and non-iterative analytical approach to achieve a competitive unit energy cost in the Smart Grid environment [139].

The objective function for economic dispatch in (5.11) is optimised subject to power balance, transmission power loss, and generator capacity constraints.

$$\phi = Min\sum_{i=1}^{n} F_{it} \qquad \$/hr \tag{5.11}$$

(i) *Power balance constraints*

$$\sum_{i=1}^{n} P_i = P_D + \sum_{i=1}^{n} P_{Li} \quad MW \tag{5.12}$$

(ii) *Transmission loss constraints*

$$P_{Li} \le P_{Limax} \quad MW \tag{5.13}$$

and

(iii) *Plants capacity constraints*

$$P_{imin} \le P_i \le P_{imax} \tag{5.14}$$

Substituting the values of P_i from (5.10) and P_{Li} from (5.4) in (5.12) and simplifying:

$$\begin{aligned}\lambda^2 \sum \frac{B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}}{4\left(a_i + B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}\right)^2} \\ + \lambda \sum \left\{ \frac{\sum_{i\neq j} B_{ij}\beta_{ij} - 1}{2\left(a_i + B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}\right)} \right. \\ \left. - \frac{\left(B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}\right)\left(b_i + \sum_{i\neq j} B_{ij}\beta_{ij}\right)}{2\left(a_i + B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}\right)^2} \right\} \\ + \sum \left\{ \frac{\left(B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}\right)\left(b_i + \sum_{i\neq j} B_{ij}\beta_{ij}\right)^2}{4\left(a_i + B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}\right)^2} \right. \\ \left. + \frac{\left(b_i + \sum_{i\neq j} B_{ij}\beta_{ij}\right)\left(1 - \sum_{i\neq j} B_{ij}\beta_{ij}\right)}{2\left(a_i + B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}\right)} \right\} + P_D = 0\end{aligned} \tag{5.15}$$

Eqn. (5.15) is of the form: A λ^2+ B λ + C = 0 where

$$A = \sum \frac{B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}}{4\left(a_i + B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}\right)^2}$$

$$B = \sum \left\{ \frac{\sum_{i\neq j} B_{ij}\beta_{ij} - 1}{2\left(a_i + B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}\right)} - \frac{\left(B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}\right)\left(b_i + \sum_{i\neq j} B_{ij}\beta_{ij}\right)}{2\left(a_i + B_{ii} + \sum_{i\neq j} B_{ij}\alpha_{ij}\right)^2} \right\}$$

and

$$C = \sum \left\{ \frac{\left(B_{ii} + \sum_{i \neq j} B_{ij}\alpha_{ij}\right)\left(b_i + \sum_{i \neq j} B_{ij}\beta_{ij}\right)^2}{4\left(a_i + B_{ii} + \sum_{i \neq j} B_{ij}\alpha_{ij}\right)^2} + \frac{\left(b_i + \sum_{i \neq j} B_{ij}\beta_{ij}\right)\left(1 - \sum_{i \neq j} B_{ij}\beta_{ij}\right)}{2\left(a_i + B_{ii} + \sum_{i \neq j} B_{ij}\alpha_{ij}\right)} \right\} + P_D$$

Moreover, there are two distinct values for λ as the solution

$$\lambda = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \quad \$/MWh \tag{5.16}$$

The solution of (5.16) provides a negative and a positive value. As the incremental cost of received power, λ is unlikely to have a negative value, the more realistic positive figure is considered. Once λ is known, (5.10) provides the various plant generation, P_i $(i = 1\ to\ n)$. When the plant generation is known, then the transmission losses of the various generators are determined by (5.4) and the generation costs by (5.2). This proposed direct analytical approach is dependable and appropriate for any size Smart Grid.

5.2.4. Emission Control

A minimum energy cost mechanism cannot be the only motive of supplying energy if society is to have an uncontaminated environment. As a Smart Grid is an environmental friendly energy provider, the associated power plants need to reduce their emissions by both incorporating progressive capture and storage of the emissions in their energy production process or through a regulating and functioning administration. Apart from these tactics, generation dispatch is an effective operational arrangement to control power plant emissions in Smart Grids.

The emission dispatch also makes use of a similar objective function as economic dispatch but with different coefficients as seen in (5.17) and (5.18).

$$\Psi = Min \sum_{i=1}^{n} E_i \quad kg/h \tag{5.17}$$

The emissions of the generator, *i* is characterised by a quadratic form of its real power generation as:

$$E_i = d_i P_i^2 + e_i P_i + f_i \quad kg/h \tag{5.18}$$

There is no change in the optimisation strategy. The difference lies only in the objective function elements. That is, instead of the cost coefficients in (5.2), equation (5.18) has emission coefficients depending upon the fuel type and generator characteristics. The eco-friendly optimisation approach provides cleaner energy at an enhanced energy cost.

5.2.5. Combined Economic and Emission Control

The separate economic and emission dispatch approaches are of a conflicting nature: (a) competitive energy costs by economic dispatch and (b) eco-friendliness by emission dispatch. It is unlikely to have attractive energy costs and eco-friendliness using the separate dispatches. To achieve the full economic as well environmental benefits, the cohesive dispatching option [137] aims for symmetry between the generation costs and the level of emissions. The dual-objective, eco-friendly and economic strategy, has a solitary optimisation task with the help of a price penalty factor, *h*. The price penalty factor, h_i (\$/kg) of a generator, *i* is:

$$h_i = {(a_i\, P_{imax}^2 + b_i\, P_{imax} + c_i)}\Big/{(d_i\, P_{imax}^2 + e_i\, P_{imax} + f_i)} \quad \$/kg \qquad (5.19)$$

The above price penalty factor results in more realistic values only when the generating plants are operating at their designed maximum capacity; for other generation levels (i.e. at less-than-full load conditions), the resulting values vary widely from these more practical values. Figure 5.1 represents the output versus heat rate of traditional fossil-fuelled power plants.

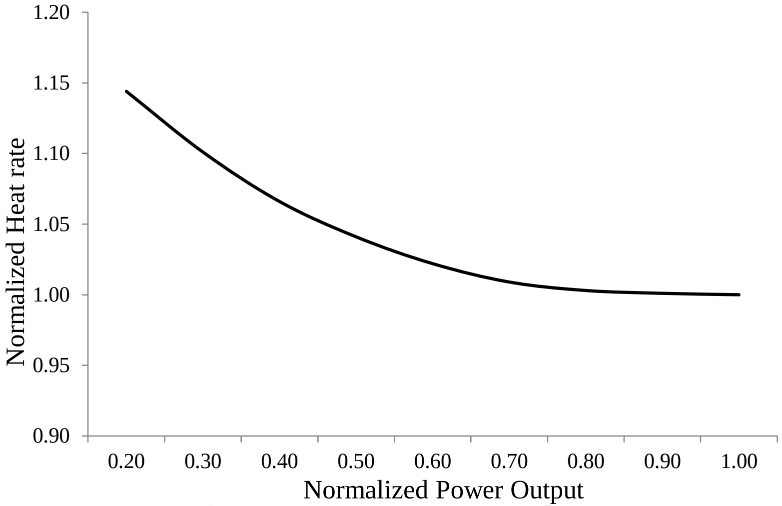


Figure 5.1. Output versus heat rate

It is widely acknowledged that, during partial load conditions, the heat rate requirements are higher, which makes the power plant less efficient and more polluting. Therefore, the penalty factor price defined in (5.19) is impracticable for partial-load operating situations. In this research, a new price penalty factor appropriate for all operating load conditions is presented in (5.20). The price penalty factors of all the generating plants taking part in the generation scheduling task are first determined at their maximum generating capacity limit by (5.19). Then, the price penalty factor with the greatest value is presumed to be the penalty factor (h_{PD}^{min}) at the minimum loading capacity of the system and likewise, the penalty factor with the lowest value is assumed to be the penalty factor (h_{PD}^{max}) at the maximum loading capacity of the system. The two stated factors are used to calculate the proposed penalty factor (h_{PD}) at any partial load condition as:

$$h_{PD} = h_{PD}^{min} + \frac{[h_{PD}^{max} - h_{PD}^{min}]}{[P_D^{max} - P_D^{min}]} \times [P_D - P_D^{min}] \quad \$/kg \tag{5.20}$$

With this price penalty factor, the objective for the combined economic and emission dispatch becomes

$$\phi_c = Min \sum_{i=1}^{n} (F_{it} + h_{PD}\, E_i) \quad \$/hr \tag{5.21}$$

For all three dispatches, the solution technique remains the same except for the difference in the coefficients of the three objective functions.

To summarise – the Smart Grid should be both economical and environmentally friendly; hence, to achieve this task, a combined economic and emission dispatch algorithm is discussed.

The Cloud can be the source for grid data storage, data exchange, communication and generation scheduling, etc. Although there are three models of Cloud services, the SaaS model is preferred due to its access flexibility, simplicity, and cost-effectiveness.

5.3. Illustrative Example and Discussion

The proposed economic and emission control strategy has been applied to several test systems but only the results from the modified IEEE 30-bus system are presented. Table C.1 (Appendix – C) shows the fuel and NO_x emission coefficients, the generators' minimum and maximum generating capacity limits, and the power loss constraints. Table C.2 (Appendix – C) gives the transmission loss coefficients. For evaluation purposes, two part loads, 800 MW and 1200 MW, are taken into consideration and their partial load price penalty factors (h_{PD}) were determined as 19.92 $/kg (800 MW) and 16.31 $/kg (1200 MW).

The outcome of the proposed direct approach was compared against the approach proposed in [138], which is a mixed integer nonlinear programming methodology offering a near optimal solution. Tables 5.1 to 5.6 depict the study outcomes.

Table 5.1. Economic Dispatch – System Demand: 800 MW

Part load penalty factor: 19.92 \$/kg.							
Unit	**P_i (MW)**	**P_{Li} (MW)**	**Fuel cost (\$/MWh)**	**Emission (kg/MWh)**	**Total energy cost (\$/MWh)**	**Power loss (%)**	**Trans. η (%)**
G_1	87.04	2.69	51.15	1.98	90.59	3.09	96.91
G_2	68.11	1.68	52.73	1.73	87.19	2.47	97.53
G_{13}	94.28	3.19	50.71	2.00	90.55	3.38	96.62
G_{22}	183.84	12.01	49.82	1.51	79.90	6.53	93.47
G_{23}	215.56	12.94	49.13	1.35	76.07	6.00	94.00
G_{27}	198.15	14.48	49.65	1.55	80.53	7.31	92.69
				Proposed method [139]		Reference method [138]	
Total cost (\$)				42411.19		42412.38	
Total emission (kg)				1354.14		1354.91	
Total power loss (MW)				46.98		46.98	
Solution time (Sec.)				27		69	

Table 5.2. Economic Dispatch for 1200 MW

Part load penalty factor: 16.31 \$/kg.							
Unit	**P_i (MW)**	**P_{Li} (MW)**	**Fuel cost (\$/MWh)**	**Emission (kg/MWh)**	**Total energy cost (\$/MWh)**	**Power loss (%)**	**Trans. η (%)**
G_1	145.20	8.35	52.40	2.82	98.39	5.75	94.25
G_2	116.31	5.65	53.37	2.43	93.00	4.86	95.14
G_{13}	153.39	8.89	52.08	2.82	98.07	5.80	94.20
G_{22}	276.64	26.76	51.29	2.97	99.73	9.67	90.33
G_{23}	319.30	27.69	50.79	2.85	97.27	8.67	91.33
G_{27}	298.84	32.35	51.18	3.24	104.02	10.83	89.17
				Proposed method [139]		Reference method [138]	
Total cost (\$)				67506.65		67508.90	
Total emission (kg)				3823.50		3824.21	
Total power loss (MW)				109.68		109.71	
Solution time (Sec.)				27		69	

The economic dispatch outcome presented in Table 5.1 shows all the six generating units were functioning within their maximum designed capacity limits and the transmission losses experienced by the generators and their transmission network were within their P_{Lmax}. Generating units G_1, G_2 and G_{13} were slightly loaded (in the range of 32 to 41 %) compared to the other generating units, whereas unit G_{22} shared 81.7 % of its maximum generating capacity limit to meet a partial load of 800 MW. The percentage transmission loss of unit G_{22} and its related network was considerably higher and its transmission efficiency, together with its transmission network was lower compared to G_1, G_2, G_{13}, and G_{23}.Consequently, the higher sharing of generation by G_{22} to meet system demands greater than 800 MW was not practically possible as seen from Table 5.2.

The generation by G_{22} exceeded its capacity limit and the transmission losses exceeded the permissible limit. Moreover, the emissions from this unit were much higher compared to units G_1, G_2, G_{13}, and G_{23}. The only positive feature about this unit was its attractive unit cost of generation ($/MWh) compared to units G_1, G_2, G_{13}, and G_{23}. In the case of system generating capacity, an expansion situation arises; G_{22} can be identified as in need of replacement (higher emissions due to aging) by a higher capacity-generating unit at the same location provided the associated transmission networks are upgraded in a cost-effective manner.

Table 5.3. Emission Dispatch for 800 MW

Part load penalty factor: 19.92 $/kg.							
Unit	**P_i (MW)**	**P_{Li} (MW)**	**Fuel cost ($/MWh)**	**Emission (kg/MWh)**	**Total energy cost ($/MWh)**	**Power loss (%)**	**Trans. η (%)**
G_1	107.62	2.84	51.41	2.27	96.63	2.64	97.36
G_2	105.17	2.65	53.06	2.26	98.08	2.52	97.48
G_{13}	113.33	3.09	51.00	2.26	96.02	2.73	97.27
G_{22}	164.12	12.03	49.68	1.20	73.58	7.33	92.67
G_{23}	192.56	13.58	48.91	1.02	69.23	7.05	92.95
G_{27}	165.72	14.31	49.45	1.01	69.57	8.64	91.36
				Proposed method [139]		Reference method [138]	
			Total cost ($)	42660.36		42661.55	
			Total emission (kg)	1301.03		1301.87	
			Total power loss (MW)	48.51		48.52	
			Solution time (Sec.)	27		69	

Table 5.4. Emission Dispatch for 1200 MW

Part load penalty factor: 16.31 $/kg.							
Unit	**P_i (MW)**	**P_{Li} (MW)**	**Fuel cost ($/MWh)**	**Emission (kg/MWh)**	**Total energy cost ($/MWh)**	**Power loss (%)**	**Trans. η (%)**
G_1	185.51	9.86	53.80	3.42	109.60	5.32	94.68
G_2	180.66	9.18	55.94	3.41	111.60	5.08	94.92
G_{13}	195.03	10.40	53.53	3.41	109.22	5.33	94.67
G_{22}	238.41	24.49	50.57	2.36	89.12	10.27	89.73
G_{23}	273.20	26.15	49.95	2.18	85.54	9.57	90.43
G_{27}	234.73	27.45	50.09	2.16	85.32	11.69	88.31
				Proposed method [139]		Reference method [138]	
Total cost ($)				67987.55		67989.72	
Total emission (kg)				3583.71		3584.42	
Total power loss (MW)				107.54		107.55	
Solution time (Sec.)				27		69	

Tables 5.3 and 5.4 exhibit the emissions dispatch outcomes for an 800 MW and 1200 MW generating facility, respectively. There was no evidence for the violation of generating capacity limits and power loss limits for the 800 MW load condition. However, for the 1200 MW load condition; G_{22} surpassed its maximum generating capacity limit, while the other units were operating within their limits. Hence, again G_{22} is likely to be displaced or needs upgrading. From the results of Tables 5.3 and 5.4, it is also obvious that the total unit costs of energy (fuel cost and emission costs, $/MWh) from unit G_2 was the highest among all the units. The generation share of G_2 was 84.02 % of its maximum capacity for a demand of 1200 MW. However, additional loading of this unit is unlikely and it is uneconomical and not particularly ‘green’. However, the transmission loss of its accompanying network was only 9.18 MW (23 MW was the upper limit of load ability) and its transmission efficiency was the highest among all the units. Therefore, there was no need for upgrading the transmission network. If generators who are connected to this line were of higher capacity, the transmission system could be effectively utilised.

Table 5.5. Combined Economic & Emission Dispatch for 800 MW

Part load penalty factor: 19.92 $/kg.							
Unit	**P_i (MW)**	**P_{Li} (MW)**	**Fuel cost ($/MWh)**	**Emission (kg/MWh)**	**Total energy cost ($/MWh)**	**Power loss (%)**	**Trans. η (%)**
G_1	104.62	2.76	51.36	2.23	95.78	2.64	97.36
G_2	99.21	2.44	52.92	2.17	96.15	2.46	97.54
G_{13}	110.45	3.04	50.94	2.22	95.16	2.75	97.25
G_{22}	167.62	12.16	49.70	1.25	74.60	7.25	92.75
G_{23}	196.19	13.58	48.94	1.08	70.45	6.92	93.08
G_{27}	170.38	14.49	49.47	1.09	71.18	8.50	91.50
				Proposed method [139]		Reference method [138]	
Total cost ($)				42609.92		42610.14	
Total emission (kg)				1301.48		1302.23	
Total power loss (MW)				48.47		48.48	
Solution time (Sec.)				27		69	

Table 5.6. Combined Economic & Emission Dispatch for 1200 MW

Part load penalty factor: 16.31 $/kg.							
Unit	**P_i (MW)**	**P_{Li} (MW)**	**Fuel cost ($/MWh)**	**Emission (kg/MWh)**	**Total energy cost ($/MWh)**	**Power loss (%)**	**Trans. η (%)**
G_1	179.87	9.57	53.59	3.34	108.02	5.32	94.68
G_2	169.65	8.44	55.44	3.24	108.33	4.97	95.03
G_{13}	188.99	10.10	53.31	3.33	107.60	5.34	94.66
G_{22}	245.20	25.04	50.69	2.47	90.98	10.21	89.79
G_{23}	280.40	26.44	50.08	2.29	87.36	9.43	90.57
G_{27}	243.73	28.24	50.23	2.31	87.92	11.59	88.41
				Proposed method [139]		Reference method [138]	
Total cost ($)				67830.98		67833.07	
Total emission (kg)				3589.26		3589.98	
Total power loss (MW)				107.82		107.93	
Solution time (Sec.)				27		69	

Tables 5.5 and 5.6 present the combined economic and emission dispatch outcomes for the same partial load conditions. From the results of the economic and

emission dispatches, it was observed G_{22} violated its upper generating capacity as well as its power loss limits. Moreover, it was less efficient compared to G_1, G_2, G_{13} and G_{23}. However, it was economical in terms of fuel costs, as well the total energy costs, and environmentally friendly too compared to the other units such as G_1, G_2, and G_{13}. Therefore, G_{22} was suitable for a combined economic and emission dispatching for loads not exceeding 1200 MW. Another observation was unit G_2 had the highest total energy costs among all the units and was extremely polluting. Economically as well as environmentally, it was unattractive; however, its associated transmission network had more room for higher load ability.

5.4. Conclusions

This section of the research has presented the concerns of the economics and emissions control of Smart Grids. Three types of dispatching options were proposed, economic, emissions, and combined economic and emissions dispatching to improve the performance of Smart Grids. A single direct dispatching algorithm has been introduced for all three dispatches to fill up the research gap (an attractive unit cost of electricity generation and environmentally friendly) and to provide a solution to the research question 1.7 (c). By the proposed dispatching algorithm, the research objective 1.8 (b) has been achieved by providing an attractive price for environmentally benign energy suitable for Cloud services in a Smart Grid.

An IEEE modified 30-bus test system was used to assess the viability of the proposed algorithm. The total unit cost of generation, unit emissions, transmission power loss, the percentage transmission efficiency, the individual unit generation, and capacity defilements were the benchmarks used while conducting the analysis. Being a direct optimisation algorithm on the Cloud platform, the solution time was noticeably less than the alternative as well as using less memory. There was no need for an initial guess to start with and no further updating while iterating. Additionally, the proposed single approach was appropriate for the above economic, emissions and combined economic and emissions control avoiding having to switch algorithms depending on the objectives.

Chapter 6

SMART GRID CAPACITY ENHANCEMENT

The research question 1.7 (a) - how to enhance the performance of Smart Grid at a real-time basis and question 1.7 (b) - how to overcome the security and stability challenges on incorporating renewable energy sources in Smart Grids by an economical manner have been answered previously. To enhance the performance of Smart Grid, capacity addition helps further, and renewable energy addition provides environmental friendliness. This part of research introduces the capacity addition of power generation through a waste-to-energy recovery process.

Solid waste generation is the result of residential inhabitants' lifestyle, as well as industrial and commercial activities throughout the world. The collection, transporting, and processing of the generated solid waste has become a serious concern for administrative authorities in metropolitan cities. Particularly, this has become a great challenge for developing countries, which are in the process of forming Smart Grids. To reuse the waste generated rather than simply dumping it, the biomass content of the waste shall be used for energy recovery, which is acknowledged as a renewable energy. For this waste-to-energy recovery process, the generated solid waste must be transported to biomass sorting sites and then to the power plant. The cost associated with this transportation forms a major share of the solid waste management. This section of the study aims to optimise solid waste transportation for energy recovery to enhance the Smart Grid capacity [140] in an economical and environmentally friendly way; thus achieving research objective 1.8 (b).

A journal paper has been published ("Cloud-Based Solid Waste Transportation Optimisation for Energy Conversion," International Journal of Energy Economics and Policy, 2017, 7(4), 291-301, Scopus Indexed, Quartile: Q2) based on the outcome of this part of research.

6.1. Introduction

The generation of solid waste is a perennial problem, which has economic and environmental effects and leads to regional climate change. Changes in lifestyles, mechanisation, suburbanisation, exponential growth in population, etc. results in 4.1 billion tons of solid waste generated per year globally [141]. More than 2/3 of the generated waste is simply dumped in open sites outside the residential areas and the remaining is recycled and used for waste-to-energy recovery [142]. There are environmental and health issues for humans and a scarcity of land for useful societal activities since the major portion of solid waste becomes dumping material. Moreover, the composition of the generated waste is a mixture of biomass and toxic waste, electronic, pharmaceutical and animal [143]. Recently, there has been a growing awareness among the public to handle the waste management issue seriously in order to reduce pollution and perhaps reuse it. One feasible solution is develop an energy recovery program from the biomass component of the waste generated in the same location as the Smart Grid since a Smart Grid is a consortium for renewable energy sources.

6.2. Solid Waste transportation

The greatest operating expense of the solid waste management industry is collecting the waste from the residents' locations and transferring it to a sorting centre. The cost associated with this process varies from 50 to 75 % of the entire solid waste managing budget [144]. The common challenges in solid waste collecting and transference are:

- lack of support from the community for the established programmes,
- usage of incompatible collecting trucks,
- implementing illogical routes for waste collecting,
- unrealistic work crew size and working hours,
- the lack of maintenance for vehicles,
- excessively long shipping to endpoint, and
- the solid waste loss during transporting.

Improving any of the above concerns could significantly improve financial benefits.

6.3. Transportation Cost Optimisation

The cost of transporting solid waste has two main components, fixed costs (indirect cost) and variable costs. The fixed costs remain unchanged irrespective of the load transferred, whereas the variable costs depend on the quantity of the load transferred to the site, which are mainly fuel costs. The amount of fuel used is determined by the vehicle route, from collection to sorting centre, with the goal to minimise the time and distance. Currently, environmental concerns have a high priority in the Smart Grid era; therefore, the ecological degradation caused by the transporting vehicles needs statutory control to promote proper fuel usage.

The fuel usage of transfer trucks rests on many factors such as the type of transporting vehicle used, its capacity, age, fuel type, whether properly maintained, rate of speed, route distance, the load on the vehicle, etc. In addition, the transporting route conditions, traffic congestion, and the driver's attitude and his driving skills also play a role in fuel consumption. Due consideration given to all these factors will make the transportation process more efficient and environmentally friendly.

6.4. Cloud's Significance in Optimisation

6.4.1. Cloud Computing Prototype

Cloud computing is an innovative IT-based despatch prototype for computing resources on request. The main benefits of Cloud facilities for users are that without any investment in computing hard ware, users can access the Cloud services and pay accordingly [145]. An efficient Cloud Prototype, as in Figure 6.1, depicts the integration of the end-users with the Cloud providers through an internet.

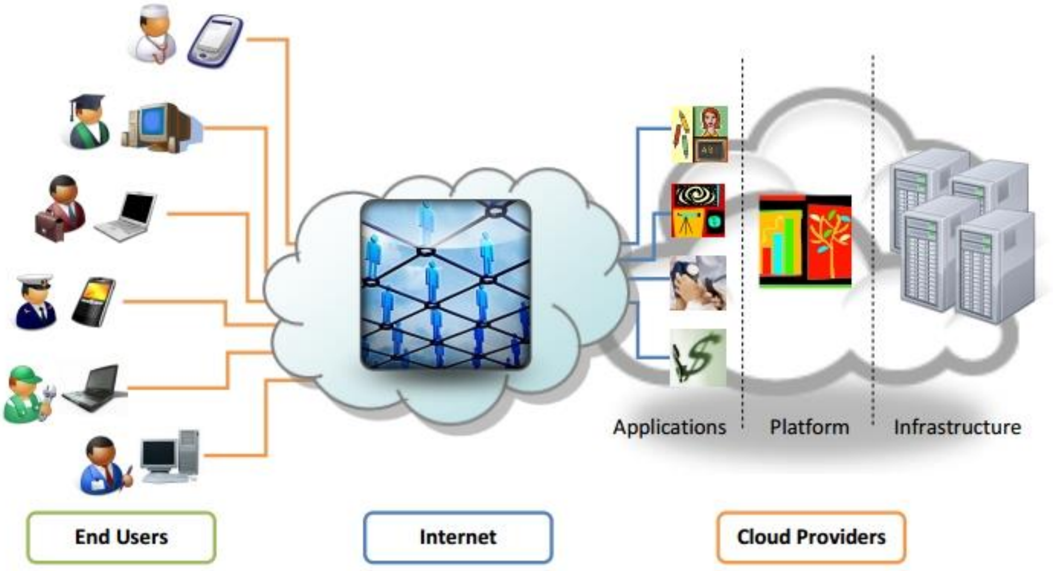


Figure 6.1. Cloud Prototype [145]

6.4.2. Cloud Application Services

The Cloud application services are *Infrastructure as a Service (IaaS)*, *Platform as a Service (PaaS)*, and *Software as a Service (SaaS)* as shown in Figure 6.2.

IaaS is the basic layer offering virtual machines and additional assets like load balancers, IP addresses, and virtual local area networks, etc. Example: Amazon Web Services (AWS).

PaaS is a hardware service model on the top of IaaS offering computing platforms comprising of operating systems, language execution environment, database, and web server. Example: Windows Azure.

SaaS is an application service model offering access to servers equipped with application packages. The user needs to pay only for the services availed. Example: Microsoft office 365.

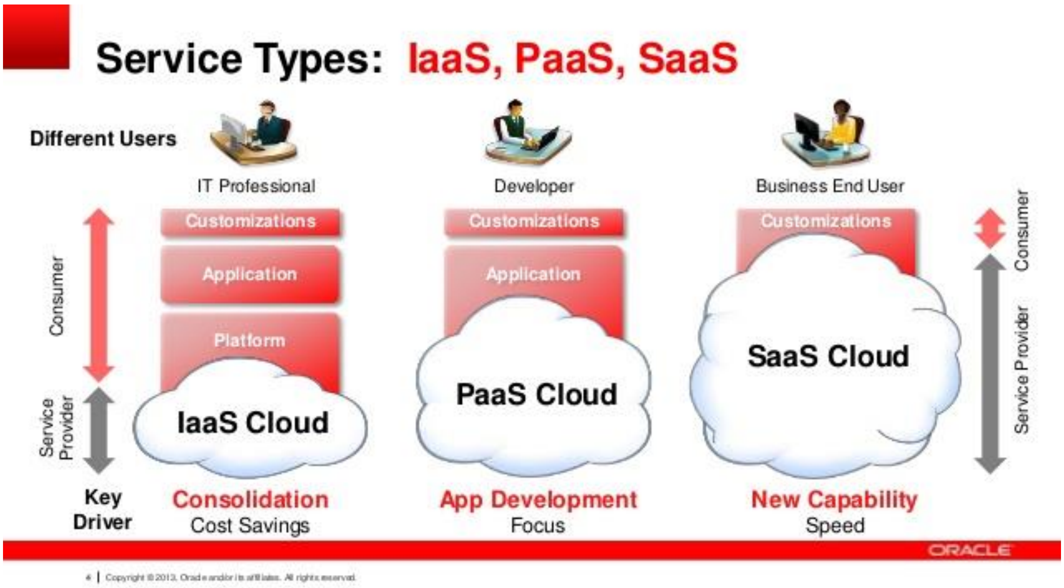


Figure 6.2. Service Types [145]

6.4.3. Cloud's Suitability

The large amount of garbage produced and the mechanism to handle this with a minimum environmental effect are the main concerns of the administrators. The effective solid waste handling process includes a massive quantity of information, such as the:

- amount of waste produced in various zones on a daily basis,
- waste collecting strategies,
- the extent and quality of transporting systems,
- sorting station status, and
- recovery/treatment/disposal logistics, etc.

A typical solid waste disposal system also includes many shareholders such as the municipal council, district headquarters and Smart Grid administrators, weather forecasting stations, pollution and traffic control bodies, the public, truck owners and drivers, and sorting site controllers, etc. To manage the enormous amount of data and the various shareholders, an efficient and informative system such as the Cloud is the right choice. For this study, the SaaS application service model was considered for the transportation optimisation task because of its readiness, suppleness, and economic viability.

6.5. The Intended Transportation Optimisation Strategy

In electric utility grids, performing power dispatch is the cost-effective way to balance the power generation against the demand, and to maintain system reliability subject to system infrastructure and operating constrictions. To perform the generation-demand optimisation, the generators' operating costs follows a quadratic equation form (5.2) composed of its power generation and its fuel costs coefficients.

$$F_i = a_i P_i^2 + b_i P_i + c_i \quad \$/h \tag{6.1}$$

For waste transfer, trucks and lorries with diesel engines have been the standard choice. Their performance characteristics are similar to the fossil-fuelled power plants in electric energy systems. Consequently, for solid waste transportation optimisation, the same quadratic equation (5.2) renamed as (6.1) will be used.

6.5.1. Objective Function

Following (6.1), equation (6.2) was formed with the operating costs (fixed and variable cost) coefficients of the vehicles used for solid waste transportation and the load of the vehicles as the varying parameter. Thus, the objective function becomes the same as (6.2) and the constraints the same as in (6.3) and (6.4).

$$TC_T = \sum_{i=1}^{n} TC_i = \sum_{i=1}^{n} (a_i W_{Di}^2 + b_i W_{Di} + c_i) \quad \$ \tag{6.2}$$

(i) Load balance constraints (neglecting losses)

$$\sum_{i=1}^{n} W_{Di} = W_D \quad Tons \tag{6.3}$$

(ii) Vehicle loading capacity constraints

The load on each vehicle, W_{Di} is constrained by its maximum limit, i.e.

$$W_{Di} \leq W_{Di\,max} \tag{6. 4}$$

6.5.2. Optimum Load Sharing - Economic Dispatch

The incremental cost, λ of delivered load to the transfer station is given by

$$dTC_i / dW_{Di} = \lambda = 2a_i W_{Di} + b_i \quad \$/Ton \tag{6.5}$$

or

$$W_{Di} = \lambda\,(1/2a_i) - (b_i/2a_i) \quad Tons \tag{6.6}$$

Then, (6.7) gives the overall load at the transfer station or the total waste collected by all vehicles.

$$\sum_{i=1}^{n} W_{Di} = W_D = \lambda \sum_{i=1}^{n} (1/2a_i) - \sum_{i=1}^{n} (b_i/2a_i) \tag{6.7}$$

Let $k_1 = \sum_{i=1}^{n} (b_i/2a_i)$, and $k_2 = \sum_{i=1}^{n} (1/2a_i)$, then (6.7) takes a simple form as

$$W_D = \lambda\, k_2 - k_1 \quad Tons \tag{6.8}$$

or

$$\lambda = (W_D + k_1) / k_2 \qquad \$/Ton \tag{6.9}$$

Putting the value of λ in (6.6) and simplifying provides the optimum load for each vehicle as

$$W_{Di} = (W_D + k_1 - b_i\, k_2)/2\, a_i\, k_2 \ Tons \tag{6.10}$$

The overall operating cost of *n*-vehicles operating in parallel to meet the load, W_D can be achieved by substituting (6.10) with (6.1) and simplifying results in a single cost function for all vehicles as in (6.11).

$$TC_T = AW_D^2 + BW_D + C \quad \$ \tag{6.11}$$

where $A = \sum_{i=1}^{n} 1/4a_i\, k_2^2$; $B = \sum_{i=1}^{n} k_1/2a_i\, k_2^2$ and $C = \sum_{i=1}^{n} \{(1/4a_i)\,(k_1^2/k_2^2 - b_i^2) + c_i\}$

Equation (6.11) is the overall costs of waste transportation without considering the losses while transferring.

6.5.3. Losses during Transportation

While transferring solid waste to the sorting stations, some quantity of waste is lost due to the vehicle body type whether open or closed, the body condition, the way that it is loaded, the driving speed and the driver's skill, road conditions, traffic and weather conditions, etc. In this research, the waste transporting losses are correlated to the power transmission losses in electric systems [131] and are represented as in (6.12).

$$W_{TL} = \sum_{i=1}^{n} \sum_{j=1}^{n} W_{Di}\, B_{ij}\, W_{Dj} \qquad Tons \tag{6.12}$$

Since $W_{Di} = (W_D + k_1 - b_i\, k_2)/2a_i\, k_2$ by (6.10), then load of vehicle, j is $W_{Dj} = (W_D + k_1 - b_j\, k_2)/2a_j\, k_2.$

Substituting W_{Di} and W_{Dj} in (6.12) and then manipulating, the losses all through the waste transfer process, W_{TL} becomes

$$W_{TL} = (\alpha W_D^2 + \beta W_D + \gamma) \qquad Tons \tag{6.13}$$

where $\alpha = (1/4k_2^2)\,\{\sum_{i=1}^{n} B_{ii}/a_i^2 + 2\sum_{i\neq j}^{n} B_{ij}/a_i a_j\}$

$$\beta = (1/4k_2^2)\,\{2\sum_{i=1}^{n} (k_1 - b_i k_2)\, B_{ii}/a_i^2 + 2\sum_{i\neq j}^{n} [2\, k_1 - k_2\,(b_i + b_j)]\, B_{ij}/a_i a_j\}$$

$$\gamma = (1/4k_2^2)\{\sum_{i=1}^{n} (k_1 - b_i k_2)^2 B_{ii}/a_i^2 + 2\sum_{i\neq j}^{n} (k_1 - b_i k_2)(k_1 - b_j k_2) B_{ij}/a_i a_j\}$$

6.5.4. Waste Received at the Sorting Station

The difference between the total waste delivered by all vehicles and the loss of waste during transportation gives the quantity of waste received, W_R at the sorting station.

i. e. $W_R = \sum_{i=1}^{n} W_{Di} = W_D - W_{TL}$ *Tons* (6.14)

Substituting (6.13) in (6.14) and manipulating

$W_R = - \alpha W_D^2 + W_D (1 - \beta) - \gamma$ *Tons* (6.15)

Then, the receivable waste, W_{Ri} from a vehicle, *i* at the sorting station would be

$W_{Ri} = (W_R + k_1 - b_i k_2)/2 a_i k_2$ *Tons* (6.16)

6.6. Transportation with Environmental concern

While transferring the waste generated from the point of collection to the sorting stations, the fossil-fuelled trucks pollute the regional zones resulting in air, soil and water contamination. The amount of pollution depends on several factors such as the fuel efficiency of the vehicle, the quality of fuel used, the age of the vehicle, the local weather, and the driving behaviour, etc. The vehicular emissions are less harmful during the daytime due to the dispersion into the higher altitudes, whereas the air pollution becomes more harmful to human health during the night due to the weather and the thermal inversion effect. Such harmful pollution levels, due to solid waste transportation, are not permissible in the Smart Grid system. Therefore, the waste handling needs to be carried out with a minimum of vehicular emissions.

6.6.1. Eco-friendly Dispatch

To perform emission dispatch, the same objective function used for economic dispatch is practical, with a change of cost coefficients, to vehicular emission coefficients. For this reason, the objective function for emission dispatch becomes:

$E_T = \sum_{i=1}^{n} E_{Ti} = \sum_{i=1}^{n} (d_i W_{Di}^2 + e_i W_{Di} + f_i)$ *kg* (6.17)

The emission dispatch logic is the same as the economic dispatch. From the emission dispatch outcome, the load on each vehicle is known; that's why, the total operating cost, TC_T and the corresponding emission, E_T are obtainable from (6.11) and (6.17) respectively.

6.6.2. Eco-friendly Economic Dispatch

Both economic dispatch and emission dispatch follow a similar form of objective functions but the former results in minimum costs whereas the latter ends with minimum emissions. The optimal solution with both economic viability and environmental friendliness is more attractive than minimum cost and minimum emission realisation. Therefore, in this work, an optimal solid waste transportation system with acceptable emission levels, in the Smart Grid environment, at a competitive operating cost, has been proposed. To combine both objective functions, a price penalty factor *h* is defined, which facilitates a single stage optimisation rather than separate economic and emission dispatches. The Cloud environment is the platform to store all the relevant data and to perform this optimisation.

The objective function for environmentally friendly economic dispatching is:

$$\Phi = \sum_{i=1}^{n} (a_i W_{Di}^2 + b_i W_{Di} + c_i) + h \sum_{i=1}^{n} (d_i W_{Di}^2 + e_i W_{Di} + f_i) \qquad \$ \qquad (6.18)$$

Equation (6.19) shows the concise form of (6.18).

$$\Phi = \sum_{i=1}^{n} (a_i + h\, d_i) W_{Di}^2 + (b_i + h\, e_i) W_{Di} + (c_i + h\, f_i) \qquad \$ \qquad (6.19)$$

Where $(a_i + h\, d_i)$, $(b_i + h\, e_i)$ and $(c_i + h\, f_i)$ are the blended cost coefficients.

The price penalty factor, *h* for a given load, W_D shall be resolved as

Step 1: Substitute a_i, b_i, and c_i in (6.11) and determine its value.

Step 2: Substitute d_i, e_i, and f_i in (6.11) and determine its value.

Step 3: Divide the value of step 1 by the value of step 2 to calculate the price penalty factor, *h* ($/kg).

The operating costs of the environmentally friendly economic dispatch lies in between the costs of economic and emission dispatches. Likewise, the magnitude of emission lies in between the emission levels of the economic and emission dispatches. Thus, it is sensible to promote the environmentally friendly economic dispatch and the flowchart (Figure 6.3), which is a Cloud-based dispatching algorithm, helps to achieve this outcome.

6.7. Application to a Metropolitan area

Chennai, a large metropolitan city in the state of Tamil Nadu India has a population of around 9 million with a land area of 1189 square kilometres [146, 147]. The solid waste generated per day reaches 5200 tons with a biomass content of 69 % [147]. To facilitate solid waste management, there are eleven transfer stations, one biomass sorting station, and two dumping yards. For a developing country with rapid industrialisation and with exponential growth in population, the waste handling system in practice is inadequate. Moreover, Chennai is in the process of becoming a Smart City with all the Smart Grid technology. The current Smart Grid is expanding its generation capacity through renewable energy sources to become more environmentally friendly since it is a coastal city with four tropical seasons. Wind energy conversion systems and solar PV have proven successful and energy recovery from biomass could be included in this success story. This section of the research proposes a waste-to-energy project from the biomass content of the solid waste generated in Chennai. The major task involved in this effort is the transfer of the waste collected to a biomass-sorting station, which would form the major financial component of the waste management budget. Consequently, a Cloud-based optimisation strategy to transfer a certain portion of the solid waste generated to the biomass-sorting site is discussed, which would be the fuel for the waste-to-energy project in the Smart Grid.

The optimisation strategy proposes the solid waste transfer from one of the city centre’s transfer stations to the sorting station with a round-trip distance of 19 km. The transfer station normally receives 54 tons of garbage daily. The travel time to deliver the collected garbage was about 30 minutes during the traffic peak hours 7.30 to 11.30 am and 4.30 to 9.30 pm on this route. The incurred cost is \$538.34 for 54 tons and no emission monitoring is in practice.

To transfer 54 tons of waste, three lorries were chosen [146] and can be characterised as:

Lorry 1: 6 years old, 6T capacity and open type
Lorry 2: 8 years old, 6T capacity and open type
Lorry 3: 9 years old, 6T capacity and open type

The transportation cost equations of the vehicles are

Lorry 1: $TC_1 = 0.2012\ W_{D1}^2 + 2.0095\ W_{D1} + 38.3595\ \$$
Lorry 2: $TC_2 = 0.2555\ W_{D2}^2 + 2.4339\ W_{D2} + 35.3260\ \$$
Lorry 3: $TC_3 = 0.2479\ W_{D3}^2 + 2.3127\ W_{D3} + 39.0617\ \$$

The corresponding CO_2 emission equations are

Lorry 1: $E_{T1} = 0.0650\ W_{D1}^2 + 0.8163\ W_{D1} + 49.24$ kg
Lorry 2: $E_{T2} = 0.0520\ W_{D2}^2 + 0.9818\ W_{D2} + 53.53$ kg
Lorry 3: $E_{T3} = 0.0470\ W_{D3}^2 + 0.8468\ W_{D3} + 51.49$ kg

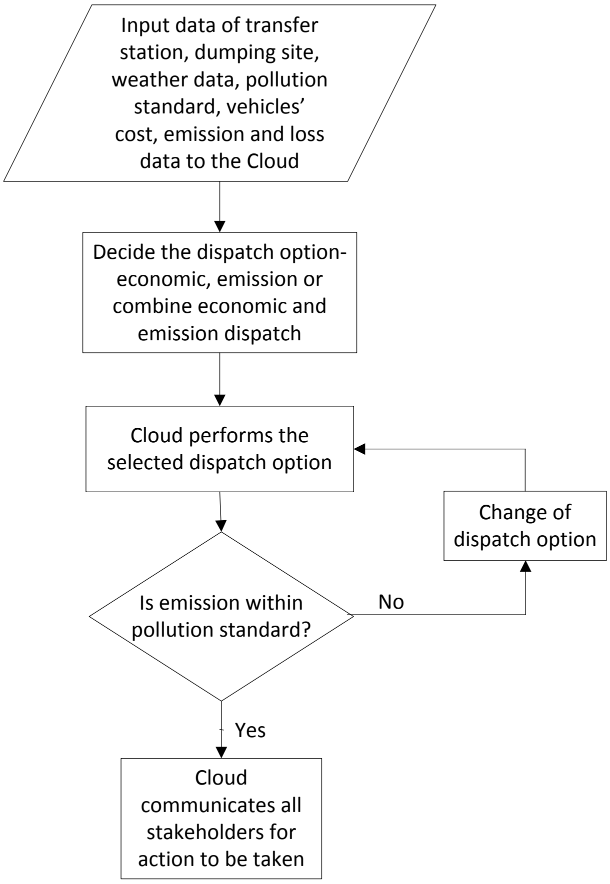


Figure 6.3. Cloud-based Dispatching Strategy

Figure 6.4 presents the schematic depiction of the open type lorries chosen, the transfer station, and the biomass-sorting site in Chennai. Table 6.1 shows the operating cost coefficients, and the CO_2 (major pollutant) emissions coefficients of the lorries chosen.

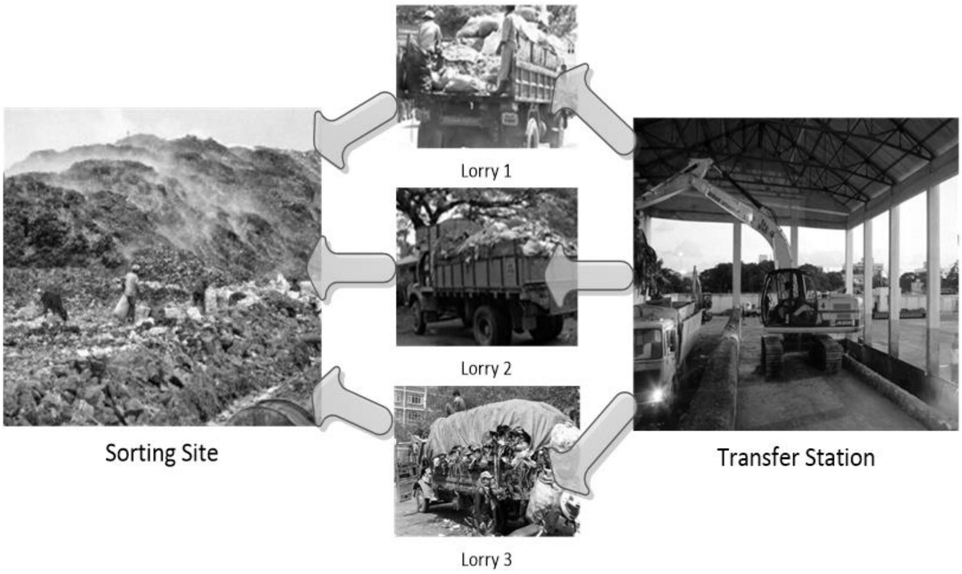


Figure 6.4. Transportation Pathway

Table 6.1. Vehicle Characteristics [146]

Transport	**Transportation cost coefficients**			**CO_2 Emission coefficient**		
	a_i ($\$/\text{Ton}^2$)	**b_i ($\$/\text{Ton}$)**	**c_i ($\$$)**	**d_i (kg/Ton^2)**	**e_i (kg/Ton)**	**f_i (kg)**
Lorry 1 **6 years old, 6T capacity**	0.2012	2.0095	38.3595	0.0650	0.8163	49.24
Lorry 2 **9 years old, 6T capacity**	0.2555	2.4339	35.3260	0.0520	0.9818	53.53
Lorry 3 **8 years old, 6T capacity**	0.2479	2.3127	39.0617	0.0470	0.8468	51.49

The lorries must run at a pre-determined speed of 20 km/h through the fixed route until the estimated quantity of waste reaches the sorting station. Table 6.2 presents the transportation loss coefficients for the selected route and the selected lorries.

Table 6.2. Transportation Loss Coefficients

0.0065		
	0.0082	
		0.0073

6.7.1. Economic Dispatch Outcome

Table 6.3 depicts the outcome of the economic mode of transfer of solid waste to the sorting station. Although all the lorries are of identical capacity, their load sharing is not, ranging from 15.97 tons to 21.33 tons. Predominantly lorry 1 received the maximum share since its operating costs are the lowermost compared to the other two. Lorry 2 shared the least, as its operating cost was the highest among all three. The loss of waste during transportation varied from 2.15 tons to 2.72 tons and the total loss of waste worked out to 7.08 tons (13.11 % of the total load). As far as CO_2 emissions were concerned, lorry 3 emitted the least and lorry 1 released the most. Though the optimal sharing of lorry 3 was greater than lorry 2, its corresponding CO_2 emissions were lower than lorry 2 since its emissions were less significant than lorry 2. Lorry 1 emitted the most owing to its greater load share compared to the others. Lorry 1 must complete four round-trip trips; Lorries 2 and 3 should complete three round-trip trips since their maximum loading capacity is only 6 tons. The solid waste transfer incurs a cost of \$458.94 (less by 17.3 % with respect to the existing transportation practice) and releases 257.43 kg of CO_2 into the atmosphere (no emission measures are in practice in the existing transportation system).

6.7.2. Eco-friendly Dispatch Outcome

The purpose of emission dispatch is to minimise the polluting emissions from the lorries used for waste transfer. As fossil-fuelled lorries emit a significant amount of CO_2, the local pollution concentration level might violate the limit set by the Smart Grid administration. For this reason, emissions regulation becomes inevitable and solid waste transportation needs to be planned such that vehicular emissions are minimal.

Table 6.3. Economic Dispatch Outcomes

Lorry 1		**Lorry 2**	
Waste Dumped, WD (Tons)	21.33	Waste Dumped, WD (Tons)	15.97
Waste Delivered, WR (Tons)	18.61	Waste Delivered, WR (Tons)	13.82
Transmission Loss, WTL (Tons)	2.72	Transmission Loss, WTL (Tons)	2.15
Transportation Cost, (\$)	172.78	Transportation Cost, (\$)	139.33
CO_2 Emission (kg)	96.23	CO_2 Emission (kg)	82.46
Number of trips	4	Number of trips	3
Lorry 3		**Total Quantities**	
Waste Dumped, WD (Tons)	16.70	Total Waste Dumped, WD (Tons)	54
Waste Delivered, WR (Tons)	14.49	Total Waste Delivered, WR (Tons)	46.92
Transmission Loss, WTL (Tons)	2.21	Total Transmission Loss, WTL (Tons)	7.08
Transportation Cost, (\$)	146.83	Total Transportation Cost, (\$)	458.94
CO_2 Emission (kg)	78.74	Total CO_2 Emission (kg)	257.43
Number of trips	3	Total Number of trips	10

For the purposes of this study a model replicating the transporting of 54 tons of solid waste was conducted applying emission dispatching and the outcome is shown in Table 6.4. The solid waste transfer incurred a cost of \$471.26 and released 254.14

kg of CO_2 into the atmosphere. Compared to the economic dispatch, there was an additional operating cost of $12.32 and a decrease of 3.29 kg of CO_2 emitted into the atmosphere. For the most part lorry 3 took the largest load since its emissions were the lowest compared to the other two vehicles and lorry 1 took the smallest load as its emissions was the highest. Lorries 1 and 2 needed to complete three round-trip trips, and lorry 3 had to accomplish four round-trip trips since the maximum loading capacity of each lorry was only 6 tons. From the economic and emission dispatch outcomes, the optimum loading capacities, operating costs, and emissions are distinct for each vehicle, though they had the same maximum loading capacity.

Table 6.4. Eco-friendly Dispatch Outcomes

Lorry 1		**Lorry 2**	
Waste Dumped, WD (Tons)	15.39	Waste Dumped, WD (Tons)	17.65
Waste Delivered, WR (Tons)	13.38	Waste Delivered, WR (Tons)	15.14
Transmission Loss, WTL (Tons)	2.01	Transmission Loss, WTL (Tons)	2.41
Transportation Cost, ($)	116.95	Transportation Cost, ($)	157.85
CO_2 Emission (kg)	77.20	CO_2 Emission (kg)	87.05
Number of trips	3	Number of trips	3
Lorry 3		**Total Quantities**	
Waste Dumped, WD (Tons)	20.96	Total Waste Dumped, WD (Tons)	54
Waste Delivered, WR (Tons)	18.18	Total Waste Delivered, WR (Tons)	46.70
Transmission Loss, WTL (Tons)	2.78	Total Transmission Loss, WTL (Tons)	7.30
Transportation Cost, ($)	196.46	Total Transportation Cost, ($)	471.26
CO_2 Emission (kg)	89.89	Total CO_2 Emission (kg)	254.14
Number of trips	4	Total Number of trips	10

6.7.3. Eco-friendly Economic Dispatch Outcome

The economic and emission dispatch results showed operation costs are lower and emission levels were greater in the economic dispatch whereas for the emission dispatch the opposite was true. The environmental friendly economic dispatch algorithm results were similar to the economic dispatch with the only difference being the operating costs coefficients were replaced by the blended cost coefficients. The blended cost coefficients were determined as below:

Step 1: The equation of $AW_D^2 + BW_D + C$ *($)* given by (6.11) with the transportation cost coefficients of vehicles, a_i, b_i, and c_i is $0.0774\ W_D^2 + 2.2328\ W_D + 112.6392$ and its value was $ 458.94.

Step 2: The equation of $AW_D^2 + BW_D + C$ *(kg)* with the emission coefficients of vehicles, d_i, e_i, and f_i is $0.0179\ W_D^2 + 0.8849\ W_D + 154.1890$ and its value was 254.14 kg.

Step 3: The ratio of the value from step 1 and the value from step 2 assigned the value of the price penalty factor, h ($/kg) as 1.78 $/kg.

Step 4: The blended cost coefficients were calculated by using the expressions $(a_i + h\ d_i)$, $(b_i + h\ e_i)$ *and* $(c_i + h\ f_i)$ from (6.19).

The environmentally friendly economic dispatch has been executed as the economic dispatch with the blended cost coefficients and the dispatch outcomes have been shown in Table 6.5.

The operating cost for transferring 54 tons of solid waste was $460.20 and the corresponding CO_2 emissions totalled 255.66 kg. The operating cost was relatively modest between the cost of the economic and emission dispatches and similarly for the CO_2 emissions. The transportation loss was less by 0.23 tons with respect to the emission dispatch. Lorry 1 must complete four round-trip trips, and lorries 2 and 3 must complete three round-trip trips.

Considering the environmentally friendly economic transportation option, the net solid waste received at the sorting station was 46.93 tons. Assuming the same types of vehicles and the same method of operation, and the daily collection of 5200 tons of solid waste, then the quantity received at the sorting station would be 4519 tons. According to the prevailing solid waste composition [146, 147], 69 % is biomass content (3118 Tons) which is ideally suited for power generation in Chennai. Following the Pearson/Aguada Infrapower technology [148] for waste to energy conversion, 12 MW of electrical energy could be achieved per day, which results in an environmentally friendly economic capacity addition to the ongoing Smart Grid project in Chennai.

Table 6.5. Eco-friendly Economic Dispatch Outcomes

Lorry 1		**Lorry 2**	
Waste Dumped, WD (Tons)	19.40	Waste Dumped, WD (Tons)	16.62
Waste Delivered, WR (Tons)	16.93	Waste Delivered, WR (Tons)	14.37
Transmission Loss, WTL (Tons)	2.47	Transmission Loss, WTL (Tons)	2.25
Transportation Cost, ($)	153.10	Transportation Cost, ($)	146.30
CO_2 Emission (kg)	89.55	CO_2 Emission (kg)	84.20
Number of trips	4	Number of trips	3
Lorry 3		**Total Quantities**	
Waste Dumped, WD (Tons)	17.98	Total Waste Dumped, WD (Tons)	54
Waste Delivered, WR (Tons)	15.63	Total Waste Delivered, WR (Tons)	46.93
Transmission Loss, WTL (Tons)	2.35	Total Transmission Loss, WTL (Tons)	7.07
Transportation Cost, ($)	160.81	Total Transportation Cost, ($)	460.20
CO_2 Emission (kg)	81.91	Total CO_2 Emission (kg)	255.66
Number of trips	3	Total Number of trips	10

6.8. Conclusions

An economical and ecologically appropriate solid waste transportation system has become essential for developing countries like India, regardless of their development status. As an illustration, the Chennai Metropolitan Area, which is in the process of forming a Smart Grid, has been used for a solid waste transportation optimisation study with Cloud Computing. Three dispatching algorithms were suggested. The economic dispatching resulted in the lowest transferring cost (less by 17.3 % with respect to the existing transportation practice) while the emission dispatching led to the lowest emissions. The third dispatch, the environmentally friendly economic dispatch, presented a compromise of both cost and emissions. Apart from the cost and emission, the transportation loss is found to be less compared to the existing transportation tactics. The choice of selecting the type of dispatch depends on factors such as the solid waste management budget, the local weather conditions, the Smart Grid requirement, the time of travel, and the type and age of the vehicles used, etc. Although only one specific route and one type of pollutant were considered, the dispatching logic remains the same regardless of the route and vehicle emission characteristics. The proposed optimisation algorithms are also suitable for optimising the collection of solid waste with a variety of fossil-fuelled vehicles. This study showed a possible 12 MW capacity addition to the Smart Grid in Chennai resulting from waste generation. Thus, research objective 1.8 (b) has been achieved further.

Chapter 7

ADMIN DASHBOARD AND SMARTPHONE FOR SMART GRID ENERGY MANAGEMENT

Smart Grid end-users are eager to control their hourly energy consumption in their residence or business and use energy resources more intelligently and judiciously than what has been available. To meet their expectations, there is a necessity (research gap) to have a communication link between the energy providers and the consumers to exchange data and to deliver decisions from the energy providers to the consumers, which is inadequate. The prevailing situation has the room for the question 1.7 (d) - how to ease the bilateral communication needs of energy suppliers and end-users in a cost-effective way. To answer the question and to achieve the research objective 1.8 (c), this section of the study presents a Smart Grid Administrative Dashboard and a Smartphone Application [149] so consumers receive all available energy-related information transparently in real-time and can better plan their daily activities efficiently and economically, which in turn helps the Smart Grid in its generation-demand management.

A journal paper has been published ("Cloud Associated Smart Grid Admin Dashboard," Engineering, Technology & Applied Science Research Journal, 2017, 8(1), ISSN (e/p): 1792-8036, 2241-4487, Indexed in Web of Science/Thomson Reuters) based on the outcome of this part of research.

7.1. Introduction

Consumers perceive streamlining electrical energy infrastructure, for example the acceptance of Smart Grids, as an imperative infrastructure development supporting efficient energy consumption. Intelligent Smart Grids enable enhancements to the management of both power supply and demand, through modern technology for both grid-side applications and for end-users' convenience [103, 104].

7.1.1. Grid side applications

Grid-side applications permit the electricity network provider to manage assets with improved quality of supply, network planning as well as demand management, reliability of supply, and security using a series of sensors and monitors. These sensors produce an enormous quantity of data in real-time, which is collated and sent to analytical applications to produce governing conclusions to enhance efficacy and dependability of the Smart Grid. In addition, this data helps the network provider enhance integration of intermittent sources like solar and wind-generated energy into the electrical grid.

7.1.2. End-user concerns

For the principal electric consumers such as industrial, commercial and residential customers, Smart Grids include the use of 'smart meters' instead of conventional mechanical energy meters. These smart meters observe, regulate the energy usage at the consumers (end-user) terminals and communicate to the sensors. From these communications, the residential consumers are able to access real-time and complete information on their domestic energy consumption in order to become more energy-efficient through time-of-use and anticipated energy costs, and the demand-response alerts to reduce peak power demand from their reserve generators/energy storage systems, via a log-in internet site or a smartphone application. In other words, smart meters facilitate electricity variable pricing signals allowing the consumers to invest in load-shedding and load-shifting solutions. Further, consumers expect to be able to obtain a constant energy supply, and be notified of probable outages due to meteorological conditions, system failures, and power failure due to other threat.

7.2. Energy Management

Peak demand management is a continual problem for energy systems though it results for few hours in a day. Managing demand saves two power plants' worth of energy at peak hours. It involves the integration of peak demand managing plants such as renewable energy sources (solar, wind, etc.), natural gas plants and diesel generators. Solar and wind energy systems are intermittent power generators and depend on favourable weather conditions; therefore, their availability when peak demand persists, is uncertain whereas, the dependence on diesel generators is neither economical nor environmentally friendly.

Peak demand charges have been increasing over time and now account for more than 30 % of most commercial and industrial consumers' electricity charges. In utilities, energy management is the customary practice of observing, regulating, and sustaining energy, while, in Smart Grid, energy management is the primary concern. It is essential for continued operation, ecological protection and economic concerns without compromising functionality by optimally synchronising several energy sources.

In Smart Grids one of the objectives is consumers are expected to play a constructive role with the cooperation of Smart Grid administrators. For instance, consumers can take part in Smart load management i.e. planning the use of non-essential and occasionally essential electric appliance operations outside of the peak demand periods, and load shedding by employing digitally controlled and metered sub-systems to switch off or ramp down unnecessary high consumption appliances. Such actions help the grid in peak demand management and in return, the consumers receive monetary benefits by using lower off-peak energy rate periods. Apart from peak demand and load shedding participation, consumers can also promote renewable energy sources and distributed generation so they can utilise their own energy for their energy needs and export excess energy to the grid rather than buying energy from the grid at a higher energy cost.

7.3. Admin Dashboards

Although the Cloud links commendably with a Smart Grid and the end-users, the information exchange technology available to the consumers is not ready to use in real-time, not user-friendly to all types and levels of end-users, and large amounts of data delay decision-making [105, 106]. Moreover, such services are inadequate in quantity, quality, and time-bound. Consequently, a flexible and comprehensive utility-consumer collaborative information system is desirable to accommodate the requirements of the electric consumers.

The chief task of an emerging Smart Grid is gaining customer satisfaction. Deprived of this, the Smart Grid becomes inefficient, inoperative, and inconsistent in keeping its promises to its consumers. Eventually, the consumer pays for his usage. Even if the Smart Grid offers domineering assistance for its consumers, it comes at a significant cost and not when needed.

To satisfy customers' expectations and provide a reliable tool for them to take part in energy management, and for the suppliers' administrative purposes, some dashboards have been established with comprehensive facilities and services [107, 108]. They provide real-time performance of the Smart Grid, early warnings of grid anomalies, the fluctuating unit energy cost and the anticipated demand and generation, in an efficient manner. Interested IT groups can develop the dashboard to recognise the functional aspects related to combined services together with a Smart Grid and professional application server components, unified web and cloud components, etc. in a single view.

7.4. Cloud and Data Acquisition Network

The enormous volume of Smart Grid system data is attained from the grid network support as:

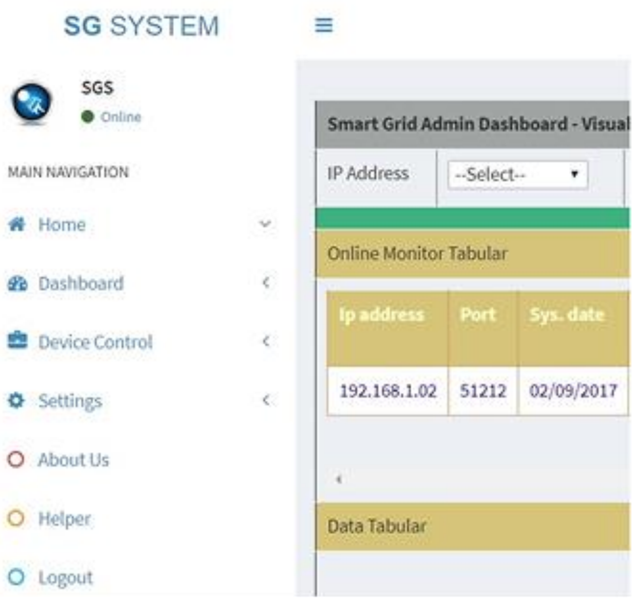
- All the power-generating sources, back up sources, and all the load points are connected to numerous sensors. The data from these sensors quantifies the power generation, the power demand and demand forecast.
- The controllers receive data from these sensors as input and scrutinise the data against the rules and regulations stipulated by the grid. Then, it passes the qualified data (i.e. within the acceptable range) after scrutiny to the Smart Grid Admin Dashboard through the associated modems. The data outside acceptable range activates the control system to issue directives to amend the status of the measuring device.
- Either LAN, WAN, CAN, HAN or satellite can be the source for data communication in the Smart Grid.
- The Cloud Server is the storage source for all the data generated with data exchange and optimisation capabilities with integrity.
- The Smart Grid Admin is the regulatory body, which can govern the ON/OFF status of renewable energy sources of the consumers to maintain the stability of the grid.

7.5. The Smart Grid Admin Dashboard

This section of the research proposes a web-based Smart Grid Admin Dashboard for Smart Grid administrative purposes and for end-users to schedule their energy usage [149]. The Cloud assists in data storage and information exchange efforts. To accomplish the task, the SaaS application service of the Cloud is considered because of its readiness, suppleness, and cost-effectiveness.

Dashboard Homepage: Figure 7.1 shows a portion of the SG Homepage with the navigation pane.

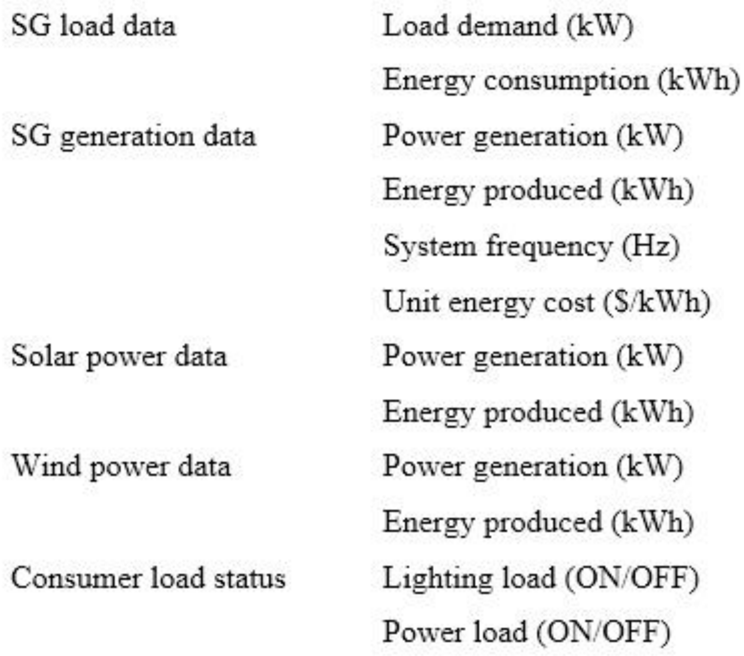
Dashboard Visualizer: To see clearly the prevailing data through the Smart Grid Admin Dashboard, a Visualizer segment is available as shown in Figure 7.2. The system administrators and end-users must provide their IP address, start date or time, and end date or time to use this facility. To maintain information boundaries, there are two types of IP addresses: one for system admin and another for the end-users. The system administers the data of all end-users, while the end-user can see those appropriate to him/her only. There are two display options in tabular form (Online Monitor Tabular and Data Tabular) and another in graphical form (Dashboard).



Ip address	Port	Sys. date
192.168.1.02	51212	02/09/2017

Figure 7.1. A portion of the Home page

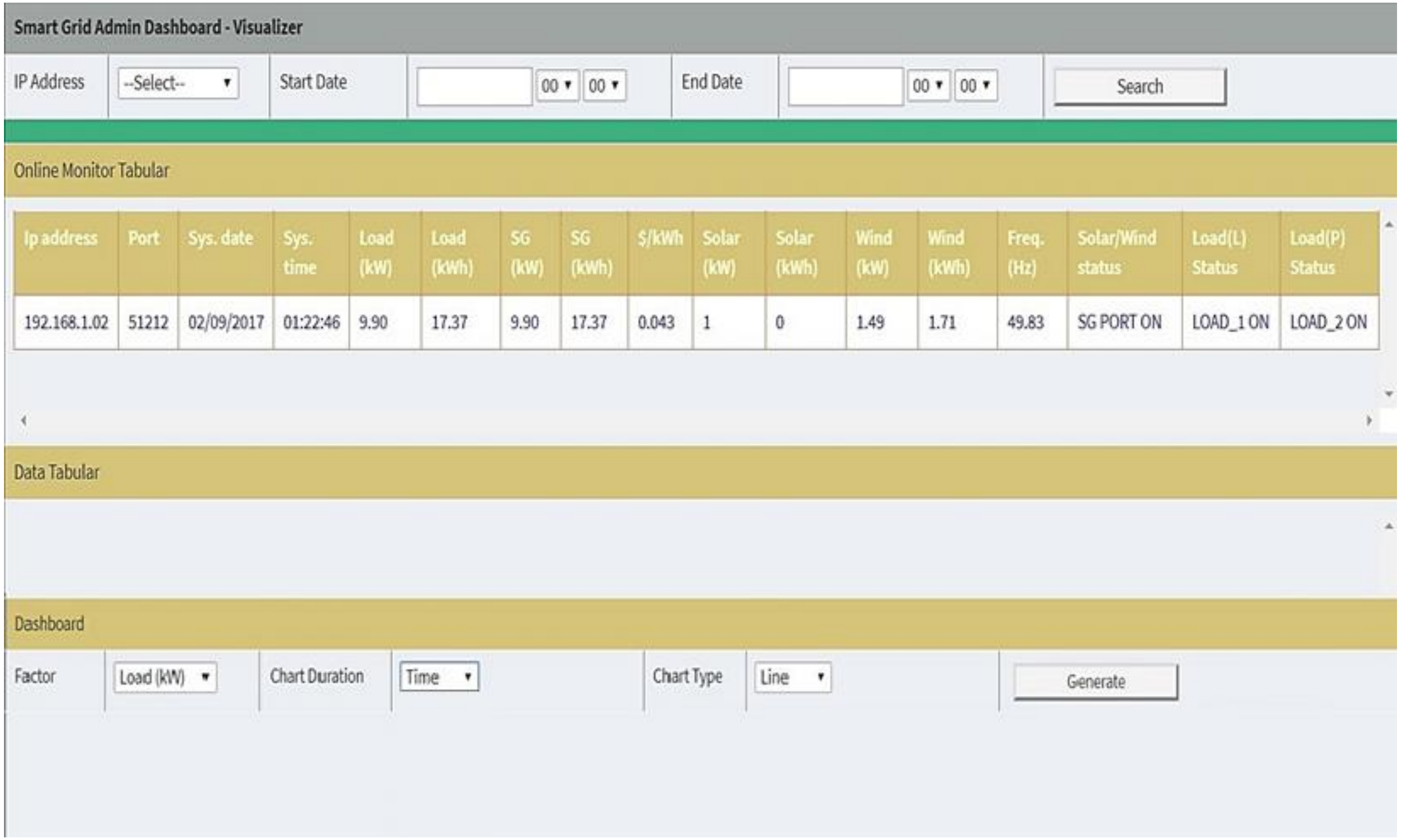
The user can visualize the subsequent data through the Online Monitor Tabular and the Data Tabular:



SG load data	Load demand (kW)
	Energy consumption (kWh)
SG generation data	Power generation (kW)
	Energy produced (kWh)
	System frequency (Hz)
	Unit energy cost ($/kWh)
Solar power data	Power generation (kW)
	Energy produced (kWh)
Wind power data	Power generation (kW)
	Energy produced (kWh)
Consumer load status	Lighting load (ON/OFF)
	Power load (ON/OFF)

The Online Monitor Tabular

- The information provided by the online monitor tabular is exclusively for the system admin. When the admin needs to monitor the latest system data, the admin can log in and complete his responsibilities. The information is not reachable to the latest data.



Smart Grid Admin Dashboard - Visualizer

IP Address: --Select--
Start Date: 00 00
End Date: 00 00

Online Monitor Tabular

Ip address	Port	Sys. date	Sys. time	Load (kW)	Load (kWh)	SG (kW)	SG (kWh)	$/kWh	Solar (kW)	Solar (kWh)	Wind (kW)	Wind (kWh)	Freq. (Hz)	Solar/Wind status	Load(L) Status	Load(P) Status
192.168.1.02	51212	02/09/2017	01:22:46	9.90	17.37	9.90	17.37	0.043	1	0	1.49	1.71	49.83	SG PORT ON	LOAD_1 ON	LOAD_2 ON

Data Tabular

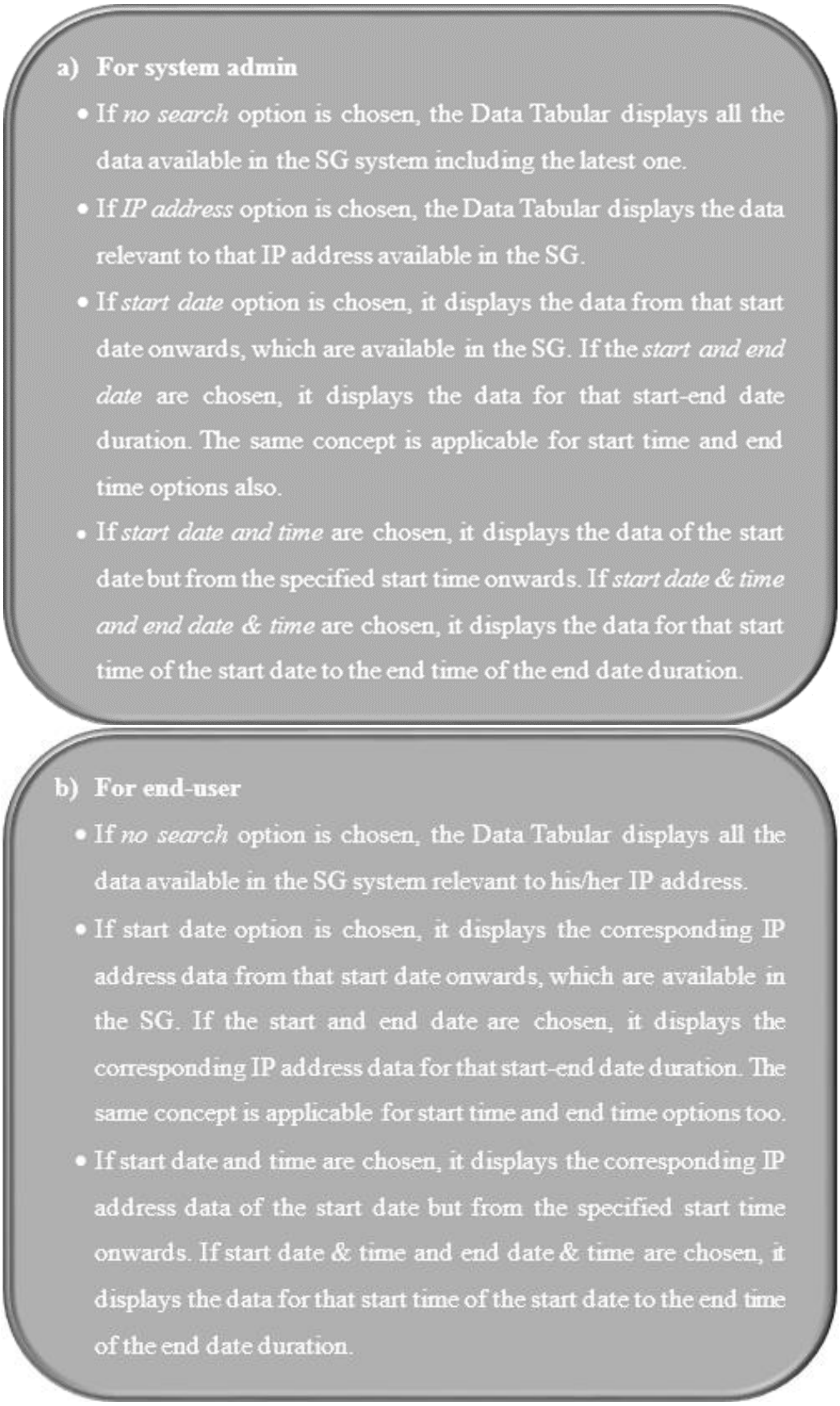
Dashboard

Factor: Load (kW)
Chart Duration: Time
Chart Type: Line

Figure 7.2. Smart Grid Admin Dashboard-Visualizer

The Data Tabular

Figure 7.3 displays the options available to the system admin and the end-users.



a) For system admin

- If *no search* option is chosen, the Data Tabular displays all the data available in the SG system including the latest one.
- If *IP address* option is chosen, the Data Tabular displays the data relevant to that IP address available in the SG.
- If *start date* option is chosen, it displays the data from that start date onwards, which are available in the SG. If the *start and end date* are chosen, it displays the data for that start-end date duration. The same concept is applicable for start time and end time options also.
- If *start date and time* are chosen, it displays the data of the start date but from the specified start time onwards. If *start date & time and end date & time* are chosen, it displays the data for that start time of the start date to the end time of the end date duration.

b) For end-user

- If *no search* option is chosen, the Data Tabular displays all the data available in the SG system relevant to his/her IP address.
- If start date option is chosen, it displays the corresponding IP address data from that start date onwards, which are available in the SG. If the start and end date are chosen, it displays the corresponding IP address data for that start-end date duration. The same concept is applicable for start time and end time options too.
- If start date and time are chosen, it displays the corresponding IP address data of the start date but from the specified start time onwards. If start date & time and end date & time are chosen, it displays the data for that start time of the start date to the end time of the end date duration.

Figure 7.3. Data Tabular Options

Dashboard for Graphical display

Three components, *Factor, Chart Duration* and *Chart Type components* are available in the Dashboard for Graphical Display. This graphical option is for the use of both the system admin as well the end-user. Figure 7.4 presents the various types of information available under the *Factor component* for displaying:

- system demand,
- system generation,
- unit cost of energy,
- solar and wind power generation (by end-users),
- system frequency, and
- lighting and power loads of the end-users.

The dashboard has the ability to preserve the retrieved information for future cross-referencing with no additional logging in required.

With the aid of the *Chart Duration component* (Figure 7.5), a logged in user can view the associated data for a day or for the year. The ability to see large amount of data is possible due to the Cloud's support.

Figure 7.6 shows two types of visual graphics, a line graph and a bar chart under the *Chart Type component*. To compare variations over the same period with more than one data group, the *line graph* is user-friendly and informative, and to parallel data between dissimilar groups or to track changes over time (day, week, month, and annual), the *bar chart* is the best choice.

7.6. Smart Grid Admin Dashboard Displays

The Admin Dashboard has several options for retrieving data by the system admin and end-users, a few options are highlighted below, with the data retrieval logic remaining the same for other options.

a) Data Visualization by Admin

In this option, the system admin can visualise the latest data entry of a system as in Figure 7.7 whereas the end-user cannot. In addition, the system admin can see the relevant data of an end-user by the end user's IP address, and the latest data from the grid as in Figure 7.8. The system admin can visualise all of the energy-related events from all the end-users on a specific date by entering the date of interest on the start date. Figure 7.9 shows some of the data for a few end-users on the date 2/9/2017.

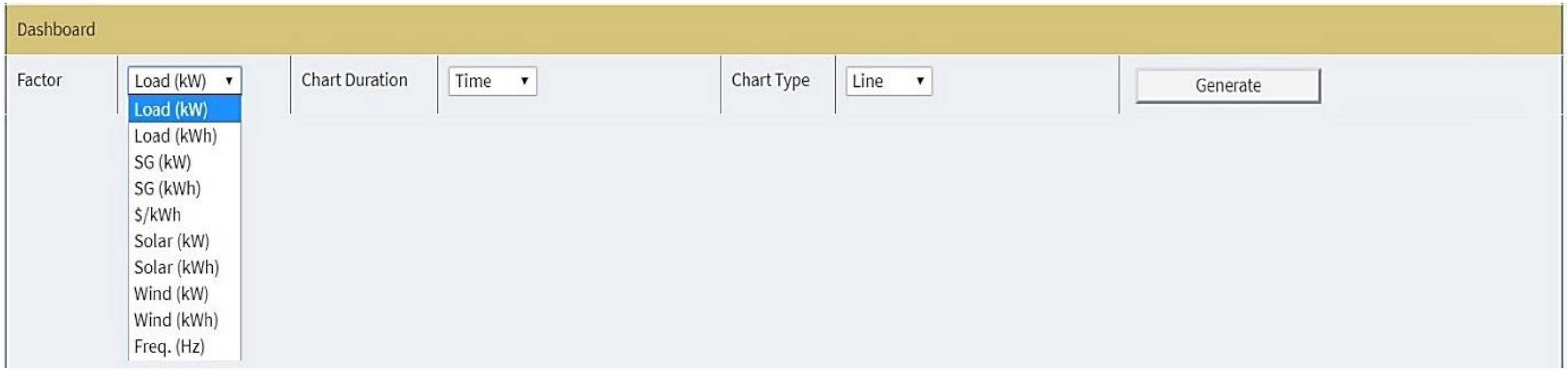


Figure 7.4. Factor Component

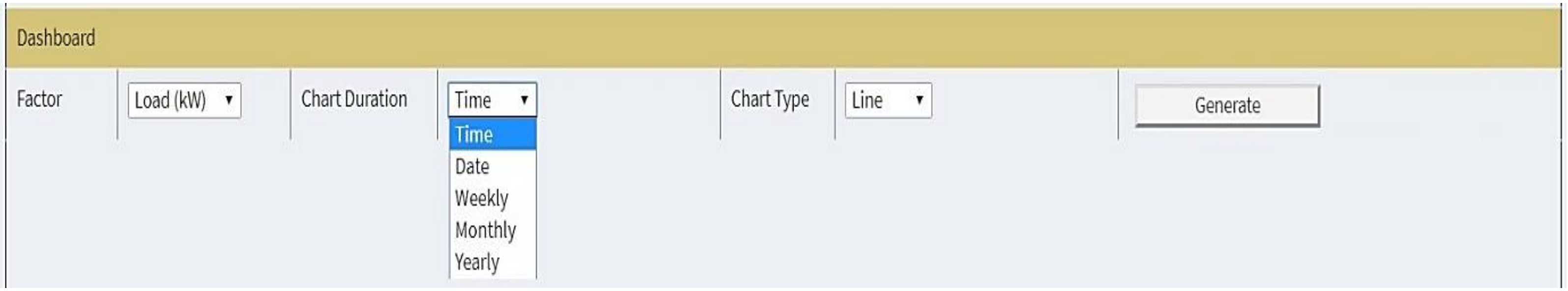


Figure 7.5. Chart Duration Component

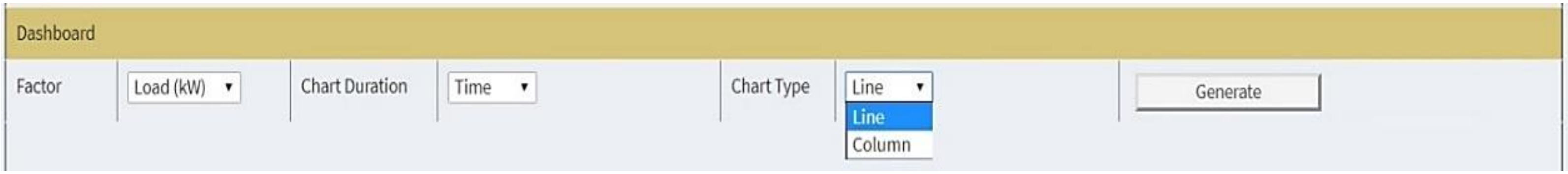
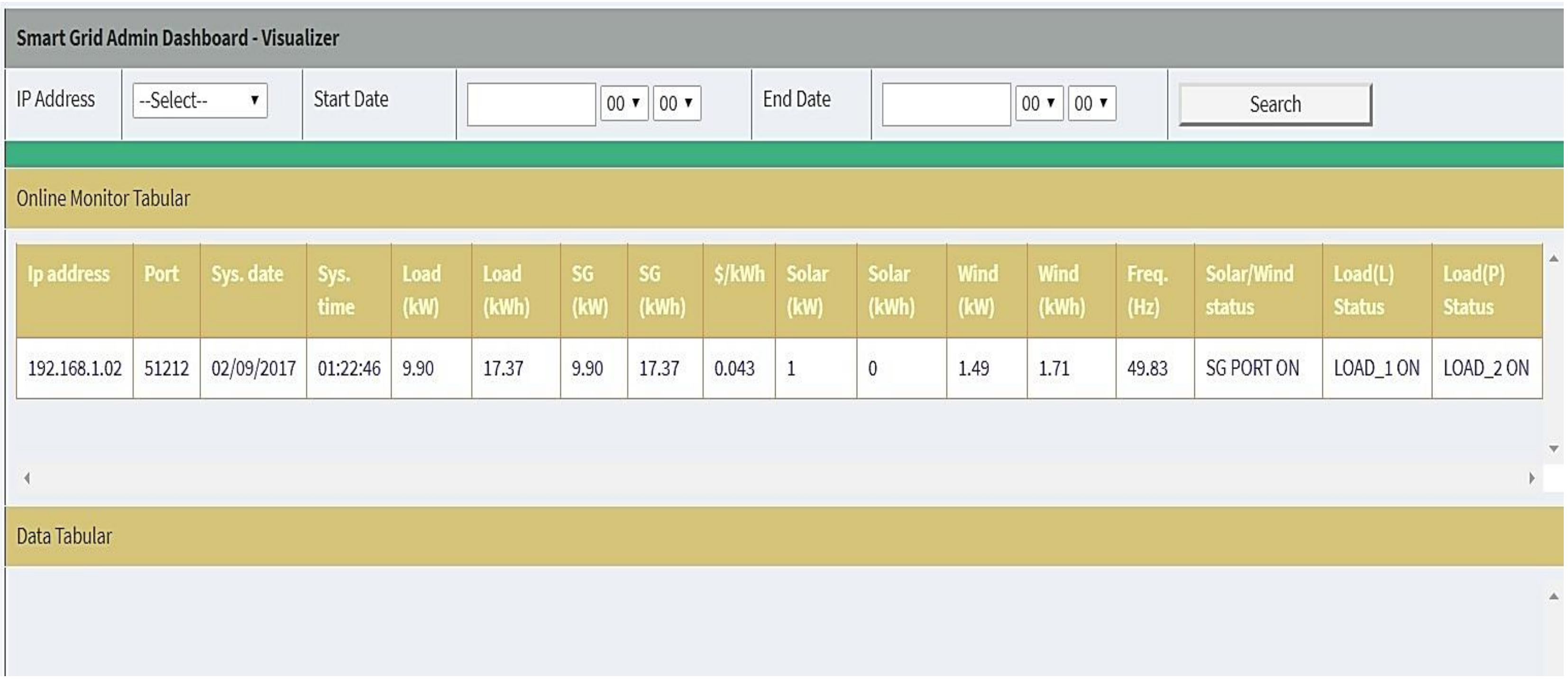
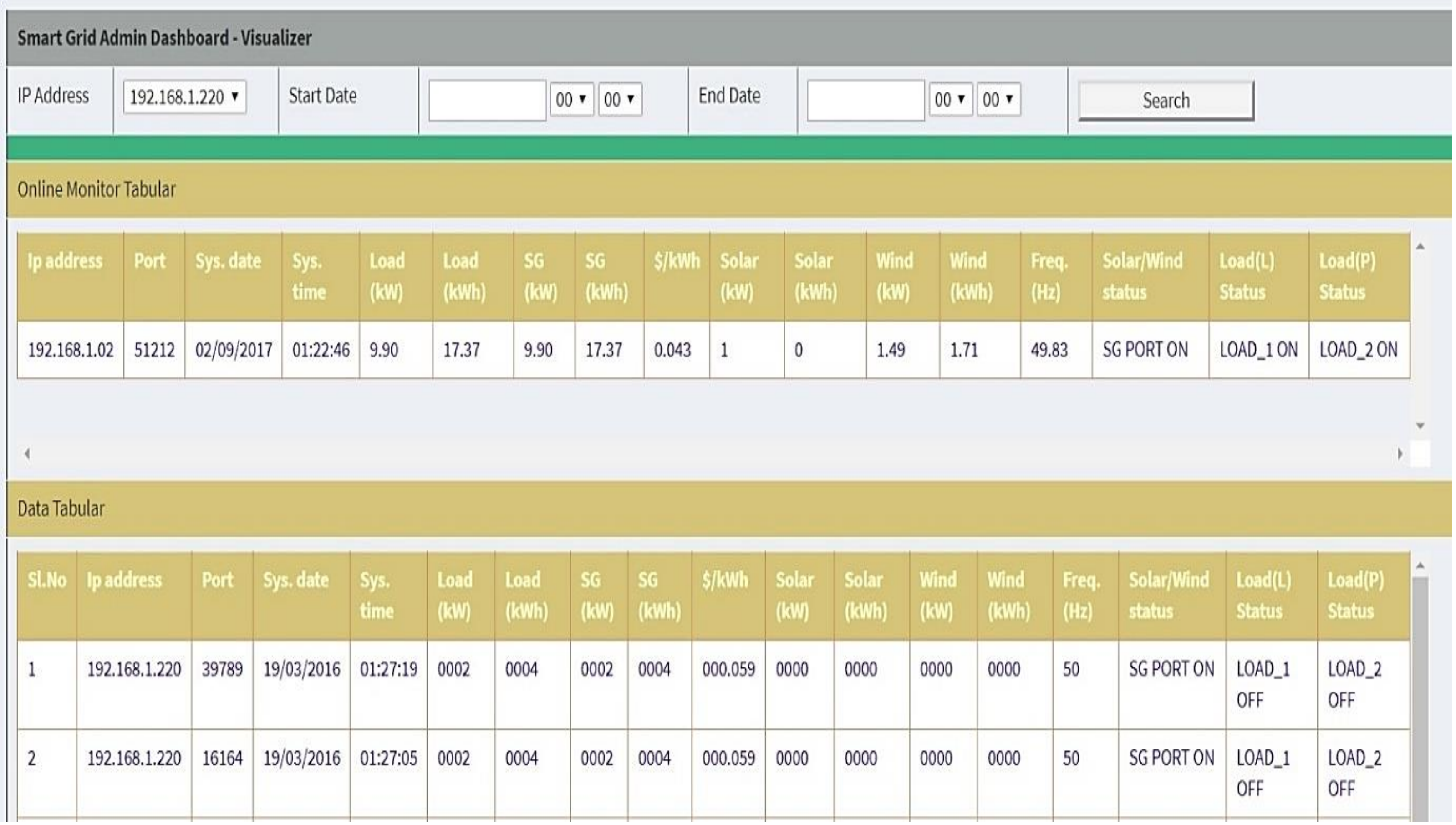


Figure 7.6. Chart Type Component



Ip address	Port	Sys. date	Sys. time	Load (kW)	Load (kWh)	SG (kW)	SG (kWh)	$/kWh	Solar (kW)	Solar (kWh)	Wind (kW)	Wind (kWh)	Freq. (Hz)	Solar/Wind status	Load(L) Status	Load(P) Status
192.168.1.02	51212	02/09/2017	01:22:46	9.90	17.37	9.90	17.37	0.043	1	0	1.49	1.71	49.83	SG PORT ON	LOAD_1 ON	LOAD_2 ON

Figure 7.7. Latest Data Visualisation by Admin



IP Address 192.168.1.220 ▾ Start Date 00 ▾ 00 ▾ End Date 00 ▾ 00 ▾

Online Monitor Tabular

Ip address	Port	Sys. date	Sys. time	Load (kW)	Load (kWh)	SG (kW)	SG (kWh)	$/kWh	Solar (kW)	Solar (kWh)	Wind (kW)	Wind (kWh)	Freq. (Hz)	Solar/Wind status	Load(L) Status	Load(P) Status
192.168.1.02	51212	02/09/2017	01:22:46	9.90	17.37	9.90	17.37	0.043	1	0	1.49	1.71	49.83	SG PORT ON	LOAD_1 ON	LOAD_2 ON

Data Tabular

Sl.No	Ip address	Port	Sys. date	Sys. time	Load (kW)	Load (kWh)	SG (kW)	SG (kWh)	$/kWh	Solar (kW)	Solar (kWh)	Wind (kW)	Wind (kWh)	Freq. (Hz)	Solar/Wind status	Load(L) Status	Load(P) Status
1	192.168.1.220	39789	19/03/2016	01:27:19	0002	0004	0002	0004	000.059	0000	0000	0000	0000	50	SG PORT ON	LOAD_1 OFF	LOAD_2 OFF
2	192.168.1.220	16164	19/03/2016	01:27:05	0002	0004	0002	0004	000.059	0000	0000	0000	0000	50	SG PORT ON	LOAD_1 OFF	LOAD_2 OFF

Figure 7.8. Data Visualisation by IP Address

Online Monitor Tabular

Ip address	Port	Sys. date	Sys. time	Load (kW)	Load (kWh)	SG (kW)	SG (kWh)	$/kWh	Solar (kW)	Solar (kWh)	Wind (kW)	Wind (kWh)	Freq. (Hz)	Solar/Wind status	Load(L) Status	Load(P) Status
192.168.1.02	51212	02/09/2017	01:22:46	9.90	17.37	9.90	17.37	0.043	1	0	1.49	1.71	49.83	SG PORT ON	LOAD_1 ON	LOAD_2 ON

Data Tabular

															ON	ON
23	192.168.1.02	51943	02/09/2017	01:17:35	12.35	19.76	12.35	19.76	0.043	0	0	1.85	2.32	49.83	SG PORT ON	LOAD_1 ON	LOAD_2 ON
24	192.168.1.02	52719	02/09/2017	01:17:21	10.05	15.08	10.05	15.08	0.043	2	0	0	0	49.97	SG PORT ON	LOAD_1 ON	LOAD_2 OFF
25	192.168.1.220	22315	19/03/2017	01:18:16	2000	0003	0015	0003	000.047	0000	0000	0000	0000	50	SG PORT ON	LOAD_1 ON	LOAD_2 ON
26	192.168.1.220	49534	19/03/2017	01:18:03	0015	0003	0015	0003	000.047	0000	0000	0000	0000	50	SG PORT ON	LOAD_1 ON	LOAD_2 ON

Figure 7.9. Data Visualisation of many end-users

b) Data Visualization by End-users

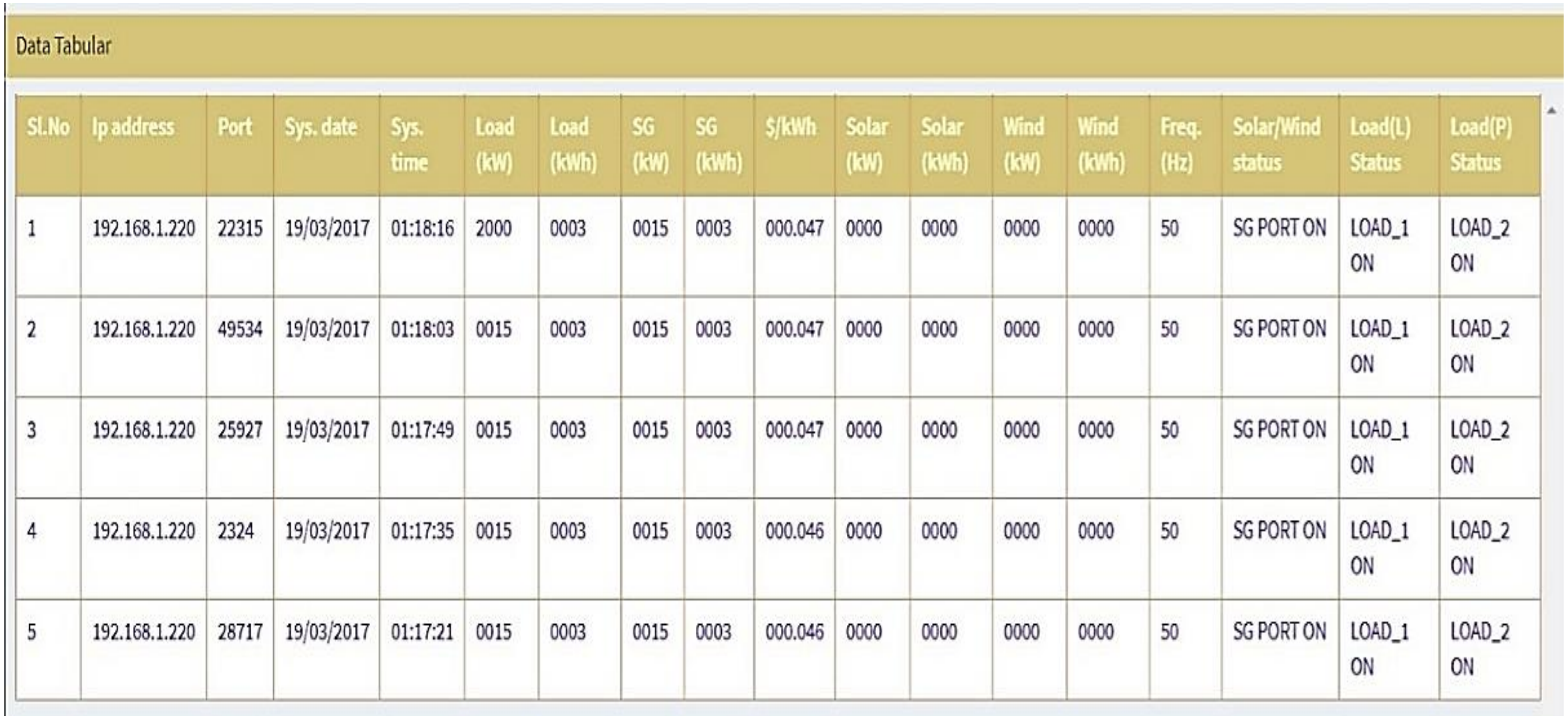
The Admin Dashboard has the option for viewing the energy-associated actions of an end-user during various hours of the day by entering the specific date and time. For an end user with an IP address 192.168.1.220 on 19/3/2016 during the hours 01:17:21 – 01:18:16, Figure 7.10 depicts the relevant data for the intended date and time.

The Admin Dashboard can help end-users reduce costs through better energy planning as well as improve the efficiency of the Smart Grid by participating in demand management by providing the time-of-use as well as the forecasted energy price. To access this service, the end-user can choose the *sub-component-unit energy cost*, $/kWh from the *Factor component*. Figure 7.11 shows the energy cost variations during a certain period in a *line graph* and *bar chart* form.

Apart from peak demand and load shedding participation, the Admin Dashboard [149] encourages end-users who generate their own renewable energy to manage their energy demands as well as export excess energy back into the grid rather than buying energy from the grid at an additional cost. The dashboard provides the option of visualising the end-users import and export energy behaviour by showing the ON and OFF indicators as seen in Figure 7.9.

7.7. Smartphones in Smart Grid

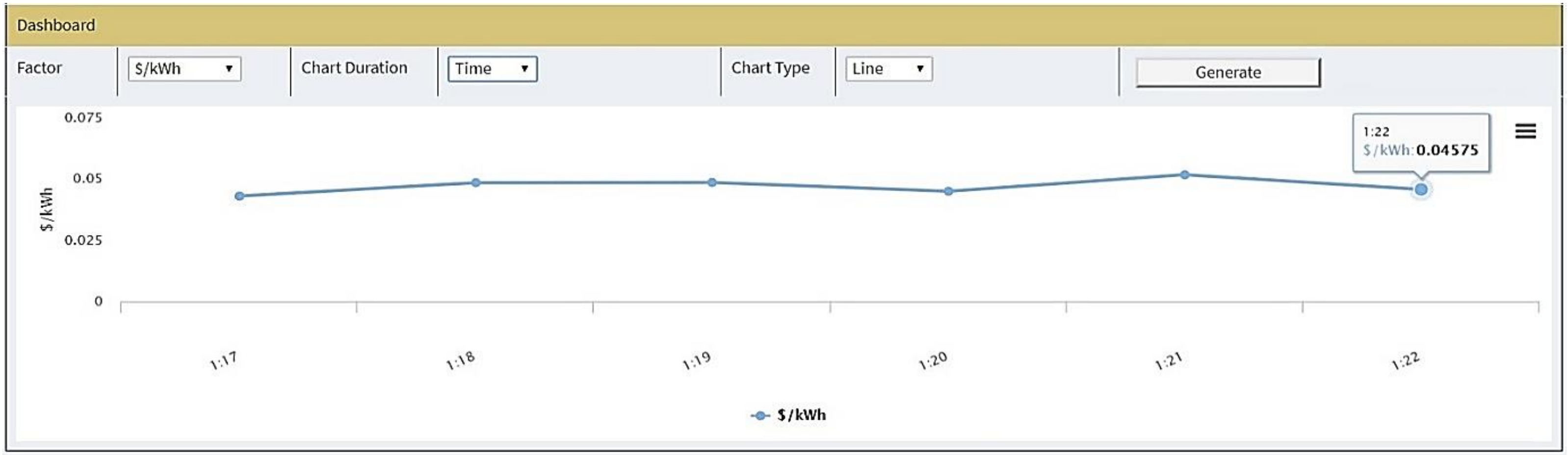
As the flow of information between the end-users and grid operators becomes increasingly essential in Smart Grids, new Dashboards and Smartphone energy management applications are rapidly being designed. Edison [109] introduced the SCE Demand Response (DR) Alert mobile application to obtain and share routine alerts about forthcoming DR events, carried directly to the end user’s smartphone. Cognizant [110] has developed both sequential and simultaneous screening smartphones for Smart Grid energy management information exchanges between customers and energy providers by embracing a mobile-first mind-set concept. Siemens Demand Response Management System (DRMS) is a demonstrated software platform, which permits utilities to coordinate all the features of their demand response (DR) programs through a single, cohesive system. The authors [111, 112] discussed how the energy portal logic could provide users feedback on the usage of their connected energy devices, the messages by the grid operators to the users about energy conservation, and how to remotely control or automate their devices through existing media, such as smartphone apps, websites, or computer software.



Data Tabular

Sl.No	Ip address	Port	Sys. date	Sys. time	Load (kW)	Load (kWh)	SG (kW)	SG (kWh)	$/kWh	Solar (kW)	Solar (kWh)	Wind (kW)	Wind (kWh)	Freq. (Hz)	Solar/Wind status	Load(L) Status	Load(P) Status
1	192.168.1.220	22315	19/03/2017	01:18:16	2000	0003	0015	0003	000.047	0000	0000	0000	0000	50	SG PORT ON	LOAD_1 ON	LOAD_2 ON
2	192.168.1.220	49534	19/03/2017	01:18:03	0015	0003	0015	0003	000.047	0000	0000	0000	0000	50	SG PORT ON	LOAD_1 ON	LOAD_2 ON
3	192.168.1.220	25927	19/03/2017	01:17:49	0015	0003	0015	0003	000.047	0000	0000	0000	0000	50	SG PORT ON	LOAD_1 ON	LOAD_2 ON
4	192.168.1.220	2324	19/03/2017	01:17:35	0015	0003	0015	0003	000.046	0000	0000	0000	0000	50	SG PORT ON	LOAD_1 ON	LOAD_2 ON
5	192.168.1.220	28717	19/03/2017	01:17:21	0015	0003	0015	0003	000.046	0000	0000	0000	0000	50	SG PORT ON	LOAD_1 ON	LOAD_2 ON

Figure 7.10. Data Visualisation of an end-user (IP: 192.168.1.220)



Dashboard

Factor: $/kWh

Chart Duration: Time

Chart Type: Line

Figure 7.11 (a). Energy Cost in Line Chart Form

Dashboard

Factor: $/kWh

Chart Duration: Time

Chart Type: Column

Figure 7.11 (b). Energy Cost in Column Chart Form

This paper proposes a communication application through smartphones to improve management of the power supply and demand by energy suppliers, as well as end-users. The Smart Grid administrators can control and make decisions for system performance optimisation through this smartphone application, while the end-users can monitor their electrical power consumption, unit energy costs, weather conditions, renewable energy generation, etc. To accommodate these features as discussed, a smartphone application is presented in the next section.

7.8. The Smartphone App

The smartphone application allows the registered users (both system administrators and end-users) to monitor the existing data of the Smart Grid by providing their respective *user name* and *password*. Like the Admin Dashboard, there are two categories of usernames: one exclusively for the system admin, and the other for the end-user. The system admin can control, monitor, and manipulate the data of all end-users, whereas the end-user is entitled to view the information and data relevant to him/her only.

7.8.1. Smartphone App for Real-time monitoring

To know what precisely occurs at a definite time in the various physical locations of the Smart Grid system plays a dynamic role in the entire grid's operations and the preventative and control measures to overcome serious incidents. To ensure grid security and reliability, the placement of Phasor Measurement Units (PMUs) becomes crucial. This new app is designed to monitor grid operations on a real-time basis from data provided by the PMUs. For complete system observability, the PMUs must be placed at strategic locations in a cost-effective manner. The application has been developed based on the Modified Invasive Weed Optimisation method and has been tested by several analytical systems. The outcome of an IEEE 7-bus and a 14-bus system analysis is presented through iPhone screenshots.

Login : New user must register first and an existing user must login directly with the respective user name and password.

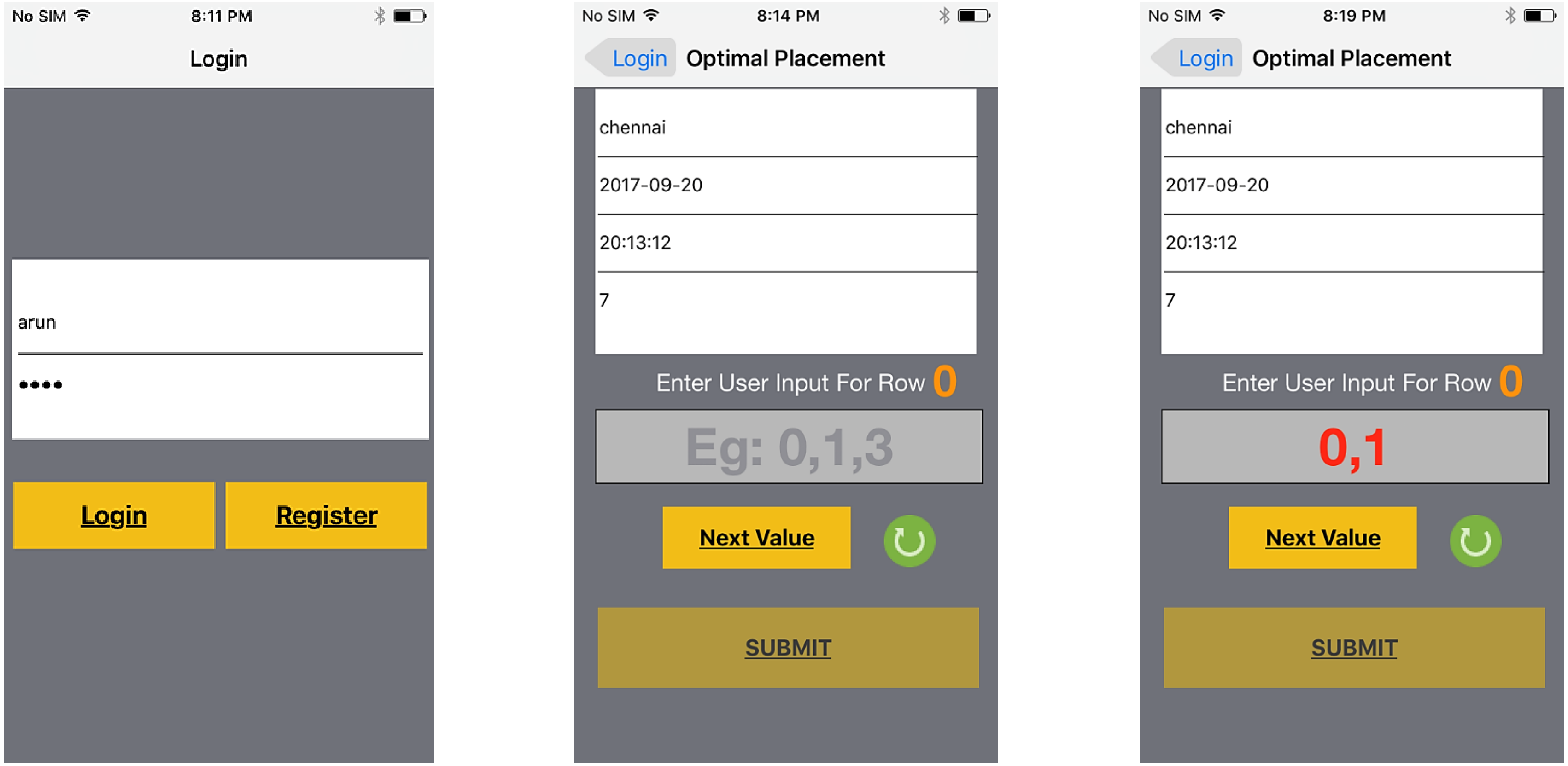
Smart Grid location : The admin must enter the grid location and the number of buses in the grid system as in Figure 7.12

(a). The iPhone screen displays the intended location, the number of buses, and the present date and time as in Figure 7.12 (b).

To perform optimal PMU placement, elements of the connectivity matrix must be entered. For a 7-bus system, the connectivity matrix has 7-rows (0 to 6) and 7-columns (0 to 6), and there will be 49elements with either a 0 or 1 value. To save time, effort, and memory space, only elements having a value of 1 will be used in the Enter User Input for Row slot. For instance, in row 0, columns 0, 1, and 3 have the value of 1 as displayed in Figure 7.12 (b). Figure 7.12 (c) displays the actual entry process for row 0. Once completed for row 0, pressing the Next Value button will move to the next row 1 as in Figure 7.12 (d), and so on. Once the values of row 6 have been entered, the *Submit button* prompts as in Figure 7.12 (e), and tapping it displays the optimal solution as in Figure 7.12 (f).

Optimal solution : The optimal display (Figure 7.12 (f)) presents the bus numbers where the PMUs have been placed, and the system observability level. Column 2 of the display shows the PMUs have been placed at buses 1 and 3 (indicated by value 1). Column 3 shows the level of observability. Since all the values are 1 and above, the system is completely observable.

The IEEE 14-bus system analysis is also shown. It has 196 elements with either a 0 or value of 1. The admin as a user has entered these values for all rows (0 to 13) and columns (0 to 13) and a sample screen shot is shown for row 13 as in Figure 7.13 (a). The optimal PMU placements are presented in Figure 7.13 (b) and (c). For a 14-bus system, four PMUs are needed and their strategic locations have been found to be buses 1, 5, 6, and 8 and all the buses are of a completely observable nature.



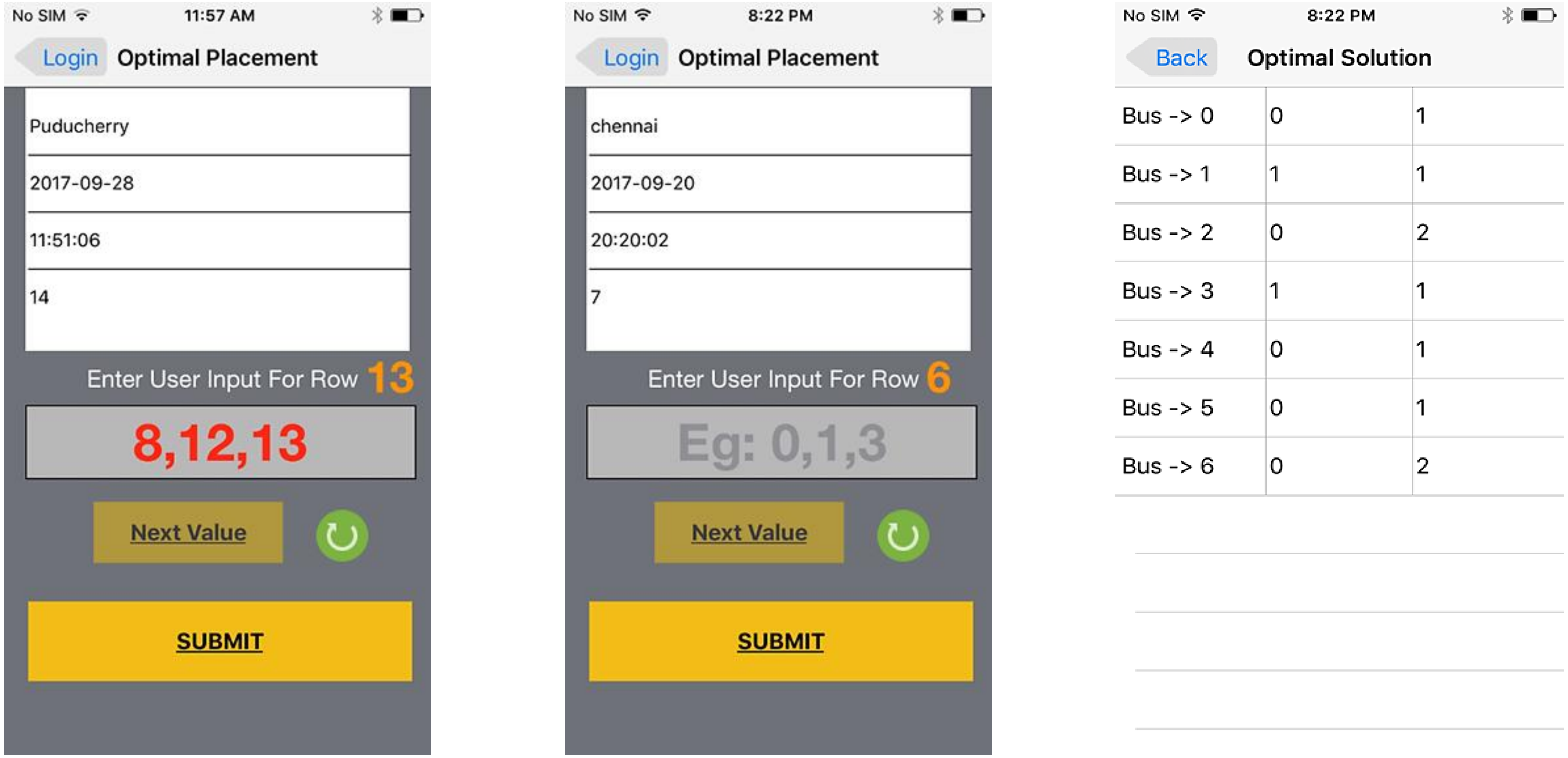
arun
••••

chennai
2017-09-20
20:13:12
7

chennai
2017-09-20
20:13:12
7
0,1

(a) Log in screen (b) Intended location (c) Row 0 entry process

Figure 7.12. Smartphone with IEEE 7-bus system



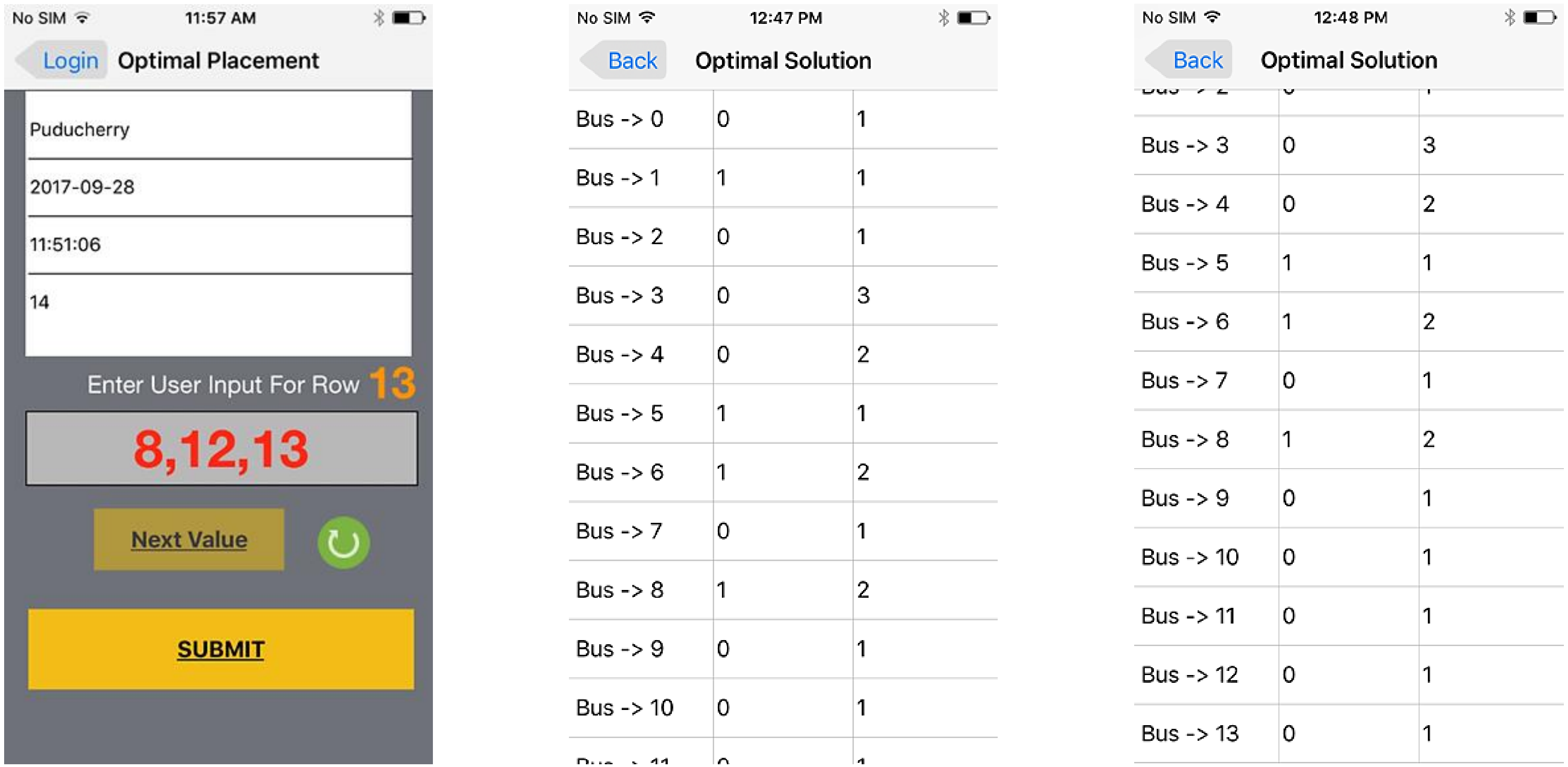
Puducherry
2017-09-28
11:51:06
14
Enter User Input For Row 13
8,12,13

chennai
2017-09-20
20:20:02
7
Enter User Input For Row 6
Eg: 0,1,3

Bus -> 0	0	1
Bus -> 1	1	1
Bus -> 2	0	2
Bus -> 3	1	1
Bus -> 4	0	1
Bus -> 5	0	1
Bus -> 6	0	2

(d) Row 1 - completion (e) Submit prompt (f) Optimal solution

Figure 7.12. IEEE 7-bus system



Puducherry

2017-09-28

11:51:06

14

Enter User Input For Row 13

8,12,13

(a) Test system

Bus -> 0	0	1
Bus -> 1	1	1
Bus -> 2	0	1
Bus -> 3	0	3
Bus -> 4	0	2
Bus -> 5	1	1
Bus -> 6	1	2
Bus -> 7	0	1
Bus -> 8	1	2
Bus -> 9	0	1
Bus -> 10	0	1

(b) Optimal solution

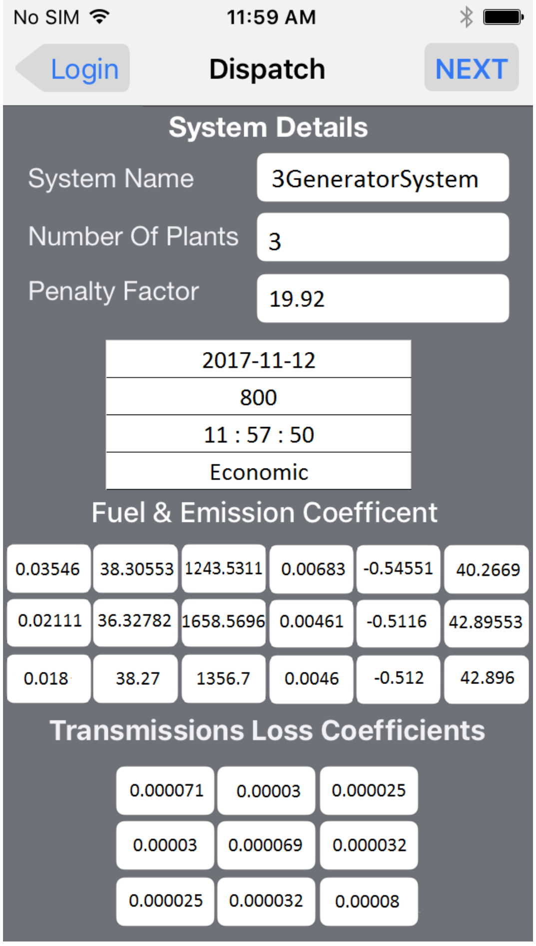
Bus -> 3	0	3
Bus -> 4	0	2
Bus -> 5	1	1
Bus -> 6	1	2
Bus -> 7	0	1
Bus -> 8	1	2
Bus -> 9	0	1
Bus -> 10	0	1
Bus -> 11	0	1
Bus -> 12	0	1
Bus -> 13	0	1

(c) Optimal solution continuation

Figure 7.13. Smartphone with IEEE 14-bus

7.8.2. Smartphone App for Generation Scheduling

The generation scheduling smartphone application is designed in such a way that the system admin controls the dispatching strategy whereas the end-users can see the energy cost (fuel cost primarily) and the emission levels from the Smart Grid system for the intended dispatch option. Since the power demand is of a variable nature, there is a provision for entering the demand in MW, and the probable time. In the application, there are standard system data such as 3 generators, 6 generators, and a IEEE 30-bus system, etc. for ease of operation, and can also accommodate any size of systems. The fuel costs and emission data for a system remain the same irrespective of the varying demand conditions. There is an option for choosing a dispatch type from the dispatch options: economic, emission, and combined economic and emission dispatches. Figure 7.14 (a) displays the screen shot of the smartphone app illustrating all the above data input options. Figures 7.14 (b), (c), and (d) provide a sample economic dispatch outcome from the 3 generators, 6 generators, and IEEE 30-bus system.



System Details

System Name: 3GeneratorSystem
Number Of Plants: 3
Penalty Factor: 19.92

2017-11-12
800
11 : 57 : 50
Economic

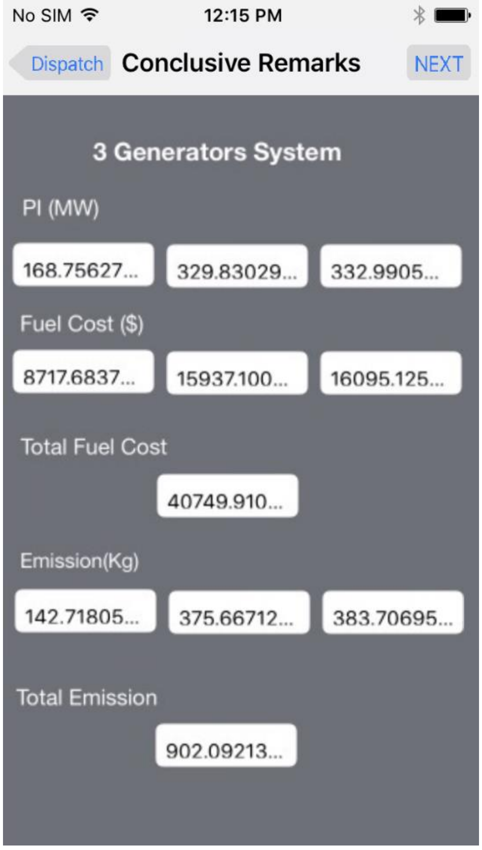
Fuel & Emission Coefficent

0.03546	38.30553	1243.5311	0.00683	-0.54551	40.2669
0.02111	36.32782	1658.5696	0.00461	-0.5116	42.89553
0.018	38.27	1356.7	0.0046	-0.512	42.896

Transmissions Loss Coefficients

0.000071	0.00003	0.000025
0.00003	0.000069	0.000032
0.000025	0.000032	0.00008

Figure 7.14 (a) Data input



3 Generators System

PI (MW)

168.75627... 329.83029... 332.9905...

Fuel Cost ($)

8717.6837... 15937.100... 16095.125...

Total Fuel Cost

40749.910...

Emission(Kg)

142.71805... 375.66712... 383.70695...

Total Emission

902.09213...

(b) **3 generator system output**

6 Generators System

PI (MW)

35.35889... 13.847541... 144.70812...

141.50299... 290.99011... 282.59470...

Fuel Cost ($)

2310.1467... 1110.8169... 7482.6673...

7373.8971... 14044.100... 13608.351...

Total Fuel Cost

45929.98...

Emission(Kg)

30.683919... 19.200194... 104.35037...

99.83335... 284.50590... 266.59795...

Total Emission

805.17171...

(c) 6 generator system output

IEEE Test Bus System

PI (MW)

84.487042... 65.976703... 92.065718...

181.315177... 212.57957... 194.16440...

Fuel Cost ($)

4320.4275... 3481.3921... 4666.602...

9029.0811... 10436.770... 9633.356...

Total Fuel Cost

41567.630...

Emission(Kg)

163.96356... 111.93573... 181.65573...

266.15493... 278.39389... 288.10125...

Total Emission

1290.2051...

(d) IEEE 30 bus system output
Figure 7.14. Dispatch outcomes

For ease of visualization by the system admin and end-user, the generation scheduling dispatch outcome shows the individual plant generating status, the fuel costs incurred by each participating plant, the overall fuel costs required to meet the load demand, and the individual plant emissions along with the overall emissions due to the power generated. Other dispatch outcomes can be performed similar to the economic dispatch option already provided on the Cloud.

7.9. Conclusions

This section of the research presented a Cloud-assisted Smart Grid Admin Dashboard and a Smartphone App for system administrators and end-users. These services have been designed to be portable and user-friendly and help facilitate the exchange of data between utilities and consumers on a real-time basis, and update consumers of utility decisions on energy production costs, service continuity, maintenance scheduling, and probable blackouts due to weather, cyber threats. Moreover, the Smart Grid administrators can control and make decisions for system performance optimisation. Cloud Computing, as a reliable platform promoted as providing trustworthy and necessity-based access to various computing resources, has been the nucleus for these services.

Hence, the research question 1.7 (d) has been answered and the research objective 1.8 (c) has been achieved through the introduction of the Smart Grid Administrative Dashboard and the Smartphone App [149] so consumers receive all available energy-related information transparently in real-time and can better plan their daily activities efficiently and economically, which in turn helps the Smart Grid in its generation-demand management. Though both the Smart Grid Admin Dashboard and the Smartphone App have multitasking capabilities, only a few applications have been discussed to demonstrate their suitability for all levels of users.

Chapter 8

CONCLUSIONS

This PhD research proposed Cloud Computing strategies for enhancing Smart Grid performance in developing countries. The optimal placement of Phasor Measurement Units with priority for renewable energy connected buses, wireless communication tactics for data dissemination and querying, and optimisation of energy costs with environmental benefits are the main concepts focussed on in this research.

Chapter 1 discussed the global economic dependence on energy sustainability, the persistent fiscal as well as ecological need for the redesign of the existing energy system with an intelligent, reliable and efficient energy system, i.e. the Smart Grid. This is then followed by a review of the reasons why developing countries need a Smart Grid, such as the *need for increasing capacity, the significant power losses, the environmental degradation, the quality and reliability of the power supply, and energy deficits.* In addition, there are distinct advantages for the widespread adoption of Cloud Computing in the Smart Grid environment. Finally, the, research questions 1.7 (a) to (d), and research objectives 1.8 (a) to (c) were presented followed by the research contributions.

Chapter 2 presented a comprehensive assessment of Phasor Measurement Unit placement in a Smart Grid, such as the bisecting search method, a non-dominated sorting genetic algorithm, the simulated annealing and genetic algorithms, the unique perception of depth of un-observability method, the binary integer programming technique, and the invasive weed optimisation strategy. Wireless communication technology suitable for Smart Grids to aggregate, store, and disseminate the data gathered by the PMUs to control centres, utility stakeholders and consumers for appropriate action was also discussed. Further, there was an analysis of the optimisation strategies to provide affordable, environmentally friendly energy such as multi-objective Particle Swarm optimisation for environmental/economic dispatch, fireworks algorithm for unit commitment, two-stage robust optimisation for constrained unit commitment, the binary/real coded artificial bee colony algorithm, and the binary neighbourhood field optimisation strategy. In addition, there was an assessment of the applications on the Cloud in Smart Grid energy management, communication and information management, and the advent of dashboards and smartphones for supplier-consumer interactions. This chapter is of great help to identify the research gap and the data availability.

Chapter 3, discussed how to provide real-time monitoring of a renewable energy integrated Smart Grid using the redesigned invasive weed optimisation algorithm and a model was presented for the distribution of PMUs at certain buses to accommodate renewable energy and intermittent resources, which introduced unique challenges to grid operators. This enhanced technology allows for the best-fit “weeds” with more opportunities to survive and produce more seeds, which greatly overcomes the premature convergence issues experienced by the conventional IWO. The proposed User-defined Invasive Weed Optimisation strategy is cost-effective, fast, and ultimately provides complete system observability. Thus by the proposed optimisation strategy, the research gap to monitor Smart Grid performance has been fulfilled, the question 1.7 (a) how to enhance the performance of Smart Grid at a real-time basis and question 1.7 (b) how to overcome the security and stability challenges on incorporating renewable energy sources in Smart Grids by an economical manner have been answered, and the research objective 1.8 a) (i) enhancing the performance of the Smart Grid by an appropriate PMU placement strategy has been achieved.

Chapter 4 described a wireless communication strategy for data dispensing and querying suitable for a Smart Grid in a wireless environment. A wireless broadcasting system suitable for mobile devices known as wireless XML stream has been introduced for Smart Grid communications. The Wireless XML Streaming is an appropriate technique for broadcasting XML data over a mobile environment for efficient query processing by consumers to avoid excessive consumption of consumers’ smartphone battery power. Thus, by the presented wireless communication tactics, the research question 1.7 (a) has been answered further and the research objective 1.8 a) (ii) wireless communication tactics for data dissemination and querying, has been achieved.

Chapter 5 proposed a sustainable economic and emission control strategy for the Smart Grid, which is a non-iterative analytical algorithm for generation scheduling by Smart Grids subject to system equality and inequality constraints. Transmission power loss is a significant concern and affects the unit cost of generation. Three types of dispatching were proposed to address this concern, economic, emission, and combined economic and emission dispatching for improving the performance of Smart Grids. A single direct dispatching algorithm was used for all three dispatches, which is fast, cost-effective, Cloud-based, and no needs for switching to another dispatch. Thus, by the proposed dispatching algorithm, the research question 1.7 (c) has been answered and the research objective 1.8 (b) has been achieved by providing an attractive price for environmentally benign energy suitable for Cloud services in a Smart Grid.

Chapter 6 of this research introduced a Cloud-based biomass resource management strategy for Smart Grid capacity enhancement. The collecting, transporting, and processing of solid waste has become a great challenge for developing countries. This section of the research identified the waste-to-energy recovery strategy as a source for expanding the energy generating capacity of Smart Grids. As transporting waste to the power generation site is a major share of the solid waste management budget, an economical and environmentally friendly transportation optimisation algorithm has been newly proposed. This section of the study optimised the solid waste transportation for energy recovery to enhance the Smart Grid capacity [140] in an economical and environmentally friendly way; thus achieving research objective 1.8 (b) further.

Chapter 7 demonstrated a Smart Grid Admin Dashboard and a Smartphone App for system admin staff and end-users. These tools allow end-users to receive energy-related information transparently on a real-time basis and aids in planning consumers activities in an economical way, which in turn helps the Smart Grid in generation-demand management. Moreover, the smart grid administrators can control and make decisions for system performance optimisation. Hence, the research question 1.7 (d) has been answered and the research objective 1.8 (c) has been achieved through the introduction of the Smart Grid Administrative Dashboard and the Smartphone App [149] so consumers receive all available energy-related information transparently in real-time.

Finally, this chapter completes the research thesis by summarising and highlighting the principal contributions and possible future exploration directions.

8.1. Thesis Contributions

The main outcomes of this study have been published in six research papers [15, 25, 89, 139, 140, and 149]. The primary contributions to achieve the research objectives and solutions to the research questions are summarised as follows.

a) A comprehensive review on Smart Grid Developments across the globe has been presented supporting the essential need Smart Grids because of its economic, environmental, and service reliability benefits, and its encouraging international acceptance.

b) The research brought out the key reasons why developing countries need a Smart Grid. The need for adding capacity, the significant transmission and distribution power losses, the environmental degradation due to electricity generation, the poor quality and reliability of the power supply, and the energy deficits were the main reasons identified. In addition, the implementation issues of Smart Grids in developing countries were also explored.

c) The existing monitoring and observation systems have their technical constraints to cope with the ever-changing renewable energy markets, and these systems need improving to meet the Smart Grid requirements. The PMU placement strategy meant for this purpose has not been prioritised to address the renewable energy connected buses, since a loss of renewable energy generation may result in a system blackout. A cost-effective and fast PMU placement approach with an emphasis on renewable energy buses has been developed, the User-defined Invasive Weed Optimisation (UIWO) strategy. Test results using the IEEE and the Indian utility grid confirm its suitability.

d) A wireless broadcasting system suitable for mobile devices known as wireless XML stream has been introduced for Smart Grid communications. Wireless XML Streaming is an appropriate technique for broadcasting XML data over a mobile environment for efficient query processing by consumers as to avoid excessive consumption of consumer’s battery power. Research has revealed the contribution of the query-processing algorithm has a significant effect in identifying frequent queries. The frequency threshold considered is very quick and did not affect the update throughput. The space required by the algorithm was less than 1MB and the cost involved was similar to the cost of executing a kilobyte size data. This size is small enough to fit within a modern second level cache.

e) This research proposed a new non-iterative analytical algorithm for generation scheduling of Smart Grids with economic and emission control strategies on the Cloud platform. The objectives were achieved only through changes in operating and control policies, without any changes to the system configuration. Being a direct optimisation algorithm on the Cloud platform, the solution time is short using little memory space. There is no need for an initial estimate to start with or further updating while iterating. Further, test results indicated the strategy discussed is appropriate for the economic, the emission or the combined economic and emission controls, thereby avoiding having to switch to another algorithm, depending on the objectives.

f) To enhance the addition of generating capacity in a Smart Grid, this research introduced a waste-to-energy concept. For this purpose, the biomass component of the waste generated has been considered and its transportation has been optimised subject to economic and environmental constraints with the Cloud's assistance. A realistic Indian based-model has been developed with an additional generating capacity of 12 MW has been virtually achieved.

g) A Cloud-assisted Smart Grid Admin Dashboard and Smartphone App to improve system administrators and end-users' functionality has been developed. These tools facilitate the exchange of data between utilities and consumers on a real-time basis, and the updating of utility decisions to consumers on energy production costs, service continuity, maintenance scheduling, and probable blackouts due to weather, and cyber threats. Moreover, the Smart Grid administrator can control and make decisions for system performance optimisation.

8.2. Scope for Future Work

The following areas are subjects for further research in the continuation of this thesis.

a) During the PMU placement optimisation process, the buses with renewable energy sources were given priority to maintain system reliability. However, for possible future research, this algorithm has room for optimising the redundancy at all the buses. In addition, the proposed strategy could be extended to systems considering the impact of zero-injection buses, single-line outage, and PMU failures in the future.

b) The proposed Wireless XML Streaming for broadcasting XML data over a mobile environment for quick query processing by consumers has been tested with only a few clients. When the number of clients increases, there is a chance for traffic congestion and reduced speed of operation. As a possible future topic, determining the optimum number of clients, the query processing time and the energy requirements could be studied with a larger model or in a small Smart Grid environment.

With dynamic data analysis and control, more power providers will be able to link to the grid and sell power as supply and demand become more fluid and interconnected. Consumers and businesses, likewise, will become more adept at monetizing their consumption patterns. Hence research expansion is probable with dynamic data analysis and control.

c) The economic and emission control strategy proposed for a Smart Grid has been studied with thermal power plants with quadratic cost functions. For economic and emission controls, the switching of fuels is another strategy followed in energy systems. As a possible research topic, this option could be of use for demand management in Smart Grids. In addition, apart from the transmission loss consideration as a cost function, the operating efficiency of the generating plants and the station transformer efficiency could also be accounted for by appropriate means while optimising.

Software-based demand response reduces the cost of implementing demand response by up to 90%. More importantly, it introduces the concept of visibility to demand response. Utilities, or rather, the cloud-based platforms employed by utilities, can look at the consumption patterns of millions of its users at once and rapidly determine which customers would be willing to participate in a demand response event, how much these customers will charge for participation, and how much was actually saved. Hence, the optimisation strategy could include demand response on a real-time basis.

d) Adding generating capacity to the Smart Grid through the waste-to-energy concept has been experimented with in an Indian context. India is a semi-tropical country with limited rail fall and 50-60 % humidity. Moreover, only diesel vehicles with an open roof body construction were considered for transportation. The magnitude of the additional generating capacity depends on the quality and quantity of the biomass transferred. The criteria such as humidity, rain, road conditions and type of vehicle could be changed by choosing different regions or countries and then the proposed strategy could be followed.

e) Though both the Smart Grid Admin Dashboard and the Smartphone App have multitasking facilities, only few applications were incorporated. The suitability of these apps is limited to a maximum of 62-buses and the data input is a time-consuming job. Hence, further research can be done on modifying the programming to suit larger systems with additional tasks, and a more user-friendly input instrument.

REFERENCES

1. Hebra, A., *The reality of generating and transmitting ultrahigh voltage power, Part 1.* IEEE Instrumentation & Measurement Magazine, 2012. **15**(2): p. 26-31.
2. Locke, G. and P.D. Gallagher, *NIST framework and roadmap for smart grid interoperability standards, release 1.0.* National Institute of Standards and Technology, 2010. **33**.
3. *WEO - World Energy Outlook Database*. 2014; Available from: www.worldenergyoutlook.org/weo2014/.
4. Andersson, G., et al., *Causes of the 2003 major grid blackouts in North America and Europe, and recommended means to improve system dynamic performance.* IEEE transactions on Power Systems, 2005. **20**(4): p. 1922-1928.
5. Rios, M.A., et al., *Value of security: modeling time-dependent phenomena and weather conditions.* IEEE Transactions on Power Systems, 2002. **17**(3): p. 543-548.
6. *Toward a Smarter Grid ABB's Vision for the Power System of the Future*. 2010.
7. DOE, *The Smart Grid-an introduction*. 2008, (US) Department of Energy.
8. Huang, Qi, Shi Jing, Jianbo Yi, and Wei Zhen. "Data Management in Smart Grid", Innovative Testing and Measurement Solutions for Smart Grid, 2015.
9. Aiello, M. and G.A. Pagani. The smart grid's data generating potentials. in Computer Science and Information Systems (FedCSIS), 2014 Federated Conference on. 2014. IEEE.
10. Deign, J., *DATA MANAGEMENT AND ANALYTICS FOR UTILITIES*. 2013, Smart Grid Update.
11. Mell, P. and T. Grance, *The NIST definition of Cloud Computing.* 2011.
12. Plummer, D., *Cloud Computing: Definition and describing an emerging phenomenon.* Gartner Group, Stamford, CT, 2008.
13. Armbrust, M., et al., *A view of Cloud Computing.* Communications of the ACM, 2010. **53**(4): p. 50-58.
14. Fehrenbacher, K. *5 Reasons Why Developing Countries Need Smart Grids, Too*. 2011; Available from: https://gigaom.com/2010/02/11/5-reasons-why-developing-countries-need-smart-grids-too/.
15. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, "The implementation issues of Smart Grid in developing countries," One Curtin International Postgraduate Conference, OCPC, Dec.10-12, 2017.
16. Thiam, D.-R., *Renewable decentralized in developing countries: Appraisal from microgrids project in Senegal.* Renewable Energy, 2010. **35**(8): p. 1615-1623.
17. Mathews, J. and H. Tan, *China's continuing renewable energy revolution: global implications.* 2014.
18. Central Statistics Office, G.o.I. 2016; Available from: www.mospi.gov.in.
19. Bank, W. *Toward a Sustainable Energy Future for All: Directions for the World Bank's Energy Sector*. 2013; Available from: http://www.worldbank.org/content/dam/Worldbank/document/SDN/energy-2013-0281-2.pdf.
20. IEA. *Technology roadmap-Smart Grids by International Energy Agency,* . 2014; Available from: www.iea.org/publications/freepublications/publication/smartgrids_roadmap.pdf.
21. Fadaeenejad, M., et al., *The present and future of smart power grid in developing countries.* Renewable and Sustainable Energy Reviews, 2014. **29**: p. 828-834.

22. SIA Partners, E.O. *Blackouts and electricity theft: levers for deploying Smart Grids in developing countries?* ; Available from: http://energy.sia-partners.com/blackouts-and-electricity-theft-levers-deploying-smart-grids-developing-countries.
23. CGD. Centre for Global Development ranks CO2 emissions from power plants worldwide. Available from: http://www.cgdev.org/article/cgd-ranks-co2-emissions-power-plants-worldwide-press-release
24. World Resources Institute. Available from: http://timesofindia.indiatimes.com/home/environment/global-warming/Greenhouse-gases-India-fourth-biggest-emitter-but-lags-far-behind-top-three/articleshow/47807927.cms
25. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, “Smart Grid Developments across the Globe” North Borneo Research Colloquium (NBRC) 2016.
26. Energy, U.S.D.o., 2014 Smart Grid System Report. 2014, Department of Energy’s Report to Congress: Washington, DC 20585. p. 1-23.
27. Energy, D.U.S.D.o., Synchrophasor Technologies and their Deployment in the Recovery Act Smart Grid Programs. 2013.
28. Chakrabarti, S., E. Kyriakides, and D.G. Eliades, Placement of synchronized measurements for power system observability. IEEE Transactions on Power Delivery, 2009. 24(1): p. 12-19.
29. Baldwin, T., et al., Power system observability with minimal phasor measurement placement. IEEE Transactions on Power Systems, 1993. 8(2): p. 707-715.
30. Milosevic, B. and M. Begovic, Nondominated sorting genetic algorithm for optimal phasor measurement placement. IEEE Transactions on Power Systems, 2003. 18(1): p. 69-75.
31. Nuqui, R.F. and A.G. Phadke, Phasor measurement unit placement techniques for complete and incomplete observability. IEEE Transactions on Power Delivery, 2005. 20(4): p. 2381-2388.
32. Rakpenthai, C., et al., An optimal PMU placement method against measurement loss and branch outage. IEEE Transactions on Power Delivery, 2007. 22(1): p. 101-107.
33. Rihan, M., M. Ahmad, and M.S. Beg. Phasor measurement units in the Indian smart grid. in Innovative Smart Grid Technologies-India (ISGT India), 2011 IEEE PES. 2011. IEEE.
34. Mazlumi, K., et al., Presenting a New Method Based on Branch Placement for Optimal Placement of Phasor Measurement Units. Journal of Operation and Automation in Power Engineering, 2014. 2(1): p. 32-39.
35. A. R. Mehrabian, and C. Lucas. A novel numerical optimization algorithm inspired from weed colonization, Ecological Informatics, 1(4), 355-366, 2006.
36. Zhigang Ren, Wen Chen, Aimin Zhang, Chao Zhang, Enhancing Invasive Weed Optimization with Taboo Strategy, GECCO’13 Companion, July 6–10, 2013, Amsterdam, The Netherlands.
37. Amir Hossein Nikoofard, Hossein Hajimirsadeghi, Ashkan Rahimi-Kian and Caro Lucas, Multiobjective invasive weed optimization: Application to Pareto improvement models in electricity markets, Applied Soft Computing, 12(1), 100-12, 2012.

38. S. Roy, S.M. Islam, S. Das, and S. Ghosh, Multimodal optimization by artificial weed colonies enhanced with localized group search optimizers, Applied Soft Computing, 13(1): 27–46, 2013.
39. Henryk Josiński et al. The Expanded Invasive Weed Optimization Metaheuristic for Solving Continuous and Discrete Optimization Problems, Scientific World Journal, 831691, 2014.
40. D. Rama Prabha, T. Jayabarathi, Optimal placement and sizing of multiple distributed generating units in distribution networks by invasive weed optimization algorithm, Ain Shams Engineering Journal, 7, 683–694, 2016.
41. A. K. Barisal, R. C. Prusty, Large scale economic dispatch of power systems using oppositional invasive weed optimization, Applied Soft Computing, 29, 122–137, 2015.
42. A. Basak, D. Maity, and S. Das, "A differential invasive weed optimization algorithm for improved global numerical optimization," Applied Mathematics and Computation, 2013, 219, 6645–6668.
43. Sun, W., et al., Air indexing for on-demand XML data broadcast. IEEE Transactions on Parallel and Distributed Systems, 2014. 25(6): p. 1371-1381.
44. Shin, H.-Y., Energy-and latency-efficient broadcastingmechanism supporting long-term evolution e-multimedia broadcast/multicast service transmission. IET Communications, 2013. 7(15): p. 1644-1655.
45. Im, S. and J. Choi, MLAIN: Multi-leveled air indexing scheme in non-flat wireless data broadcast for efficient window query processing. Computers & Mathematics with Applications, 2012. 64(5): p. 1242-1251.
46. Hu, W., et al., A Real-time scheduling algorithm for on-demand wireless XML data broadcasting. Journal of Network and Computer Applications, 2016. 68: p. 151-163.
47. Goel, V., G. Panwar, and A.K. Ahlawat. Energy efficient air indexing schemes for single and multi-level wireless channels. in Advance Computing Conference (IACC), 2013 IEEE 3rd International. 2013. IEEE.
48. Chung, Y.D., S. Yoo, and M.H. Kim, Energy-and latency-efficient processing of full-text searches on a wireless broadcast stream. IEEE Transactions on Knowledge and Data Engineering, 2010. 22(2): p. 207-218.
49. Extensible Markup Language (XML): World Wide Web consortium site. Available from: https://www.w3.org/TR/xml/.
50. Moradi, M. and M. Keyvanpour, XML and Semantics. International Journal of Electrical and Computer Engineering, 2015. 5(5).
51. Salminen, A., E. Jauhiainen, and R. Nurmeksela, A life cycle model of XML documents. Journal of the Association for Information Science and Technology, 2014. 65(12): p. 2564-2580.
52. Fürst, K. and T. Schmidt. Internet-based data interchange with XML. in Information Technologies 2000. 2000. International Society for Optics and Photonics.
53. Choi, H. and S. Sim, A study on efficiency of markup language using DOM tree. Wireless Personal Communications, 2016. 86(1): p. 143-163.
54. Mirabi, M., H. Ibrahim, and L. Fathi, PS+ Pre/Post: A novel structure and access mechanism for wireless XML stream supporting twig pattern queries. Pervasive and Mobile Computing, 2014. 15: p. 3-25.
55. Briskilal, J. and D. Satish. An effective enactment of broadcasting XML in wireless mobile environment. in Recent Trends in Information Technology (ICRTIT), 2014 International Conference on. 2014. IEEE.

56. Cao, Y., C.-H. Lung, and S. Majumdar, Efficient message delivery models for XML-based publish/subscribe systems. Computer Communications, 2016. 85: p. 58-73.
57. XML Path Language (XPath): World Wide Web consortium site. Available from: http://www.w3.org/TR/xpath20.
58. XML Query Language (XQuery): World Wide Web consortium site. Available from: http://www.w3.org/XML/Query.
59. Chang, T.-P., Mining Frequent User Query Patterns from XML Query Streams. The International Arab Journal of Information Technology, 2014. 11(5).
60. Li, H., et al., Efficient frequent itemset mining methods over time-sensitive streams. Knowledge-Based Systems, 2014. 56: p. 281-298.
61. Li, W., et al. A Sampling Method of Finding Top-k Frequent Items on Timestamp-Based Stream. in Web Information System and Application Conference (WISA), 2014 11th. 2014.
62. Mirabi, M., et al., An encoding scheme based on fractional number for querying and updating XML data. Journal of Systems and Software, 2012. 85(8): p. 1831-1851.
63. Park, J.P., C.-S. Park, and Y.D. Chung, Lineage encoding: an efficient wireless XML streaming supporting twig pattern queries. IEEE transactions on knowledge and data engineering, 2013. 25(7): p. 1559-1573.
64. Fawaz, K. and H. Artail, DCIM: Distributed cache invalidation method for maintaining cache consistency in wireless mobile networks. IEEE Transactions on Mobile Computing, 2013. 12(4): p. 680-693.
65. Cormode, G. and M. Hadjieleftheriou, Finding the frequent items in streams of data. Communications of the ACM, 2009. 52(10): p. 97-105.
66. Singh, A. and J. Agarwal. Proposed algorithm for frequent item set generation. in Contemporary Computing (IC3), 2014 Seventh International Conference on. 2014.
67. Talaq, J. H., El-Hawary, F., El-Hawary, M. E: ‘Summary of environmental/economic dispatch algorithms’, IEEE Trans. On Power Systems, 1994, 9, pp. 1508-1516.
68. Abido, M. A: ‘Multiobjective Particle Swarm optimization for environmental/Economic Dispatch Problem’, Electrical Power System Research, 2009, 79, pp. 1105-1113.
69. Meza, J.L.C., M.B. Yildirim, and A.S. Masud, A model for the multiperiod multiobjective power generation expansion problem. IEEE Transactions on Power Systems, 2007. 22(2): p. 871-878.
70. Kim, Y.-C. and B.-H. Ahu, Multicriteria generation-expansion planning with global environmental considerations. IEEE Transactions on engineering management, 1993. 40(2): p. 154-161.
71. Saravanan, B., C. Kumar, and D. Kothari, A solution to unit commitment problem using fire works algorithm. International Journal of Electrical Power & Energy Systems, 2016. 77: p. 221-227.
72. Wang, Q., J.-P. Watson, and Y. Guan, Two-stage robust optimization for Nk contingency-constrained unit commitment. IEEE Transactions on Power Systems, 2013. 28(3): p. 2366-2375.
73. Chandrasekaran, K., et al., Thermal unit commitment using binary/real coded artificial bee colony algorithm. Electric Power Systems Research, 2012. 84(1): p. 109-119.

74. Wu, Z. and T.W. Chow, Binary neighbourhood field optimisation for unit commitment problems. IET Generation, Transmission & Distribution, 2013. 7(3): p. 298-308.
75. Balza, L., R.A. Jiménez, and J.E. Mercado Díaz, Privatization, Institutional Reform, and Performance in the Latin American Electricity Sector. 2013, Inter-American Development Bank.
76. Jiménez, R., T. Serebrisky, and J. Mercado, Sizing Electricity Losses in Transmission and Distribution Systems in Latin America and the Caribbean.
77. Kim, H., et al. Cloud-based demand response for smart grid: Architecture and distributed algorithms. in Smart Grid Communications (SmartGridComm), 2011 IEEE International Conference on. 2011. IEEE.
78. QDR, Q., Benefits of demand response in electricity markets and recommendations for achieving them. US Dept. Energy, Washington, DC, USA, Tech. Rep, 2006.
79. ABB, I., Rocky Mountain Institute, Energy Efficient Design of Auxiliary Systems in Fossil-Fuel Power Plants. 2013.
80. Brynjolfsson, E., P. Hofmann, and J. Jordan, Cloud Computing and electricity: beyond the utility model. Communications of the ACM, 2010. 53(5): p. 32-34.
81. Buyya, R., et al., Cloud Computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility. Future Generation computer systems, 2009. 25(6): p. 599-616.
82. Cearly D W, S.D.M. Key Attributes Distinguish Cloud Computing Services. 2009; Available from: https://www.gartner.com/doc/909318/key-attributes-distinguish-cloud-computing.
83. Woodford, C. Cloud Computing. 2015; Available from: http://www.explainthatstuff.com/cloud-computing-introduction.html.
84. Dán, G., et al. Cloud Computing for the power grid: From service composition to assured clouds. in Presented as part of the 5th USENIX Workshop on Hot Topics in Cloud Computing. 2013.
85. Bera, S., S. Misra, and J.J. Rodrigues, Cloud Computing applications for smart grid: A survey. IEEE Transactions on Parallel and Distributed Systems, 2015. 26(5): p. 1477-1494.
86. Ugale, B.A., et al. Role of Cloud Computing for smart grid of India and its cyber security. in 2011 Nirma University International Conference on Engineering. 2011. IEEE.
87. Maheshwari, K., et al. Toward a reliable, secure and fault tolerant smart grid state estimation in the cloud. in Innovative Smart Grid Technologies (ISGT), 2013 IEEE PES. 2013. IEEE.
88. Simmhan, Y., et al. An analysis of security and privacy issues in smart grid software architectures on clouds. in Cloud Computing (CLOUD), 2011 IEEE International Conference on. 2011. IEEE.
89. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, "Cloud Computing for energy management in smart grid - an application survey," Materials Science and Engineering, 2016, 121(1), pp. 012010.
90. Wang, Y., et al. Research of electric power information security protection on cloud security. in Power System Technology (POWERCON), 2010 International Conference on. 2010. IEEE.
91. NIST, NIST framework and roadmap for smart grid interoperability standards‟, release1.0

http://www.nist.gov/public_affairs/releases/upload/Smartgrid_interoperability_final.pdf (2010).

92. Gungor, V.C., Sahin, D., Kocak, T., Ergut, S., Buccella, C., Cecati, C. and Hancke, G.P. (2013) A Survey on Smart Grid Potential Applications and Communication Requirements. IEEE Transactions on Industrial Informatics, 9, 28-42. http://dx.doi.org/10.1109/TII.2012.2218253
93. Smart Grid Update, Data Management and Analytics for Utilities, Available at: [http://www.smartgridupdate.com/dataforutilities/pdf/DataManagementWhitePaper.pdf].
94. Fitzpatrick, G.J. and Wollman, D.A. (2010) NIST Interoperability Framework and Action Plans. IEEE Power and Energy Society General Meeting, Minneapolis, 25-29 July 2010, 1-4. http://dx.doi.org/10.1109/pes.2010.5589699
95. European Commission. European technology platform smart grids: vision and strategy for Europe’s electricity networks of future, http://ec.europa.eu/research/energy/pdf/smartgrids_en. pdf.
96. C. Yeoa, S. Venugopalb, X. Chua, R. Buyya, Autonomic metered pricing for a utility computing service. J. Future Gener. Comput. Syst. 26(8), 1368–1380 (2010)
97. ZHAO Junhua, WEN Fushuan, XUE Yusheng, and LIN Zhenzhi, “Cloud Computing: Implementing an Essential Computing Platform for Future Power Systems,” Automation of Electric Power Systems, vol. 34, pp. 1-7, 2010.
98. WANG Dewen, SONG Yaqi, and ZHU Yongli, “Information Platform of Smart Grid Based on Cloud Computing,” Automation of Electric Power Systems, vol. 22, pp. 7-12, 2007.
99. W. Overcloys, J. Broberg, and R. Buyya, Introduction to Cloud Computing, in Cloud Computing: Principles and Paradigms, ed. by R. Buyya, J. Broberg, A. Goscinski (New York: Wiley, 2011), pp. 1–41
100. R. Buyya, C. S. Yeo, S. Venugopal, J. Broberg, and I. Brandic, “Cloud Computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility,” Future Generation Computer Systems, vol. 25, no. 6, pp. 599–616, 2009.
101. R. N. Calheiros, R. Ranjan, A. Beloglazov, C. A. F. D. Rose, and R. Buyya, “CloudSim: A toolkit for modelling and simulation of Cloud Computing environments and evaluation of resource provisioning algorithms,” Software: Practice and Experience, vol. 41, no. 1, pp. 23–50, Jan. 2011.
102. M. D. de Assunc¸ A. di Costanzo, and R. Buyya, “A cost-benefit analysis of using Cloud Computing to extend the capacity of clusters,” Cluster Computing, vol. 13, no. 3, pp. 335–347, Sep. 2010.
103. Powel Fact Sheet (2016), Powel Dashboard Template for ArcGIS - a simpler way of analyzing your data, https://www.powel.com/globalassets/product-information/smart-grid/fs-powel-dashboard-eng.pdf
104. OpenEnergyMonitor, Open source monitoring for understanding energy, https://openenergymonitor.org/
105. DISCERN (2013), Role-based access, anonymization, and security concepts for the comprehensive Smart Grid dashboard system, www.discern.eu
106. EirGrid Group, Smart Grid Dashboard, http://smartgriddashboard.eirgrid.com/#all
107. Jatin Pherwani (2013), Management of Smart Electricity Grids A dashboard to monitor and control power in a way of the future. Final Year Design Project, CET, IIT Guwahati)

108. University of Illinois at Chicago, Smart Grid - The UIC Energy Dashboard, https://sustainability.uic.edu/smartgrid/
109. Edison, "Introducing the SCE Demand Response (DR) Alerts mobile app.," https://www.sce.com/wps/portal/.../demand-response/demand-response-mobile-app
110. Cognizant, "Digital Transformation for Utilities: Creating a Differentiated Customer Experience Through Mobility," https://www.cognizant.com/whitepapers/digital-transformation-for-utilities-creating-a-differentiated-customer-experience-through-mobility-codex2132.pdf
111. B. Karlin, A. Sanguinetti, and N. Davis, et.al., "Diffusion of Feedback: Perceptions and Adoption of Devices in the Residential Market," Human Computer Interaction (HCII) Conference. Los Angeles, CA: ACM, 2015
112. N. Strother, and B. Lockhart, "In-home displays, networked hem systems, standalone hem systems, web portals, and paper bill hem reports: Global market analysis and forecasts," Chicago, IL: Navigant Consulting Inc. 2013
113. M. Amin, H. Moussa, and O. Mohammed, "Development of a wide area measurement system for smart grid applications," IFAC Proceedings, vol. 44, no. 1, pp. 1672-1677, August 2011
114. O. A. Mousavi, R. Cherkaoui, and M. Bozorg, "Blackouts risk evaluation by Monte Carlo Simulation regarding cascading outages and system frequency deviation," Electric Power Systems Research, vol. 89, pp. 157-164, August 2012
115. C. W. Taylor, Wide Area Measurement, "Monitoring and Control in Power Systems, Workshop on Wide Area Measurement," Monitoring and Control in Power Systems 2006
116. A. Chakrabortty, and C.F. Martin, "Optimal measurement allocation for parametric model identification of electrical networks," Nonlinear Theory and Its Applications, IEICE, vol. 2, no. 3, pp. 302-319, July 2011
117. M. Shahraeini, M. S. Ghazizadeh, and M. H. Javidi, "Co-optimal placement of measurement devices and their related communication infrastructure in wide area measurement systems," IEEE Trans. Smart Grid, vol. 3, no. 2, pp. 684–691, June 2012
118. D. Novolsel, K. Vu, V. Centeno, S. Skok, and M. Begovic, "Benefits of synchronized measurement technology for power grid application," Proc. 40th Annu. Hawaii Int. Conf. Syst. Sci., Waikoloa, HI, USA, January 2007
119. M. Chenine and L. Nordström, "Modeling and simulation of wide-area communication for centralized PMU-based applications," IEEE Trans. Power Delivery, vol. 26, no. 3, pp. 1372–1380, July 2011
120. M. Hurtgen and J.-C. Maun, "Advantages of power system state estimation using phasor measurement units," Proc. 16th Power Syst. Comput. Conf., Glasgow, Scotland, 2008
121. R. K. Mai, Z. Y. He, L. Fu, B. Kirby, and Z. Q. Bo, "A dynamic synchrophasor estimation algorithm for online application," IEEE Trans. Power Delivery. vol. 25, no. 2, pp. 570-578, April 2010
122. B. K. S. Roy, A. K. Sinha, and A. K. Pradhan, "An optimal PMU placement technique for power system observability," Int. J. Elect. Power Energy System, vol. 42, no. 1, pp. 71–77, November 2012
123. A. Naumann, P. Komarnicki, M. Powalko, Z.A. Styczynski, and J. Blumschein, "Experience with PMUs in Industrial Distribution Networks," Proc. IEEE PES, July 2010

124. A. Carta, N. Locci, and C. Muscas, “A PMU for the measurement of synchronized harmonic phasors in three-phase distribution networks,” IEEE Trans on Instrumentation and Measurement, vol. 58, no. 10, pp. 3723–3730, October 2009
125. Yih-huei Wan, Analysis of Wind Power Ramping Behavior in ERCOT Yih-huei Wan, March 2011 (National Renewable Energy Laboratory)
126. Sunil Malival, "Study of Power System Security in Indian Utility 62 Bus System," International Journal of Engineering Research and Development (IJERD) ISSN: 2278-067X
127. D. Rama Prabha and T. Jayabarathi, “Optimal placement and sizing of multiple distributed generating units in distribution networks by invasive weed optimization algorithm,” Ain Shams Engineering Journal, vol. 7, pp. 683–694, April 2016
128. Energy, U. D., “Factors affecting PMU installation costs, Smart Grid Investment Grant Program,” https://energy.gov/oe/downloads/factors-affecting-pmu-installation-costs-october-2014
129. Su, C.-L. and D. Kirschen (2009). "Quantifying the effect of demand response on electricity markets." IEEE Transactions on Power Systems 24(3): 1199-1207.
130. Nguyen, D. T., M. Negnevitsky and M. de Groot (2013). "Market-based demand response scheduling in a deregulated environment." IEEE Transactions on Smart Grid 4(4): 1948-1956.
131. Mohamed E. El-hawary, The Smart Grid—State-of-the-art and Future Trends, Journal Electric Power Components and Systems, 42, 2014 - Issue 3-4, 239-250.
132. Litvinov, E., T. Zheng, G. Rosenwald and P. Shamsollahi (2004). "Marginal loss modeling in LMP calculation." IEEE Transactions on Power Systems 19(2): 880-888.
133. Maghouli, P., S. H. Hosseini, M. O. Buygi and M. Shahidehpour (2009). "A multi-objective framework for transmission expansion planning in deregulated environments." IEEE Transactions on Power Systems 24(2): 1051-1061.
134. Agency, I. E. (2003). Power generation investment in electricity markets, OECD Publishing.
135. Arabali, A., M. Ghofrani, M. Etezadi-Amoli, M. S. Fadali and M. Moeini-Aghtaie (2014). "A multi-objective transmission expansion planning framework in deregulated power systems with wind generation." IEEE Transactions on Power Systems 29(6): 3003-3011.
136. Davidson, I. E., A. Odubiyi, M. O. Kachienga and B. Manhire (2002). "Technical loss computation and economic dispatch model for T&D systems in a deregulated ESI." Power Engineering Journal 16(2): 55-60.
137. Talaq, J., F. El-Hawary and M. El-Hawary (1994). "A summary of environmental/economic dispatch algorithms." IEEE Transactions on Power Systems 9(3): 1508-1516.
138. Tang, L. and P. Che (2013). "Generation scheduling under a CO_2 emission reduction policy in the deregulated market." IEEE Transactions on Engineering Management 60(2): 386-397.
139. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, “Sustainable Economic and Emission Control Strategy for Deregulated Power Systems" International Journal of Energy Economics and Policy, 2017, 7(5), 102-110.
140. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, “Cloud-Based Solid Waste Transportation Optimisation for

Energy Conversion," International Journal of Energy Economics and Policy, 2017, 7(4), 291-301.

141. Hoornweg, D., and Bhada-Tata, P (2012), What a Waste - A Global Review of Solid Waste Management (World Bank,), Washington, DC.
142. Chalmin P., and Gaillochet C (2006), From waste to resource - An abstract of world waste survey, Cyclope, Veolia Environmental Services, Edition Economica, France.
143. World Bank (2012), What a Waste: A Global Review of Solid Waste Management. Urban Development Series Knowledge.
144. Ebenezer Owusu-Sekyere., Emmanuel Harris., and Ebenezer Bonyah (2013), Forecasting and Planning for Solid Waste Generation in the Kumasi Metropolitan Area of Ghana: An ARIMA Time Series Approach, International Journal of Sciences Research Article, 2: 69-83.
145. Adel Nadjaran Toosi (2014), On the Economics of Infrastructure as a Service Cloud Providers: Pricing, Markets, and Profit Maximization. Ph.D. Thesis, Department of Computing and Information Systems, the University of Melbourne.
146. CMDA (2015), Chennai Metropolitan Development Authority - Solid Waste Management, <http://www.cmdachennai.gov.in.>.
147. Ministry of Urban Development. (2013), Guidance Note Municipal Solid Waste Management on a Regional Basis. Government of India. <http://www.urbanindia.nic.in>.
148. C. Palanichamy, N. Sundar babu, and C. Nadarajan, Municipal Solid Waste Fueled Power Generation for India, IEEE TRANSACTIONS ON ENERGY CONVERSION, VOL. 17, NO. 4, DECEMBER 2002
149. Naveen, P.; Kiing Ing, Wong; Kobina Danquah, Michael; Sidhu, Amandeep S.; Abu-Siada, Ahmed, "Cloud Associated Smart Grid Admin Dashboard," Engineering, Technology & Applied Science Research Journal, 2017, 8(1), ISSN (e/p): 1792-8036, 2241-4487.

APPENDIX – A1

MATLAB generalised coding for UIWO

```
%% Problem Definition
n = input('Number of bus: ');
m = input('Fix Placement: '); %insert as [x x ...]
display('Enter 1 if m = n & m and n are connected, and 0 if
othewise');
connectivity = input ('Binary connectivity: ');
for i = 1:n
    bus(i) = cellstr(sprintf('x%d',i));
end

ObjF = sym ('x',[n 1]);
for i=1:n
x(i) = ObjF(i);
end

%% Gray Code Initialization
Range = repmat(2, 1,n);
[GrayCode,GrayCodeLength] = ImprovedGenerateGrayCode( Range );

GrayCodeF = GrayCode(all(GrayCode(:,m),2),:);
[GrayCodeRow, GrayCodeCol] = size(GrayCodeF);

%% Initialization
for i = 1 : n
   for j = 1 : n
   if connectivity(i,j)==1
       ObjF(i,j) = sym(sprintf('x%d', j));
   else
       ObjF(i,j) = 0;
   end
end
end
ObjFn = sum(ObjF,2);


%% Elimination of unfit row
for k = 1 : GrayCodeRow
    ObsFn(k,:) = double(subs (ObjFn,[bus(1:n)],[GrayCodeF(k,:)]));
end
combination = horzcat(GrayCodeF,ObsFn);
location = (combination(all(combination(:,n+1:2*n),2),:)).';

%% Best Fit Solution
Fn = mat2cell (location,[n,n]);
bus = Fn{1};
obs = Fn{2};

bus_sum = sum(bus);
bus_ind = find(bus_sum == min(bus_sum));

obs_ind = obs(:,bus_ind);
obs_sum = sum(obs_ind);

obs_ind = find(obs_sum == max(obs_sum));
```

```
disp('The optimum placement is: ');
index = bus_ind(obs_ind);
disp(transpose (bus(:,index)));
disp('with observability of ');
disp(transpose(obs(:,index)));
```

APPENDIX – A2

Modified IEEE 14-bus test system incorporated with wind turbines

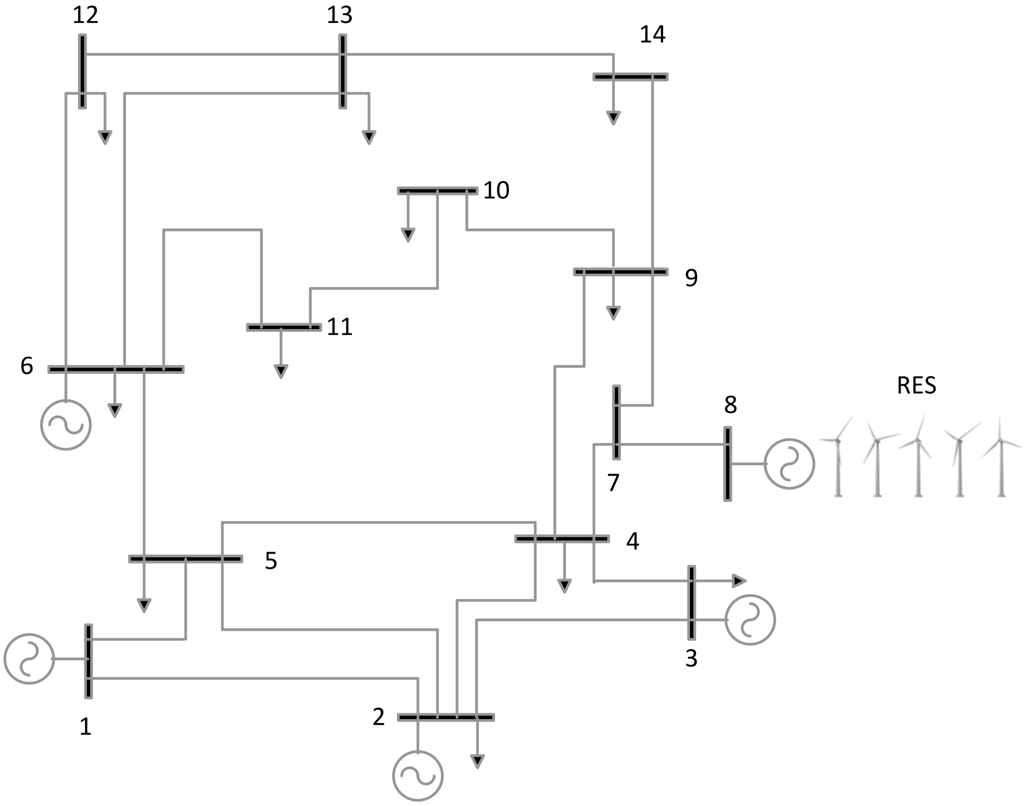


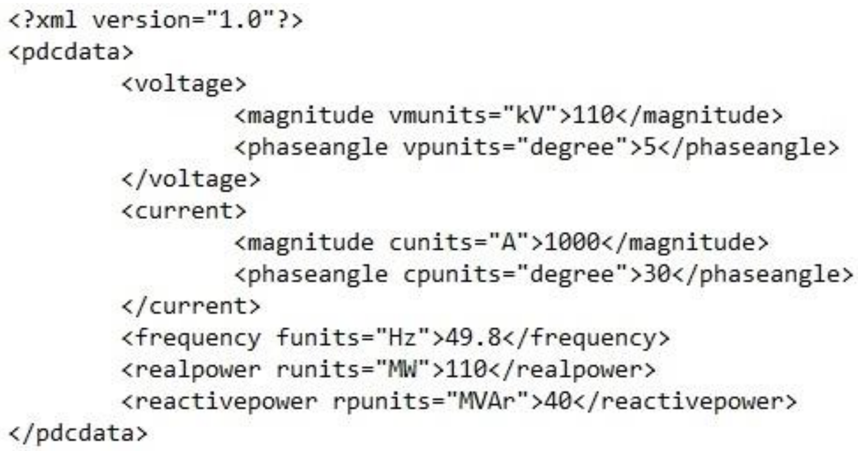
Figure A2.1. Modified IEEE 14-bus test system

APPENDIX – B

Illustrations of XML data

```
<details>
    <system id="01" name="Chennai">
        <name>Chennai </name>
        <datetime date="20160405" time="20:10">2016040520:10</datetime>
        <demand>200</demand>
        <energycost>
            <cost type="Industrial">industrial </cost>
            <cost type="commercial">commercial</cost>
            <cost type="residential">residential</cost>
        </energycost>
        <schedule adate="20161010" atime="20:10"> maintenance on 2016/10/10 20:10 </schedule>
        <weather>
            <temperature value= “35” unit=”celsius”>
                <value>35 celsius</value>
            </ temperature>
            <humidity value= “29” unit=” percent”>29 percent</humidity>
            <wind speedvalue= “300” > 300 mps </wind>
            <clouds value= “10” name=”clear”>sunny</clouds>
        </weather>
        <securitythreat>nosecuritythreat</securitythreat>
    </system>
</details>
```

(a)



```
<?xml version="1.0"?>
<pdcdata>
        <voltage>
                <magnitude vmunits="kV">110</magnitude>
                <phaseangle vpunits="degree">5</phaseangle>
        </voltage>
        <current>
                <magnitude cunits="A">1000</magnitude>
                <phaseangle cpunits="degree">30</phaseangle>
        </current>
        <frequency funits="Hz">49.8</frequency>
        <realpower runits="MW">110</realpower>
        <reactivepower rpunits="MVAr">40</reactivepower>
</pdcdata>
```

(b)

Figure B.1. (a) & (b) – Illustrations of XML data

APPENDIX - C

Modified IEEE 30-bus data

Table C.1. Generators Data

Unit	Production cost coefficients		NO$_x$ Emission coefficients		P_{min} MW	P_{max} MW	P_{Limax} MW
G_1	a_i	0.0462	d_i	0.0152	35	210	21
	b_i	43.5454	e_i	0.5557			
	c_i	311.6271	f_i	8.5156			
G_2	a_i	0.0558	d_i	0.0157	35	215	23
	b_i	43.9992	e_i	0.5276			
	c_i	335.5767	f_i	8.7855			
G_{13}	a_i	0.0455	d_i	0.0145	50	250	30
	b_i	43.0066	e_i	0.5408			
	c_i	321.5069	f_i	8.9632			
G_{22}	a_i	0.0289	d_i	0.0159	40	225	25
	b_i	40.9056	e_i	-1.4666			
	c_i	662.1819	f_i	9.3562			
G_{23}	a_i	0.0259	d_i	0.0147	130	325	35
	b_i	40.3774	e_i	-1.9011			
	c_i	682.9365	f_i	18.2348			
G_{27}	a_i	0.0266	d_i	0.0171	125	315	40
	b_i	40.9752	e_i	-1.9366			
	c_i	674.6163	f_i	19.4532			

Table C.2. Transmission Loss Coefficients (x10^{-3})

0.178	0.019	0.011	0.023	0.032	0.091
0.019	0.152	0.024	0.039	0.065	0.036
0.011	0.024	0.170	0.071	0.029	0.027
0.023	0.039	0.071	0.210	0.025	0.019
0.032	0.065	0.029	0.025	0.150	0.021
0.091	0.036	0.027	0.019	0.021	0.225