Intelligent Decision Support System for Including Consumers' Preferences in Residential Energy Consumption in Smart Grid

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Abstract—**Smart Grid is a novel initiative the aim of which is to deliver energy to the users and also to achieve consumption efficiency by means of two-way communication. The Smart Grid architecture is a combination of various hardware devices, management and reporting software tools that are combined within an ICT infrastructure. This infrastructure is needed to make the smart grid sustainable, creative and intelligent. One of the main goals of Smart Grid is to achieve Demand Response (DR) by increasing the end users' participation in decision making and increasing the awareness that will lead them to manage their energy consumption in an efficient way. Approaches proposed in the literature achieve demand response at the different levels of the Smart Grid, but no approach focuses on the users' point of view at the home level on a continuous basis and in an intelligent way to achieve demand response. In this paper, we develop such an approach by which demand response can be achieved on a continuous basis at the home level. To achieve this, the dynamic notion of price will be utilized to develop an intelligent decision-making model that will assist the users in achieving demand response.**

I. INTRODUCTION

It is estimated that the global demand for energy will rise by 44 percent by the year 2030 [1]. As shown in Figure 1, in order to meet that demand, renewable sources of energy are the fastest-growing source of world energy, with consumption increasing by 3.0 percent per year; meanwhile, this rate is 1.7 % for coal and 2.1 % for natural gas [2]. This is in accordance with the trend where the dependence on resources to meet the energy demand is shifting from non-renewable to renewable sources to utilize green energy. Consequently, with such a shift, the costs of upgrading the old electricity delivery system, pricing and service networks have risen as these systems have the traditional supply-side options and an inadequate central capacity plan to meet the growing demand and energy shift. The new system demands a framework in which people, systems, solutions, and business processes are dynamic and flexible in responding to changes in technology, customer needs, prices, standards, policies, and other requirements [3]. This is achieved by the notion of Smart Grid. Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it in order to efficiently deliver sustainable, economic and secure electricity supplies [4].

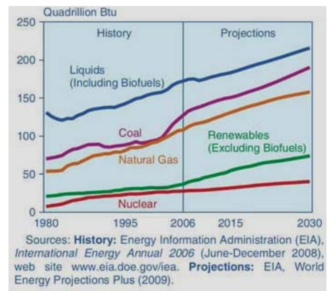

Figure 1. The use of all energy sources increases over the time frame of the IEO2009 reference case [2].

In this system, the consumers simultaneously consume the energy from different sources and at the same time produce it to return it to the grid or use it during peak times. The need for two-way communication between the utility and its customers lies at the heart of all Smart Grid initiatives. In this fashion, both parties work synergistically to manage the cost, delivery and environmental impact of power generation and energy services delivery. But to achieve energy efficiency, apart from having such architecture, mechanisms are needed that add intelligence to it at different levels. Such added intelligence varies according to the level at which it is being considered. For example, if considered from the generation side, one of the areas in which intelligence has to be added is dynamic pricing; whereas, from the consumer's perspective, it may be in the efficient utilization of energy at home level based on the price. This is supported by Schneider Electric which states that energy management needs intelligence not only to reduce energy consumption, but also to reduce operational costs [5]. Once developed, the approaches will add intelligence at the home level and will encourage customers to change their energy consumption behaviour in order to achieve energy efficiency. It has been mentioned in the literature that consumers are ready to change when they are presented with the appropriate information, but they lack the data or tools to do so [6]. Therefore, we need an approach by which we can investigate, identify and address the issues which arise for the consumers, and which adds intelligence for efficient and smart energy consumption in line with the real costs and environmental impact which will encourage consumers to utilize energy efficiently. We aim to achieve that in this paper by developing an intelligent decision-making support system at the smart home level in Smart

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Grid that works on behalf of the consumers, according to their consumption profile and utilities and leads them to the efficient utilization of energy. The paper is organized as follows. In Section II, we will discuss the literature relevant to the Smart Grid and Demand Response. In Section III, we will identify the issue that needs to be added. In Sections IV and V we propose an intelligent decision support system to achieve demand response at the home level. In Section VI, we conclude the paper.

II. LITERATURE REVIEW

A. *Smart Grid*

The initiatives taken in the form of smart grids are to shift the pattern of energy consumption from non-renewable to renewable sources and to make the consumers equal participants in the process of tuning and shifting their energy consumption to clean resources [9]. The concept of Smart Grid aims to use electricity more efficiently, support "green" sources and bring intelligence and standardization to the way that energy is transmitted, distributed, managed and consumed. A survey of the literature allows us to identify the various main elements of Smart Grid as shown in Figure2.

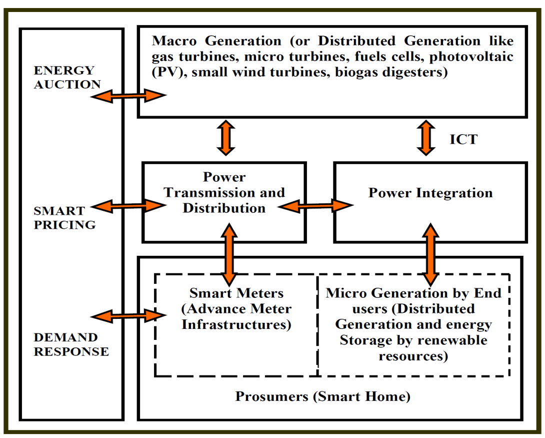

Figure 2. Smart Grid Architecture Concept

At the micro level, from the viewpoint of a smart home, there are various sophisticated ubiquitous electronic devices with the ability to communicate with each other and with a smart meter. Smart meters are microprocessor-based devices providing two-way communications capability, and will help home owners to manage their electricity usage. Through a website, for example, or a customer portal, parameters as to when loads in the home turn on and off, based on the price of electricity, could be set. The dishwasher, for instance, could be loaded and set to stand-by until the price of energy is below a certain level – typically off peak – when it would start automatically [8]. The aim of a smart meter is to act as a central point connecting all such internal devices with the outside world. The smart meters integrate data collected from the meters into billing, customer service, field services and energy-demand management. This gives a real-time view into a greater volume of data at a more granular level, leading to faster analysis and better decision-making regarding capacity demand, and the carrying out of other business processes. At smart home level, the Smart Grid, apart from providing detailed information about consumption of electricity to both users and network operators for preventing electricity wastage, also enables renewable energy resources to be connected to the grid [10]. A fully interactive ICT infrastructure is needed that helps to support the complex communication of business processes. Already, a number of initiatives propagate the use of such ICT techniques at the device level. For example, the concept of Internet of Things has been proposed that enables and facilitates wireless communication between different devices across the Smart Grid. ZigBee Smart Energy Home Area Network (HAN) Device Communications and Information Model provide secure, easy-to-use wireless home area networks for managing energy. The IPSO alliance [11] is supporting and promoting IP as a protocol for smart objects, creating the "Internet of Things" infrastructure where the Web standards are used to connect and to integrate the smart appliances for accessing their functionality. Google [7] presents Google PowerMeter which receives information from utility smart meters and energy management devices and provides customers with access to their home electricity consumption on their personal iGoogle homepage. Industries are working on supports for the IP protocol for wireless communication standards for home automation, such as ZigBee, Z-Wave [8], IEEE 802.15.4 and ANSI C12 [9]. For interoperability and seamless communication between different devices and architectures, researchers have proposed the utilization of either SOA or Ontology in Smart Grid. For example, Wood et al. [10] proposed an approach for advanced energy consumption displays (ECDs) in the home. Koen et al. [11] developed a concept that seriously considers smart homes and buildings as proactive customers (prosumers) that negotiate and collaborate as an intelligent network in close interaction with their external environment. Warmer et al. [8] proposed that an intelligent networked collaboration of homes relied on Information and Communication Technologies (ICT) to address interactions both within the smart house as well as between the smart houses, the Smart Grid and the enterprises. They found that IP-based technologies, and service-oriented approaches in particular, such as Web services, are required to interconnect all of the Smart Grid components when an information dissemination and exploitation is to coincide in an open and interoperable way. The aim of integrating such ICT technologies into the Smart Grid is to enable the efficient communication of information among different devices and sources that help to achieve Demand Response for efficient utilization of energy.

B. *Demand Response*

Demand Response (DR) activities are defined as "actions voluntarily taken by a consumer to adjust the amount or timing of his energy consumption". Actions are generally in response to an economic signal (e.g. energy price, or government and/or utility incentive) [12]. Demand Response is a reduction in demand designed to reduce peak demand or avoid system emergencies. Hence, Demand response can be a more cost-effective alternative than adding generation capabilities to meet the peak and or occasional demand spikes [13]. The underlying objective of DR is to actively engage customers in modifying their consumption in response to pricing signals. The goal is to reflect supply expectations through consumer price signals or controls and enable dynamic changes in consumption relative to price. According to the literature, much work has been done to achieve demand response. For example, Bilton et al. [14] explore the diversity of timescales, types of signals and involvement of customers in different types of demand side action. Earle et al. [13] proposed an approach for measuring the capacity impacts of demand response by California SPP and found that the uncertainty of the level of response is likely to have little effect on the capacity and reliability value of these demand response programs. Faruqui et al. [15] present a methodology for quantifying the benefits to customers and utilities of dynamic pricing programs and also proposed another approach [16] for quantifying customer response to dynamic pricing. Irastorza [17] believes more sophisticated metering and communications technologies are now economically feasible for many more customers, allowing for rate designs that provide improved economic efficiency, transparency, simplicity and fairness, and allow customers to make efficient energy choices. Kuhn [18] believes that advances such as ‘‘smart’’ meters, two-way communication, and automation technology are rapidly improving information exchange between utilities and their customers, and enabling further energy efficiency gains. Faruqui et al. have proposed a variety of rates including critical peak periods (CPP), peak-time rebate (PTR), and time of use (TOU) to demonstrate how benefits vary based on rate design. Earle et al. [13] proved that increased flexibility in program design as well as programs complementary to CPP/PTR could greatly increase their value. Discussions of CPP/PTR programs show that these tend to have fixed hours for critical peak periods and a limited number of days in which they occur. This is because rate designers and regulators are concerned whether consumers are able to understand and react to dynamic prices. Sezgen et al. [19] demonstrated how option-pricing methodologies can be used to value investments in three different kinds of demand-response strategies and they stated that enabling technologies and information/ analysis tools are essential for customers to assess the risks and value of participating in energy markets. Borenstein et al. [20] argued that participants in an RTP tariff must gain access to their own usage data in order to develop an understanding of how the facility responds to one or more load reduction actions. Since few customers have knowledge of the load shape patterns of their cumulative monthly usage, any decision to participate in an RTP tariff should be preceded by a period of time in which the customer's usage data are available through the metering and telecommunication system and a customer most likely will require some software package with which to assess the information and make sense of it. Kilanc et al. [21] developed a decision support tool for the analysis of pricing, investment and regulatory processes in a decentralized electricity market where public regulators and power companies are potential users of the model, for learning and decision support in policy design and strategic planning. Sancho et al. [22], describe software which could be used as a decision support tool for decision makers in competitive electricity markets. The main aim of their work is to simulate the way that the competitive electricity market functions by means of simple offers in the daily market. Sueyoshi et al. [23] developed an application software for analyzing and understanding a dynamic price change in the US wholesale power market. Traders can use the software as an effective decision-making tool by modeling and simulating a power market. E. M. R. Mike et al. [24] propose innovative electric power architecture, rooted in lessons learned from the Internet and microgrids, which addresses these problems while interfacing seamlessly into the current grid to allow for non-disruptive incremental adoption. Mayor et al. [25] believe that the future of power grids is expected to involve an increasing level of intelligence and integration of new information and communication technologies in every aspect of the electricity system, from demand-side devices to wide-scale distributed generation to a variety of energy markets. But by considering the structure of the Smart Grid, all of the abovementioned approaches aim to achieve demand response either at the generation level or transmission level.

III. Need to achieve Demand Response at the End-user level

The approaches proposed in the literature consider the different areas of energy generation and transmission to achieve demand response. However, less progress has been made to achieve DR effectiveness on the customer-side. By customer-side, we mean at each home level. As each user has to play its own active part in order to achieve DR, we need a system that captures the user's preference and behaviour and then assist it in changing its consumption behaviour according to the dynamic notion of price - and achieve DR; such an intelligent approach is missing in the literature. This is different from the other areas of Smart Grid that have efficient techniques to achieve demand response. Therefore, the primary issues that have been identified in the literature and which we intend to address are:

a) No approach has been proposed by which consumers' preferences and consumption profiles are considered for efficient utilization of energy.

b) Much research has been done to achieve demand response and price efficiency [13, 26-29]. But none has proposed a solution for studying the effectiveness of such systems when customers are not well trained, unwilling or too passive to respond to price signals, resulting in an increase in demand. To overcome this, we need an intelligent decision-making support system (IDSS) that assists in the decision-making process by considering customers' criteria for demand response.

c) Significant researches have highlighted the benefits of using renewable sources of energy and also integrating it with the local grid [30-34]. But no approach has been proposed that encourages the customers to increase their use of renewable sources and simultaneously shift their dependence on them and later autonomously trade off the energy with the local grid on behalf of the customers in a dynamic pricing system.

d) Many researchers present alternative interfaces, such as Energy-orb or Web interfaces like Wattson and Holmes, for sending information to customers to assist them in making decisions. In most of these approaches, the customers should be trained in the use of these interfaces and subsequently be able to react and send feedback to these signals. But instead of such interfaces, the IDSS needs to be able to make decisions on behalf of the customers and to increase the reliability of the service and customer management and consequently the Smart Grid.

e) Many researchers have presented solutions for decreasing the consumption of energy by forcing the end users to switch off the appliances or postpone their energy consumption. But none of them proposes an approach by which the users can have different alternatives which allow them to achieve what they want while simultaneously reducing the consumption of energy. The absence of such an approach means that end users will be unable to achieve demand response in an intelligent way.

IV. DEMAND RESPONSE AND END-USERS PREFERENCES FOR EFFICIENT CONSUMPTION OF ENERGY

An effective approach for achieving demand response requires techniques at the consumption level too. This is done by having an intelligent framework at the consumption side. For example, at home level, input is taken from the grid and, depending on various underlying factors, the framework assists the consumer to achieve demand response. There are no related works in the literature in this regard but the importance of such work has been discussed by Hopper et al. [27] who state that there is a role for targeted technical assistance programs to help customers to develop more sophisticated price response strategies as shown in Figure 3. There is a utility provider which sends price signals to end-users and receives the consumption information by means of a smart meter and wireless communication of the sensors (smart appliances).

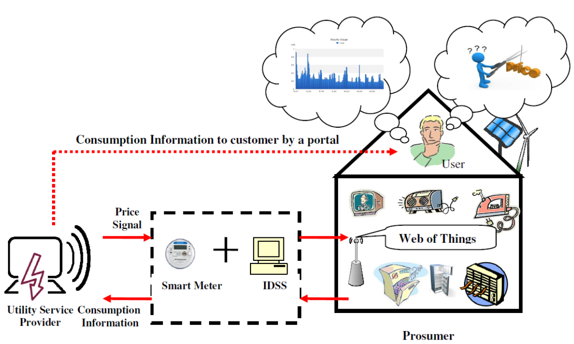

Figure 3. Intelligent Decision Support System for Energy Efficiency Consumption by End Users

The consumer mutually receives some information from the utility provider about consumption profile and price signals from various portals. It is expected that, by receiving consumption information, the consumers will change their consumption behaviour in order to mitigate cost and save on their power bill. However, in a dynamic pricing system, the consumers have no way of knowing whether their decision to modify their energy consumption is effective and efficient. This is overcome by adding intelligence at each home level. In this paper, we will develop a model by which such intelligence is added at each home level on a continuous basis by which demand response is achieved. We will propose our model in the next section.

V. INTELLIGENT DECISION SUPPORT SYSTEM MODEL

To achieve more effective demand response on the end-user side, we utilize the dynamic notion of price and develop an intelligent decision support system model that will assist demand response as shown in Figure 4.

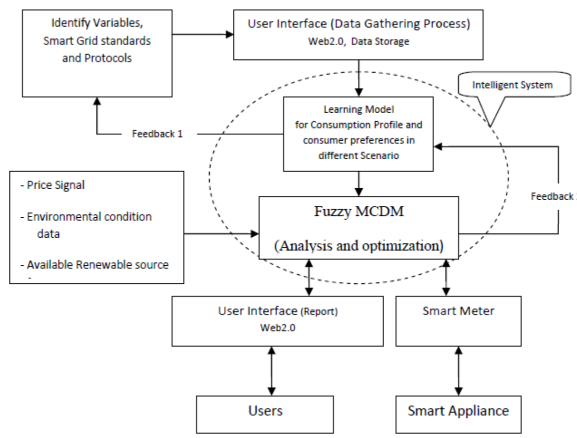

Figure 4. Intelligent decision support system model for achieving Demand Response in home level

This model is achievable by utilizing four steps as depicted in Table I. The first step is to determine the effective variables and parameters required for achieving the objectives of the next steps. By analyzing the variables, the variety of variables (qualitative, quantitative, dependent, independent, exogenous, endogenous) will be specified and then relationships and effects of the variables on each other should be clarified. For example, when consumers prepare to use the A/C, variables such as the inside and outside temperatures or the level of humidity will influence their preferred A/C settings; another factor to consider is that there may be several occupants in a house, whose preferences may be different. Residents are able to alert the system of their existence in a different way such as smart cards. In the second step, a user interface will capture the consumers' inputs on the identified variables and preferences in different scenarios that will provide an input to the learning phase and also inform the consumers about the result of the computed decision and let them modify the parameters according to their preferences.

TABLE I. FOUR STEPS FOR MODEL UTILIZATION

Step 1: To identify the different types of variables that need to be captured for studying the consumer's preferences and consumption profile.
Step 2: To develop a user interface for capturing the consumers' inputs on the identified variables and preferences
Step 3: To capture the outside variables like price signal from the grid, environmental conditions and available renewable sources and then to utilize that information and develop a Fuzzy Multi Criteria Decision Making model that will assist the consumer to achieve demand response
Step 4: To develop a neural-network-based model that learns about the consumer's preferences and consumption profile based on the preliminary data obtained from Step 2.

Step 3 has a two-fold purpose. The first is to capture the outside variables like price signal from the grid, environmental conditions and available renewable sources. Once that is done, the second is to utilize that information and develop a fuzzy rule based on the Fuzzy Multi Criteria Decision Making (MCDM) model that will assist the consumer to achieve demand response. MCDM methods include two techniques. One is a Multi Objective Decision Making (MODM) technique which will apply when the system objectives are different. In this case, when the objective is cost reduction, the system behaviour is different, whereas the system objective is to maintain lifestyle. The second is a Multi Attribute Decision Making (MADM) technique that will apply when there are many decision makers in the system and their decision should be considered in the decision-making process. According to the nature of variables such as temperature, price, comfort and economical consumption etc. and also considering the core meaning of variables and accurate communication between users and system, the Fuzzy techniques will develop terms most appropriate for this model. In this step, feedback (shown as number 2 in the model) is included in terms of addressing any changes in user behaviour or preferences and any event will be recognized by the model and will create a learning model to adapt to such events and changes. In Step 4, where a neural network model is developed, we expect to learn about the fuzzy rule-based and consumption pattern based on the preliminary data obtained in Step 2 and fuzzy MCDM in step three. Such a model will be responsible for acting autonomously on behalf of the user and in turn facilitates the decision-making process. Such a model will evolve on a continuous basis when the users modify their preferences in different scenarios. In order to develop a model that captures various terms of cost function for different classified consumption patterns, the neural networks techniques will be utilized to derive meaning from complicated or imprecise data and can be used to extract consumption patterns and detect trends that are too complex to be noticed by computers. In neural networks, the learning scheme is divided into supervised learning and unsupervised learning[35]. At first, when the system is going to recognize patterns or features in data sets, which include the correct output for each input, supervised learning will apply and then after capturing the data, an unsupervised learning technique will be applicable so that the system can act on its own in a kind of self-reflection, for this purpose a feedback (shown as number 1 in the model) is considered for identifying and capturing new emerged variables in terms of any consumer behaviour modification.

VI. CONCLUSION

The Smart Grid is a novel initiative the aim of which is to increase energy efficiency and decrease energy wastage from electricity generation to consumption. Various architectures and technologies are needed at different levels to achieve these goals. One of them is demand response that has to be achieved at the consumption side. In this paper, we developed an intelligent decision supporting system model at home level for increasing the efficiency of energy consumption in the Smart Grid. This system, which will be installed in conjunction with a smart meter, will adapt to consumers' preferences and be compatible with demand response in the Smart Grid. The analysis of our proposed approach will be according to the end users' utilities and aims to urge them to increase their consumption of renewable sources of energy and decrease the consumption of non-renewable sources.

The major significances and contributions that arise from this model are:

a. It will increase the efficiency and flexibility of the Smart Grid by which energy is utilized efficiently at home level, thereby transforming it into a smart home. This is different from the concepts of smart home that have been proposed in the literature which focus mainly on improving the lifestyle of the users.

b. It will enable a user to be actively involved in the process of achieving demand response at the consumption side. This is different from the existing approaches proposed in the literature which aim to achieve demand response at the consumption level either by voluntary load shedding or by price response only when the energy demand reaches the maximum peak of the grid.

c. A knowledge base is formed after capturing the users' various preferences and characteristics and this helps it to act autonomously on the users' behalf to achieve demand response. If any change or variation in the user's behaviour and preference is determined, then the knowledge base is updated automatically.

d. Depending on the different characteristics and preferences of the users and the energy price, the proposed IDSS determines the various alternatives such as deciding on the source from which the energy demand can be met or the level of importance according to which the energy demand of the different devices has to be met.

e. It will greatly contribute to knowledge about ways to improve energy efficiency since currently no work has been proposed in the literature that can be applied to achieving demand response at the consumption level by proactively involving the users.

We believe that this model will support end-users to adapt their consumption with dynamic pricing and to enable them to respond more intelligently to achieve demand response.

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