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Challenges of Energy Management System within Smart Grid

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Abstract

Due to energy crises and global attitude to "go green" have encouraged to integrate more and more Renewable Energy Resources (RESs) electricity generating units into the Smart Grid (SG). However, the intermittent nature of RESs, time varying load, and electricity price brings new challenges for the researchers to attain the demand-supply balance for the stable operation of SG. Hence, to cope with these challenges an Energy Management System (EMS) is an effective solution that balances the demand supply graph, exchanges or share energy between different Distributed Energy Generators (DGs), and supply energy to load economically. Hence, in this work, a brief description of EMS operation and functionality is provided, Moreover, a comprehensive review of different EMS challenges such as control, distribution, hardware, network, and security and privacy are highlighted and discussed in detail. This review will help the researchers and engineers to consider different challenges before developing and EMS.

Keywords*:* Smart Grid, Energy Management, Demand Response Program, Energy Management System

1. Introduction

A SG features two-ways communication and power flow, which is best solution for increasing demand of electrical power. The main advantages of SG include improved capacity, increased efficiency of power systems, easy maintenance, distributed power generation, lower greenhouse gas emissions, self-healing to disturbances, more options to consumers, remote monitoring of events, plug-in electric vehicle technology management [1].

However, besides these numerous benefits one of the main challenges in SG is imbalanced energy supplied from renewable and non-renewable sources. To avoid the imbalance situation, Energy Management (EM) is necessary for SG. This can be achieved by connecting home energy computers with centralized EMS that provide the current energy information to the consumers, and then consumers use that information to control their energy consumption as desired [2]. Due to energy shortage and increasing global warming, EMS has become the most desirable field of research. However, due to high penetration RESs into the power system EMS complexity increased, with the changing controlling and managing function. EMS copes to display real-time consumption of electricity on mobile and computer screens. It supports in reduction and management of electricity consumption. Moreover, EMS provides information of real-time tariffs of electricity that helps consumers to set the smart appliance to off-peak period, which results in reducing electricity bills [3].

In the last few decades, a lot of research has been conducted on appliances scheduling and EMS for increasing grid stability, reducing electricity cost, reduce peak to average ratio, and maintain the user comfort. The authors in [4] proposed two main types of EM schemes and explained In-Home Energy Management (IHEM) and Optimization based Residential Energy Management (OREM). The objective of IHEM is to save energy while considering the comfort level of the consumer a main priority. On the other hand, in OREM a Linear Programming (LP) model was discussed which minimizes the total electricity consumption at home by optimal appliance scheduling [5]. The authors in [6] discuss the different EM based DR schemes in which consumption of electrical power can be reduced by scheduling of specific loads. The authors in [7] determined different types of IHEM programs, and explained the benefits related to schemes used in IHEM such as reducing peak demand, increase savings of electricity and peak to average ratio. They outline that potential steps for efficient energy consumption are also discussed in detail. The authors in [8] analyzed main advantage of demand response for wholesale electricity markets has increased economic efficiency. Various other benefits include increased reliability, reduction in congestion, less requirement for new power capacity, better utilization of existing capacity, reduction in transmission controls and reduced prices of electricity for consumers.

Although a lot research has been conducted on EMS, however, very few consideration has been given to the different kinds of challenges faces by the EMS. Therefore, in this research work, a basic concept of transition from traditional power system to the SG is discussed. The operation and functionality of EMS is also discussed in detail. Moreover, the challenges and constrains related to implementation of EMS, direction to overcome these challenges to implement EMS to cope-up with the energy crises are described in detail.

The rest of the manuscript is organized as follows: Section 2 gives an overview of SG and EMS, moreover, the operation and functionality of EMS is also discussed. Section 3 highlights the challenges related with the implementation of EM models. Finally, the concluding remarks and future directions are presented in Section 4.

2. Smart Grid

In this section, a basic concept of transition from conventional power system to SG is provided. Moreover, a brief discussion about the EMS and its operation and functionality is presented.

A. Transition from Conventional power system to Smart grid

In traditional power distribution system, the energy is generated in a centralized manner, therefore, to transmit the energy, the voltage level is increased by power transformers and supplied to the distribution substation, where it is stepped down for consumer's utilization. However, in SG the energy is generated in a distributed manner, even consumers can generate energy and is capable of delivering that energy to grid. SG provides opportunities to monitor the distribution of generated energy and makes sure the efficient use of energy. Although SG offers numerous advantageous, however, one of the main challenges in SG is imbalanced energy supplied from renewable and non-renewable sources. This imbalance situation can be avoided by connecting home energy computers with centralized EMS that provide the current energy information to the consumers, and then consumers use that information to control their energy consumption as desired [2]. EMS copes to display real-time consumption of electricity on mobile and computer screens. It supports in reduction and management of electricity consumption. Moreover, EMS provides information of real-time tariffs of electricity that helps consumers to set the smart appliance to off-peak period, which results in reduce electricity bills [3].

B. Energy Management System

In state-of-the-art literature EM is defined as "A combination of energy efficiency activities, technique, and management of related process which result in lower energy cost and CO_2 emissions" [9]. The main goals of EMS are: (a) to realize the environmental advantages of EM through joined household utilizations with clear statistics. The analysis should take stand-by consumption into account, in addition to the fact that it avoids peak demand and decrease energy losses; (b) to reduce CO_2 emission by better management and consumption; (c) to perform a cost benefit analysis of a home EMS; (d) variable energy prices; (e) reliable Access to Information; (f) minimize maintenance and operating costs; (g) awareness of variable power transmission prices; (h) energy consumption measurements and billing fully automatic; and (i) easy access to energy consumption information and energy consumption control [10].

C. Functionality and Operation of EMS

EMS is combination of operation and control strategies for software and hardware in order to achieve EM in SG. EMS functions include energy planning, alarms, control, and energy optimization as shown in Fig. 1 [11]. A Data Energy Management System (DEMS) is proposed to the energy consumption of data centers. EMS is the basic factor of electrical energy usage. It consists of telecommunication system that sends and receives data between home and energy

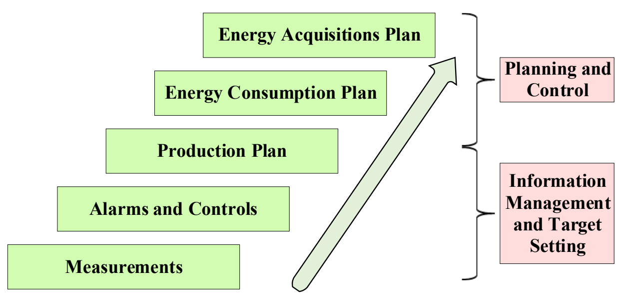

Fig. 1. EMS functions

management server. From data analysis EMS support consumers to set their appliance in off-peak hours to save cost [12]. EMS also includes communication system and smart meter that controls intelligent appliances. Smart meter uses Energy Service Portal (ESP) to give information of power consumption that information can be accessed online. EMS use the available history for controlling home appliances. The main components of home network model are smart appliances, network devices, and services. Each component contains information that helps them to interact with other components. Device features functions or services that can be accessed remotely or locally. A device can trigger other device's function with the help of its own service. The specific properties of network are Quality of Service (QoS), address, and configuration information. Networks create paths for a device to connect with other devices. Service is a process that works on service logic. Service logic control the interaction between network and device as well as device and device.

3. **Challenges** In EMS

Sudden increments in power consumption can cause power outages are not only costly for power suppliers, but also unfavorable for hospitals, traffic signals and airport control rooms, etc. It is favorable for both clients and utility providers to reduce the number and duration of peak load periods, network costs, power losses. Communication and computation advancement brings about necessary change in reliability, efficiency and power circulation systems. SG power management can improve the power efficiency of grid, to benefit the clients by scheduling home appliances according to their requirement, to facilitate energy utilization for most appropriate electric utility bills or energy resources at real time. An improved electrical grid cuts down CO_2 emission by diminishing end client control utilization during peak load time. In power plants when power is generated, an impressive measure of CO_2 radiations is released. An EMS can upgrade principal assets by reducing operation and up-keep costs. Renewable energy resources can benefit end user by cost efficient energy. Despite of these numerous advantages, there are some challenges and constraints that are needed to be focus which are discussed below in detail and are presented in Fig. 2.

A. Challenges on Hardware Based Components

Some of the challenges faced by hardware components in EMS are discussed below in detail.

1) Automatic Metering Infrastructure (AMI)

The AMI collects and analyzes the electric power utilization and communicates with the advance metering devices on schedule basis. The challenges the AMI is concerned about are security and privacy. For AMI systems, a secured protocol is essential. Motivation and incorporation of the

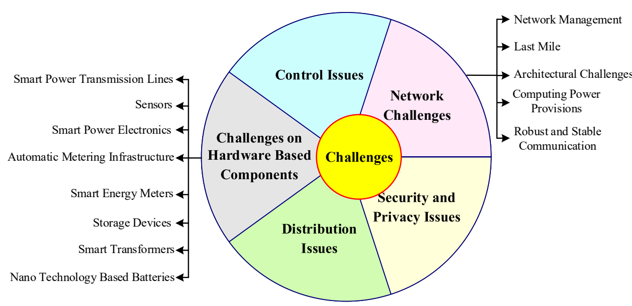

Fig. 2. EMS challenges

consumer is empowered by AMI advancements that provides the fundamental connection between the consumer and SG. Generation and storage options circulated at consumer areas can be observed and controlled through AMI advancement. AMI empowers a more circulated working model that decreases the danger of SG against terrorist attacks. AMI uses self-healing feature of SG by helping blackout administration frameworks identify and locate failures more rapidly and precisely. AMI can likewise offer, present distributed communication more limits that can be utilized to accelerate the installment of advanced operations equipment and applications [13].

2) Smart Power Electronics

The challenges to power electronics components in SG is the lack of functions to accommodate the variation in frequency and voltage [14]. The function for safely interconnecting with power electronics components such as DC/AC inverters, AC transmission lines system, alternators, DC-DC converters, and power generators in the SG [15]. A solution is needed to enable power electronics equipment and controlling devices to maximize their reliability, efficiency and cost reduction for the SG System.

3) Smart Energy Meters

The challenges to smart meters are accuracy in measurement and security threats. Smart meters can create privacy risk as it shows the information about appliances used in real time. This data reveals the information about user. The security threat is, presently how many people are at home and people feel insecure to share this data with their neighbor's meter. SG is two-way communications between consumers and utility. Smart meter consists of an electronic box and a communication interface. A smart meter measures electronically user's electrical power utilization in a specific time interval and transmits the acquired data to the utility or those responsible for metering. This data is shared with user devices informing the clients about their utility consumption and their cost. Moreover, smart meter has the capability of connecting and disconnecting in real time and control the consumer devices and equipment for load management and their perspective demand in near future. Also in view of consumers, smart metering benefits them by foreseeing the bill and managing their power consumption during peak load time [16]. The maintenance and installation cost of the smart meter comprises various challenges. Smart meter in distribution framework includes a few billion dollars of speculation for installation of the system and maintenance cost.

4) Sensors

Sensors are used as a measurement and monitoring devices for special purposes. Some of the challenges and constraints experienced by sensor network in SG are: (a) resource restraints: sensor networks system are inexpensive and resource constraint devices. Energy efficient control system for sensors is required; (b) configuration and maintenance: sensors must be configurable and remotely open in order to look after power system casually, advantageously and instantly; (c) security provisions: *s*ecurity threats indications are important for SG. Sensor networks provide security to the grid. If security protocol is not efficient enough, high valued equipment and SG operation can be in jeopardy; (d) bleak environmental circumstances*:* in SG sensors may face Radio Frequency (RF) interference, high corrosive conditions, humidity increment, vibrations, dust and other conditions affecting the function of sensor network. Thus, designing the sensor network should examine the need, i.e., if some sensors fail to operate, the whole system does not shutdown [17].

5) Storage Devices

Battery storage appears to be most important due to advanced technology and most economical. An energy storage device stores the electricity during Off-peak periods and feeds the grid during peak periods. Energy storage systems are now a necessary part of SGs due to fluctuating renewable resources and the development of micro grids. The type and size of energy storage devices require new and user-friendly solutions according to their requirement, storage location and reduction in the cost. One other advantage is the response time of battery storage devices which is in seconds. Hence storage devices enable fast response within SG. This hardware component can lighten up the complexity at transmission and distribution systems [18].

6) Smart Transformers

Once the conventional power grid becomes a SG the need for improving voltages and solving power quality, bidirectional transformers are needed. Smart transformer's online monitoring assists power providers to detect fault in real time. Advantages of Solid state transformers are power flow control, voltage sagging compensation and fault current reduction.

7) Smart Transmission Lines

The challenges to transmission lines are losses, lower efficiency, and lack of power stability during transmission and distribution operations. Flexible Alternating Current Transmission System (FACTS) devises increase power control in high voltage AC for grid operators. FACTS controllers are Integrated Circuits (IC) up to a high factor. FACTS devices system increases efficiency up to 50% of power transmission line and stability is increased by prompt response to failures in power system. The costs of FACTS technology devices must be decreased to be used for wider area applications. Decreasing the costs can be achieved by replacing silicon devices with wide band gap semiconductors like Silicon Carbide and Gallium Nitride [19].

B. Network Challenges

Communication networks supporting power grids face fundamental challenges as it is a system of systems. The benefits of SG as a whole can be achieved by removing the issues related to communication system. Communication network in conventional power grid creates interaction with control centers and individual substation by a system known as Supervisory Control and Data Acquisition (SCADA). Below are some of the basic issues related to communication networks are defined.

1) Network Management/Data Integration

The SG generates data points from millions of users. Network management is needed to convert data into useful information. Energy utilization patterns, data usage, load factors and voltage levels are determined through this data. The data should be transported efficiently to serve SG substation.

2) Last Mile

The core challenge of EM schemes is to communicate with consumers, and this require the last mile communication. Last mile communication starts for generations and ends with consumer premises [20]. Utilities find it difficult due to large cost of installation network devices and gathering data from millions of consumers.

3) Architectural Challenges

Power computation challenges is to deal with the large amount of data in real time with the on-demand facility provisions.

4) Computing Power Provisions

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5) Robust and Stable Communication

The core issue of communication network is security, authenticity and robustness. The communication network is responsible for the security and terrorist attacks on data. Encryption and authentication tools are the basic requirement for the robustness and security of the information.

C. Control Challenges

Control and automation systems requirement arises from wide use of electronic devices in energy management models. However, the automation technology used for sensing, metering, scheduling and load regulation and forecasting arises numerous financial issues. The control network should be designed to target the following requirements; (a) boosting demand response covered by variation in load; (b) synthesis of DG and storage devices in control and automation approach; (c) incorporating hybrid electric vehicles with plug-in hybrid electric vehicles; (d) state estimation and power system elements incorporating with defined communication and sensing; (e) communication network stability, latency and uncertainty issues; (f) robust control, a self-healing system requires robust control; and (g) unified risk evaluation, analysis and management [21].

D. Distribution Challenges

The challenges to power distribution within SG are voltage fluctuation control, power flow, reactive power management and system performance. Optimum system performance is achieved by careful investigation of DG integration. DG integration of additional protection challenges can provide reactive power management and voltage fluctuations. Over voltage problem arises due to DG integration, thus a deep analysis of integration is required. In less loaded systems, the overvoltage problem is of serious concern and can be tackled smartly. The power flow with in conventional electric grid is unidirectional. The DG integration raises bidirectional flow of power, resulting the protection system affected. Fault current may be supplied from DG as well as from power system due to bidirectional power flow. The increased short circuit current results in reduction of breaker capacity. The sensitivity of relays transcend with in DG, during faults. The protection in bidirectional flow of power requires a proper coordination for DG integration [22].

The nature of RER based DGs dependent upon the uncertainty and weather, which arises an additional issues of voltage fluctuations, increased cost, reliability and losses. The optimization of DGs units manages the reliability issues smartly. The optimal placement of DG is achieved by the art of optimization techniques in order to attain maximum benefits from DG units. Deployment of DGs, introduces a new concept of virtual power plant, where various DGs are connected whose total capacity is equivalent to conventional power plant. This group of generators is controlled by centralized, decentralized, and distributed manner. The cluster delivers extra advantages such as the ability to deliver peak load electricity or at short notice power generation. Virtual power plants have higher efficiency, increase capacity and optimize flexibility than conventional power plant. Extra flexibility of system improves better response to fluctuation [23].

E. Security and Privacy Issues

Cyber security in SG is a pivotal challenge. SG is an extended system which encloses power generation and facilitates electricity to devices such as home appliances, phone and computers. The extension of operation areas arises the need of increased cyber security issues within the context of SG. In fact, cyber-based threats to critical infrastructure are real and increasing in frequency. In any case, the testing of potential dangers are challenging because of the general absence of defined procedures and recommended approaches to evaluate security consolidated with the continually advancing risk. In addition, as the number of consumers in SG is increasing, privacy information, e.g., their home occupancy, will be more defenseless. Henceforth, applied techniques, thorough protection, and security evaluations are vital for complex frameworks where heterogeneous components and their clients routinely interface with each other and the IES. Data encryption is a tool used to discourage snooping from smart meters to generating unit and preserves the confidentiality of data. Strong and efficient algorithms are applied for encryption purpose. The SG devices such as smart meters, collectors and routers must be capable of encryption processing. Authentication is the process of verification of a user or entity claimed. SG must possess the strong abilities of detection and rejection on the basis of authorization and un-authorization of connections between its components, for example, meter and the utility interfaces. Applications of smart meter should be established and coded in an appropriate manner such as to prevent system from cyber criminals to access the smart meter. Data validation is an example technique used for this purpose. The detection and removal of malwares from the system is accomplished by the use of antivirus and antispyware, throughout overall applications of SG [24].

4. Conclusion And Future Directions

A brief description of EMS operation and functionality is provided, Moreover, a comprehensive review of different EMS challenges such as control, distribution, hardware, network, and security and privacy are highlighted and discussed in detail. Utilizing existing technology and using modern approaches, development in the power quality, efficiency, capacity, reliability, sustainability and curtailment in carbon footprint could be attained. EMS and DR schemes are discussed in literature and recommendations are presented. All of the DR schemes reviewed in this paper are presented on load shifting technique. Most of techniques employ scheduling algorithms to make perfect the demand profile. In all analyzed articles, price-based incentives are employed and two-way communication is essential that advances towards remarkably intensive communication between consumers and utility.

Shifting loads like dish washers or dryers might come at a very high comfort cost. In the newly proposed technique, only highly time insensitive loads are assumed to be deferrable. The focus of the newly proposed DR algorithm lies on the utility side. The utility attempts to learn and model consumer's response to price change, to recognize the exact control input (price) to send. During normal operation, the price mentioned may reflect the wholesale price of electricity, but then it is adjusted to maintain system balance at extreme times. The proposed method is very flexible in many aspects; i.e., when divided into regions, it also gives the ability to tune controllers to better accommodate specific response, as it is very likely that different regions have particular preferences of energy use. Consumers will have the most flexibility and choice, controlling their load pattern. Only the consumer and his willingness to pay certain price at different times define individual load shape. Using RTP, consumers are charged with the real price of electricity opposed to the average price that is used now. This eliminates the cross-subsidy between users. A minimum amount of communication is required to send only the price information at fixed intervals.

The major risk in this control system is the creation of higher peak demands at various time intervals. The real-time price should be selected with caution to induce the desired total demand of electricity at all times. As it is apparent, that decrease in price can create peaks in demand. Another problem is system model mismatch. For this method to work efficiently, a very accurate representation of system model is needed.

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