Energy Management System: A Review on Ruling and Reckoning Opportunities to Save Energy

Amisha Srivastava, M. Rizwan, and Rinchin W. Mosobi

Abstract The transition of conventional electric grid to smart grid is characterized with several concerns and challenges. Efficient, sustainable, and smart management of energy are one such issues. Energy management system combining hardware and software is intended for optimized energy consumption, reduced cost, and environmentally friendly solutions. It comprises collection of computerized tools integrated with home automation, buildings, advanced metering, electric vehicle, and demand side management to monitor and optimize the system performance. Energy management system communicates and interacts with both customers and energy devices to help adapt the energy consumption to the available energy supply. This paper reviews various aspects of energy management viz. home energy management system, building energy management system, advanced metering infrastructure, electric vehicle, and demand side energy management system. Such energy management system forms an interface between energy suppliers and consumers, their integration with Internet of things, machine learning/artificial neural network provide intelligent control and predictive action. Efficient use of energy at grid level and end-user level is achieved with advanced metering infrastructure. With the advancement of multilevel energy management system, its application in electric vehicles is also incorporated; owing to the major significance of energy management system in smart grid as well, this paper deals with all the important advancements and research in the same field. The comprehensive review of energy management system in various aspects is discussed, and their challenges and future perspective are also highlighted.

Keywords Energy management system · Smart grid · Machine learning · Advanced metering infrastructure · Demand response · Internet of Things

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1 Introduction

The blooming smart technology has improved the living standard of people in most part of the world and with that the energy consumption pattern has drastically changed. Furthermore, the estimated world's population by the end of 2050 is to be around 9.8 billion [1]. Such surge in population escalates the energy consumption which may globally rise to 25% by 2040 [2]. With the escalating dependence of human life style on energy, the need for technological advancement with innovative solution for sustainable energy consumption becomes significant. Researchers have now shifted their concern toward devising tools that minimize energy loss and use it proficiently. Energy management system (EMS) is one such tool and is defined as the combination of all the hardware and software that are collectively used to minimize energy wastage and provide a sustainable solution to energy saving.

Smart grid and EMS go hand in hand. Multiple features of smart grid like bi-directional communication between producer and consumer, transparent energy transmission system, eco-friendly environment, etc., are achieved to a great extent using EMS. The smart home energy management system (SHEMS) and **b**uilding energy management system (BEMS) are the emerging areas in energy management. Many software and devices have been designed to make smart homes and reduce electricity bills in big industries. The most important component of HEMS and BEMS is the advanced metering infrastructure (AMI). AMI has been adopted by a large number of countries worldwide. Smart meters unlike manual meters provide real-time monitoring and also facilitate bi-directional communication for consumers.

Electric vehicles (EVs) have gain significant importance in recent years and their role in smart grid cannot be neglected. EVs are true solution for reducing green-house gases. This paper also discusses the impact of plug-in EVs on EMS and how their charging is managed via HEMS. Studies reveal that researchers are developing interests toward demand response (DR) program. DR is primarily concerned with adjusting demand according to supply instead of adjusting supply according to demand. It allows consumers to actively participate in energy saving and is cost effective.

The paper is categorized into four sections. This section briefs the introduction; Sect. 2 presents the literature review in implementing EMS in different fields like SHEM, role of AMI, BEMS, and grid side EMS like demand response. Section 3 describes various challenges faced and possible solutions to it. And finally, a conclusion is deduced in Sect. 4.

2 Literature Review

EMS is designed with compound techno-economic objectives that are implemented at various levels. These objectives include minimizing electricity bills, maintenance cost, power losses, maintaining stability, handling frequency, and voltage deviation

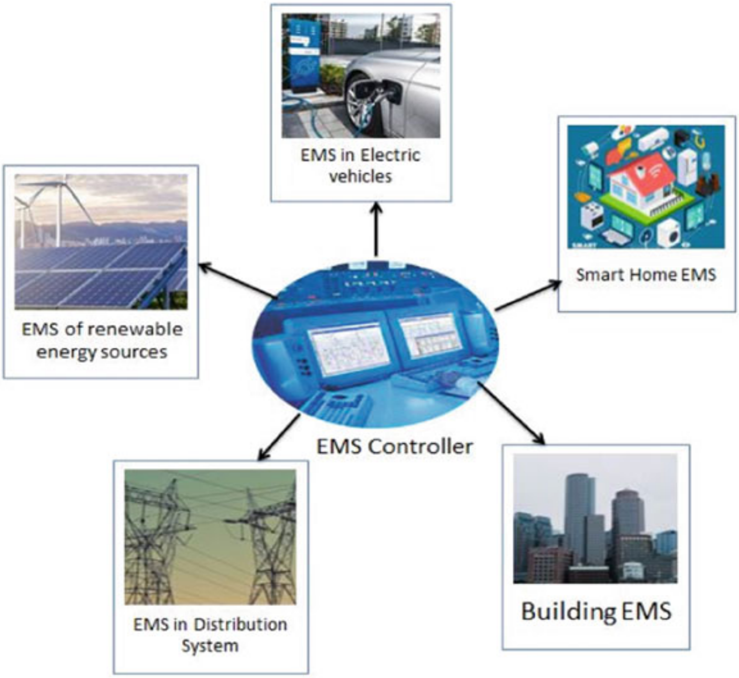

Fig. 1 Various aspects of EMS

at grid level and at the same time maximizing consumer's relaxation. Figure 1 shows various aspects of EMS in smart grid. The studies done in the field of EMS are reviewed in the further progression of paper.

2.1 Smart Home Energy Management System

Households play a significant role in increasing energy demand. One-third of the total energy mandate comes from the residential segment. The main idea behind smart homes was to design an environment where everything including generation and storage is decided, monitored, and controlled automatically with little or zero human interference. Using home area network, every digital device is interlinked with each other and can be remotely controlled making it easier and economic for user. A lot of progress is already been made toward SHEMS. SHEMS is a demand response tool that shifts and curtails demand to improve the energy consumption and production profile of a house according to electricity price and consumer comfort. The HEMS can communicate with household devices and the utility, as needed, and receive external information to improve the energy consumption and production schedule of household devices [3]. Loads in homes are categorized into controllable/scheduled loads and uncontrollable/unscheduled loads. SHEMS makes use of controllable loads such as washing machines, refrigerators, air conditioners, etc. such that appliance scheduling can be done and optimization of energy can be implemented. Inclusion of renewable energy resources with EMS has opened way for new prospects toward eco-friendly environment.

In [4], a multi-objective-mixed integer nonlinear programming (MO-MINLP) model is being discussed which aims at optimally using energy and at the same time taking care of user's comfort level in thermal and electric zones. It also deals with scheduling various loads according to a definite algorithm in order to save power. Under different user constrictions, the simulation results could provide successful reduction in energy use and optimal task scheduling. Another such work is presented in latest study [5] in which ICT is used to introduce an automatic home management system. The two main algorithms used in the system are power limit management (PLM) and smart electrical task scheduling (SETS). PLM takes care of overloading and SETS is having heuristic approach handles scheduling of loads. The software part of the system is implemented on IoT platform using Message Queuing Telemetry Transport (MQTT) protocol that transferences messages between various devices. The benefits of the system are also discussed using a case study of Gaza Strip which has restricted power sources.

Some important network protocols of smart homes include Zigbee, Z-wave, Thread, Bluetooth Mesh, and Wi-Fi. One of the concerning factor in homes is consumption of unnecessary power by some appliances such as standby power. In [6], a Zigbee communication module is used to design a wireless power strip constructing a low cost and low power networks based on IEEE 802.15.4 standard in order to reduce this standby power and the results have shown substantial decline in power consumption. The literature in [7] describes the effective switching of loads between renewable sources and grid energy using artificial neural network and machine learning algorithm, support vector machine (SVM), thereby concluding superiority of SVM over ANN. These studies reveal that EMS together with artificial intelligence can provide wonderful solutions to optimize energy and household loads can be smartly managed using SHEMS.

2.2 *Building Energy Management System*

EMS has touched almost all the sectors including industrial, residential, and academic. Building's energy consumption is a matter of great concern, and hence, managing it efficiently is the need of the hour. BEMS architecture mainly consists of communication system, interfacing technology, and sensing technology. Several environmental factors like temperature, humidity, air quality, luminance, etc., play a significant role in design of an effective BEMS which can manage almost all the considerations of building like heating, cooling, ventilation, security, alarm systems, and all such. In [8], an efficient air conditioning system is designed that operates based on the occupancy of the building and is cost effective too. It automatically adjusts the number of air conditioner units that are required to be operated at a time sensing the presence of people. Results say that it can save up to 22% of electricity bill. Similarly in [9], an EMS is designed for smart meters in residential building using fuzzy logic and implemented on microcontroller MSP430G2553. It saved energy consumption of the day by 7%, and peak demand was reduced by 34%.

In June 2011, ISO 50001 standard was created by International Organization for Standardization (ISO) that postulates the requirements for instigating an EMS in any type of organization irrespective of its size, segment, or topographical location. The ultimate aim is to reduce electricity bills, save energy, and control greenhouse effect. [10] Presents a detailed study of various aspects of ISO 50001 implementation and required tools for energy management.

2.3 Advanced Metering Interface

AMI forms the basis of EMS architecture and mainstay of smart grid. AMI is further made up of smart meters, communication network, meter data acquisition system, and gateways.

The electro-mechanical meters have been in existence since long time now but owing to their major disadvantages like collecting data door to door which may be erroneous or unidirectional communication, and emphasis is now shifted to smart energy meters (SEMs). SEMs provide an interactive interface, self-healing, or erroneous data and are multi-functional. They operate in a real-time environment and facilitate two-way communication between energy providers and consumers [11]. AMI allows remote-control of meter data and thus any customized change during peak loading hours or off-peak loading hours can be done in order to save energy and power. In [12], a system is designed using KEIL software used to write an 8051 microcontroller program that merges GSM with AMI. It basically alarms users when their pre-paid balance for meters is too low and thus overloading of appliances can be controlled. Another interesting work is presented in [13]. In this a numerical optimization technique, differential evolution algorithm is used for automatic load scheduling in SEM and simulation was implemented on MATLAB platform which ultimately minimizes energy consumption. A test site in New Delhi was selected for the purpose, and the results showed that approximately 19.42% power was saved using DE Algorithm.

The robust communication protocol used in AMI is mainly described by three networks, wide area network (WAN), neighborhood area network (NAN), and home area network (HAN). These networks allow communication among digital devices within a home or neighborhood. Meter data acquisition system performs periodic evaluation of data collected from SEMs, and accordingly logics are defined to sterilize the data (Fig. 2).

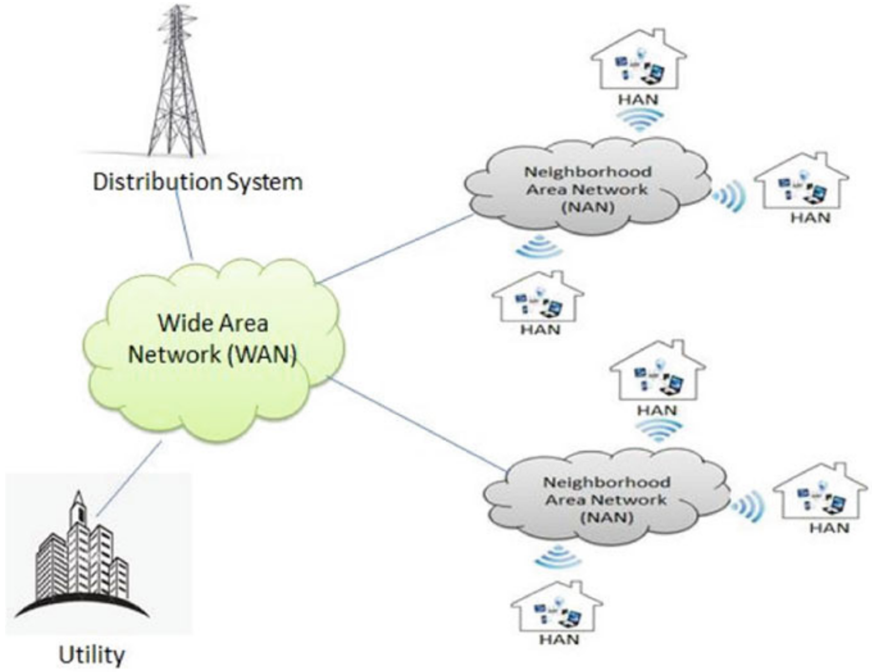

Fig. 2 Communication protocol in AMI

2.4 EMS in Electric Vehicles

Introduction of EVs in smart grid has not only controlled pollution but also plays a significant role in power system optimization with their two ways operation, i.e., vehicle to grid (V2G) in which they supply power to grid and grid to vehicle (G2V) in which power is supplied by the grid. Studies reveal that with the use of EVs, CO2, and NOX emission will be reduced [14]. Several studies have been done to analyze the impact of EVs charging and discharging in distribution system. Strong control strategies for EV charging stations reducing load burden on main grid are presented in [15]. A strong control is required in EVs which is achieved using EMS. [16] Describes the control strategies for diverse power sources used in hybrid electric vehicles. BEMS can help reduce electricity demands from residential and industrial sectors during peak loading hours, and this energy can be used to charge EVs thus maintaining a balance between generation and consumption and simultaneously improving power quality.

2.5 *Demand Side Energy Management System*

Owing to two-way communication in SG, DSM allows users to enthusiastically participate in energy saving and conserving renewables by monitoring and altering their power consumption plans according to the dynamics. This is also called demand response program (DRP). Residential DRP is classified into incentive-based and price-based DRP, and the details are given in [17].

Deep learning has become one of the popular methods for forecasting and solving complex problems with great ease. One such model depicting the overall behavior of demand response is presented in [18]. A multilevel deep learning model with multi-stage ensemble has been proposed for power forecasting at appliance level, and the performance of the algorithm is assessed on GREEND and UK-DALE, datasets that are openly obtainable. The presented model is robust, accurate, and assures proper implementation of demand response programs.

Also in a country like India which is dominated by small-sized and medium-sized buildings, Building Energy Management Open Source Software (BEMOSS) is a platform that supports implementation of DR [19–21]. Since it is an open source platform, it can be implemented via multiple protocols. It has also facilitated integration of IoT devices to monitor and regulate the data and simultaneously check energy consumption. Ultimately, DRP is encouraging consumers to become prosumers and increases reliability of grid.

3 Challenges in the Way of EMS

Although implementation of EMS in distribution system has numerous benefits. However, there are some limitations that have to be taken care of in the future designs. Some of the challenges identified and anticipated solutions are listed below.

Privacy issues are of utmost concern [22]. Large data collection may result in power thefts and cyber-attacks which are a frequent problem in AMI. More enhanced developments like advanced algorithms for cryptography are needed to maintain the security aspect of EMS. Literature in [23] presents a detailed analysis of energy savings algorithms implemented so far which can further be increased considering real-time scenarios and developing prediction based models. Another challenge faced is maintenance. EMS is composed of sensing and controlling technologies that require frequent updating and maintenance in order to check system's performance which becomes a tedious task [24]. Several complex architectures of EMS make it difficult for user to implement. More simplified designs are expected in the future with the use of artificial intelligence.

The major challenge that comes for DRPs is the establishment of appropriate control strategies and reliable market frameworks for its optimal implementation [25]. It is suggested to consider aggregated demands from various sources in order to form a novel modeling approach. Also, at times acquiring and monitoring data may be expensive which further restricts the fulfillment of the purpose of EMS. For this, use of distributed energy resources is a resilient way out. They are cost effective and simultaneously meet sustainability goals.

It is expected that the future works in the field of energy management system would consider these challenges and a more socio-economic and techno-economic developments can be seen.

4 Conclusion

Extensive research and development are being carried out to make EMS more reliable and secure. This paper provides a wide-ranging review of EMS application in various domain such as smart home energy management system (SHEM), building energy management system (BEMS), advanced metering infrastructure (AMI), and grid side demand response EMS to give readers an idea of its vast applications. Further, the several challenges encountered are also discussed. In addition, few of the recent advancement for future EMS is given below.

Merging artificial intelligence techniques and big data analytics with EMS is an area to be explored so that zero human interaction can be achieved with reduced complexity. Time of use (TOU) metering can be implemented where the utility firms charge the customers based on their energy consumption arrays during peak, off-peak and mid-peak hours. TOU tariffs encourage customer to shift their consumption to off-peaks times and thus balance the demand. This would lessen the strain on the grid. Future efforts should be aimed at creating regional or local energy hubs for centrally collaborating energy carriers and analyzing load curves of residential or industrial sectors for optimum energy saving.

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