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Review Article

Evolution of Energy Management: A Review

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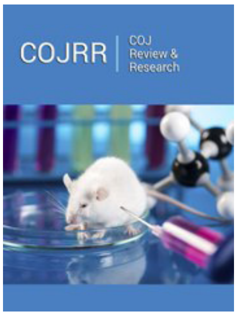
ISSN: 2639-0590



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Submission: November 08, 2021

Published: February 01, 2022

Volume 3 - Issue 5

How to cite this article: Snehashis Ghoshal*, Sumit Banerjee, Chandan Kumar Chanda. Evolution of Energy Management: A Review. COJ Rev & Res. 3(5). COJRR. 000571. 2022.
DOI: 10.31031/COJRR.2022.03.000571

Abstract

Energy management and conservation of energy has gained a lot of importance since last few decades in view of sustainable development. Methodology of implementation of energy management is not unique. The practice of energy management can be done in several ways. The choice of a particular option is application specific. Energy management has been going through a lot of evolution since its origin. Basically, energy management can be implemented at different levels. Energy management in today's application may involve information technology, control technique, communication techniques associated with power system. Such methodologies increase system flexibility by enabling the users to participate actively and independently in energy modeling. This paper tries to review the development of various energy management techniques on small scale as well as large scale basis. Evolution of energy management in different sectors, major constituents of different energy management techniques are discussed in this paper. This paper also analyses a comparative study regarding different techniques. At last, a new approach of Electric Vehicle is discussed in view of energy management as well as sustainable development.

Keywords: Demand response; Electric vehicle; EMS; Energy audit; ICT, Smart grid

Introduction

Technological advancement and economic growth are making life easier but at the cost of increased energy consumption. Unfortunately, most of the popular energy extraction techniques involve fossil fuel-based resources which is limited by nature. Besides, these resources pollute the nature. One good option to solve this problem is to use renewable resources. Although the advantage of renewable resources is that it is abundant in nature, but the main problem concerned with renewable resources is their low energy density. It is obvious that at present renewable alone cannot meet up the demand for energy. This problem can be tackled in a two- fold manner. Firstly, continuous research and development work in the field of renewable energy should be continued in search for energy intensive renewable technologies. Secondly, a proper energy mix involving renewable and existing fossil fuel-based techniques can be carried out. In this aspect energy management plays a vital role to attain energy efficiency and hence to achieve sustainable development. Energy management for an organization may be defined as the methodologies involved improving the energy performance of the concerned organization. Energy management can also be defined as the process of monitoring, controlling, and conserving energy in a building, organization or distribution system. The motivation for a successful energy management system is to optimize energy utilization thereby reducing energy costs without hampering productivity or quality. Energy management has a good potential to save energy and reduce cost simultaneously. According to the literature various methods exists for successful implementation of energy management program. Although a systematic and well-structured approach is needed for a sustainable and continuous improvement of energy management. Energy Management deals with multiple aspects from application point of view. The basic objective of energy management is to utilize energy in such an efficient manner so that uninterrupted energy supply become possible at a very reasonable rate. From commercial perspective, energy management relates to saving energy in commercial, public sector or government organizations as well as in domestic applications.

In terms of energy saving, energy management may be defined as the process of monitoring, controlling and conserving energy in a building or organization. It has been observed that energy management can be successfully implemented through two different levels such as demand side management and load side management. Demand side management is also known as utility side management in which utility companies ensure that their system is flexible enough to take care about a significant amount of load powered by renewable resources. Load side management involves management and control of energy at personal level.

Successful energy management program should involve the following: commitment from senior managerial level, energy policy of the organization, energy strategy, action plan, organizing energy management, regulatory compliance and incentives, investment, procurement, metering, monitoring and targeting, identifying opportunities, organizational culture and proper communication. Earlier, load side management was popular for larger buildings. But recently home energy management has become a matter of significant importance with proper monitoring and result- driven approaches.

Energy Management is the Tool to Conserve Energy

Implementation of proper energy management scheme leads to fulfill the following reasons: conservation of energy which directly affects energy prices, emission targets etc. conservation of energy is required to reduce environmental damage. Secondly, this will curtail the dependency on the fossil fuel which is very limited by nature. In August 2011, ISO 50001 [1] Standard regarding Energy Management was released. This establishes a framework for industrial plants, commercial, institutional, and governmental facilities to manage utilization efficiency of energy. The process is shown on the following diagram (Figure 1). Energy management has gained attention of the researchers recently.

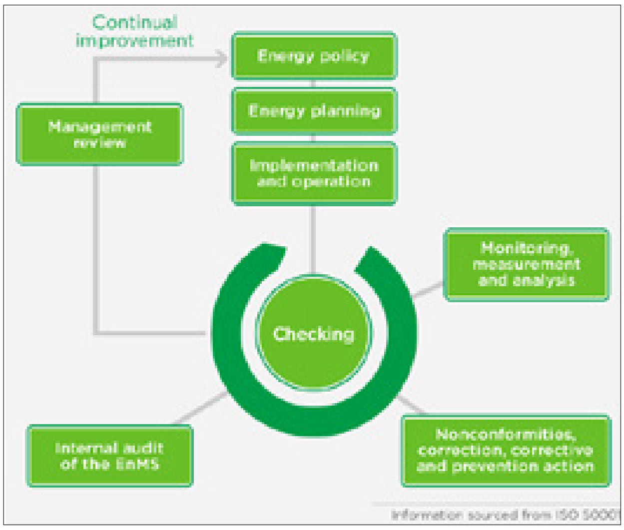

Figure 1: ISO 50001 specification for energy management [1].

Broadly, energy management research can be divided in three different sectors. Firstly, research related to small scale, as in individual building or organization. On the other hand, second part includes studies related to large scale systems as in the case of Smart Grids. The third part which is of very recent interest is application of Electric Vehicles (EV). Though, Electric Vehicles can be treated as an integrated part of modern Smart Grids. Javieda et al. [2] conducted a research work to implement energy management program in manufacturing industry in Germany to increase energy efficiency. They analyzed that implementation of energy management consists of the following:

A. Properly defining the energy management problem

B. Implementation of the concerned energy management problem

C. Controlling of energy management proposition.

This research work noted that implementation of energy management is for the benefit of both for the companies as well as for the society. Main objectives for energy management are supply security, economic efficiency, and environmental protection. Individual companies should focus on energy management practices to implement related measures and to establish energy management system. They also noted few barriers for adopting energy management protocol such as employee awareness, behavior and motivation, know-how of financial resources etc. different standards exists about implementation of energy management program. However, they cannot provide any general guidance about specific structure or method to implement energy management program in general. The mentioned research showed a multi-stage model for implementing energy management with multiple starting and ending point options. Motivation of the said research was to make optimal use of available resource and existing expertise in the companies.

Lee et al. [3] conducted a review-based study to figure out energy savings in different energy management systems. They took a part of research studies from Science Direct online (SDOL) published between 1982 to 2014 and IEEE Xplore (IEL online) mainly focusing on electrical and power electronic fields in between 1907 to 2014. In this research, energy management and saving effects of various Energy Management Systems (EMS) was considered. These include EMS industrial, company and factory Energy Management System (I/C/F) as well as Building Energy Management System (BEMS). Observation from this research is summarized below:

i. For successful implementation of energy management in I/C/F, the management plays a vital role. The nature of manufacturing sector should be changed to consumer-oriented from presently existing production driven orientation. Although energy savings was decreased from 18.89% in 1975 to 10.35% in 2013, the production efficiency was increased up to 50%.

ii. In case of BEMS, control scheduling, tariff and load control and smart home concept uplifted energy savings from 11.39% to 16.22%.

iii. Distributed sensors and controllers were used as a common platform in both BEMS and I/C/F EMS. Combination of facility operation and human behavior improved the production efficiency.

iv. In case of EMS for HVAC system, adaptation of proper feedback in terms of human intention, human interaction combination management of facility operation and human behavior by smart appliances noted highest energy savings of about 46.49% which was thrice than the average value of 14.07%.

v. Variable frequency control is the most energy efficient method for variable speed control in case of industrial motors. The average energy saving ratio was reported as 16.66% and the highest data one was reported as 40-50%.

vi. Main function of EMS for lighting system was optimization function by optimizing light intensity and reducing application artificial lighting during daytime for an effective energy management. Energy savings by such method was reported as 50%.

Future trend of EMS lies in human intention feed-forward control, smart grid and combination with production management.

Muller et al. [4] conducted a study to enable energy management for planning of energy-efficient factories. In this research, interaction between energy management and factory planning was studied. Similar research by Pav et al. [5] in European aerospace sector also supported the work from Muller et al. [4]. Further they observed that further improvement on energy management may become vital by creating a more prominent link between the corporate vision and plant objective. Dzene et al. [6] conducted a study on implementation of ISO 50001 to achieve sustainable energy action plans. This study focuses on implementation of sustainable energy action plans of Saldus municipality, Latavia with the guidelines prescribed by the aforesaid standard. These two-research works followed the choice of particular methodology among several existing ones depending on the size of municipality, existing organizational structure, present knowledge and capacity, availability of human and financial resources [7,8]. In this research, energy management was simplified by adopting four main stages such as: system development or planning, data collection, data analysis and conclusion and change of action. This study concluded that Sustainable Energy Action Plan or SEAP was very useful in view of ISO 50001 to achieve sustainable development in municipal sector at Latvia.

As already mentioned, broadly energy management research works are classified in two main classes. One is small scale implementation of energy management whereas the other is concerned with large scale applications. In this paper, section two analyses about energy management methodology in small scale applications. Section three is discussing about energy management in large scale applications. In this section a discussion on recent topic of electric vehicles is also discussed.

Energy Management in Small Scale Installations

Recently, energy management in homes has gained a lot of interest particularly with the help of digital platforms. There exist several methodologies for achieving smart home energy management systems such as demand response or demand side management. One good alternative is Smart Home Energy Management System (SHEMS). Application of these methodologies may involve information technology, control technique, communication techniques associated with power system. Such a system enables the user to participate actively and independently in energy modeling. But drawback of such an approach is that multiple end- users practicing energy management at the same time may introduce sudden peak and hence instability within the system. Such methodologies are applicable in individual households, commercial establishments etc. Smart home energy management has found its usefulness in energy sector recently and is developing at a very good pace. Development in science and technology helps to build a flexible grid concept enabling the end-users to participate actively. This evolution of smart grid over traditional power grid encourages the users to take part in energy modeling [9].

The main objective of smart energy management based on single unit or small-scale installations is to monitor, optimize and control the utilization of energy [10]. An alternative noble approach is to increase the flexibility of demand side resources i.e., the loads. This can be achieved by controlling the appliances of the consumers. So, it requires application of ICT (information and communication technology), different sensors and SCADA (Supervisory Control and Data Acquisition). Advance metering instruments are also applied to keep track bidirectional power flow [11]. Main factors under consideration in smart home energy management system are demand response, demand side management and load shifting [12]. With the help of demand response consumer participation to demand modulation with communication to the system operator is enabled [13]. Though HEMS (home energy management systems) refers to optimistic solution for simple but efficient energy management in smart homes, yet uncoordinated arrangement may lead to instability due to sudden peaks [14]. To avoid such a situation, proper coordination mechanism for smart homes was studied [15-17]. For proper modeling of load for the consumers, psychological and economic behaviors for them are required to be analyzed [18]. In [19] an investigation was carried out to study socio-economic behavior of consumer. Another study categorized household loads into different classes and studying their effect by adopting various DR methods [20-22]. Another advantage of such a technique is that it can be effective on momentary peak minimization.

DR algorithms for residential sector with latest scheduling methods and communication techniques were studied in [23]. A study was carried out about multiple DR programs with a focus on their interaction with Renewable Energy Resources [24]. For efficient implementation of energy management program in smart buildings, Rocha et al. carried out a study with an optimized model of dynamic temperature set points that take care about heating and cooling system operations [25]. In [26], energy management in multiple households with proper coordination mechanism was studied. Yalcinates et al. [27] reported that shifting of working hours of commercial buildings earlier about 1hr could result of reduction of monthly electricity rates by 1-3%. They also proposed a thermal storage for air conditioning purposes.

Constituents of HEMS

Constituents of smart home energy management system can be categorized as per the following:

1. Smart measurement system
2. Sensor mechanism
3. Information and communication technology
4. Smart appliance
5. Energy management system

Application of proper measurement system is very important criteria of HEMS. The objective of such a part is to monitor and control various parameters. For residential buildings gas, water and electricity meter are main measuring devices [28]. The interaction between end-users and the utility within a smart grid system is enhanced by real time data processing with the help of bi- directional communication through Advance Metering Infrastructure (AMI) [11]. A measurement system not only requires efficient meters for accurate measurement purpose, but also proper sensor arrangements located at suitable places are also essential. Sensors for detection of current, voltage, temperature, motion, light intensity or occupancy inside a room are required to be monitored [29]. Special purpose sensors monitoring health, smoke etc. can also be implemented to fulfill the purpose regarding smart monitoring. These sensors are embedded at different locations and send a signal to a centralized monitoring system [30].

Proper and accurate measurement requires effective transmission of data from the location of sensors to the monitoring point. This is possible by effective interaction between different sensors, meters and devices to the controlling unit. In this respect Information and Communication Technology (ICT) plays a vital role. Several domestic appliances can be integrated through either wireless or wired communication protocol [31]. The Transmission & Distribution (T&D) system can be integrated with SCADA and various temperature or other sensors for proper data acquisition. In demand side management installation of smart meter can help in achieving energy efficiency. A smart meter is such a measuring instrument which aggregates the net amount of power passing through it. This can be adjusted for the user in such a fashion that the net inflow of power from grid or power injected by the user to the grid is adjusted and balanced amount is paid by the customer. This is also known as advanced metering infrastructure [11] which enables better monitoring and control of energy resources.

Measurement devices can be made to work smart by applying a suitable control technique to the appliances, thereby making them smart appliances. Smart appliances encourage the customer to control their energy usage in an energy-efficient manner. The appliances can be monitored through integrated intelligent and communication systems. Considering the working characteristics, usage pattern, end-user preferences and comfort levels, household appliances are categorized under following three classes such as baseline loads (not controllable), burst loads (fully controllable) and regular loads (partially controllable) [22]. Baseline (must run) loads are those appliances which cannot be controlled through any program like lighting, computers, fans etc. Usage of these types of loads is dependent only on end-user behavior without any specific time interval of operation. Burst loads are schedulable loads having a specific operating time interval. As the name implies such a load nature can be shifted to a desired time interval. Washing machine and cloth dryer combination is a good example of such a load. By adjusting the time of operation of these two cycles, energy efficiency is achieved [32,33]. Regular loads are affected by environmental conditions generally. Their working is totally controllable. Thermal loads such as electric water heater, space heater, geysers, air conditioner and refrigerator are treated as regular loads [34,35]. Generally, different customers possess different habit of energy usage. So, for proper energy modeling of residential sector various parameters should be kept in mind which may include energy usage pattern, house occupant, nature of the concerned climatic zone, economic condition of the users etc. [36]. It is mentioned worthy from the above discussion that the grouping of the household appliances helps in achieving the control of the concerned appliances.

The last and most important part of HEMS is energy management system. There is not any specific model as several modeling techniques and software platforms are used by different developers. An energy management system decides about controlling and monitoring of appliances to achieve energy-efficiency. It may include the feature of scheduling and forecasting of loads and may include the control of Distributed Energy Resource (DER) also, if any.

Development in the field of HEMS

HEMS or home energy management system is a growing trend over last few decades to achieve energy efficiency. The concept of home energy management system is derived from the energy management system for household applications. The development started with very old temperature control system. In the era of energy crisis during 1970, deficiency of energy forced to imply renewable resource extraction techniques as well as establishment of various energy management techniques. Since the beginning of this millennium, application of personal computers has revolutionized this field. Development in the field of instrumentation and application of SCADA and different ICT protocols with wireless or wired technology has contributed significantly to enrich HEMS. Generally, the techniques adopted for energy management in residential sector is different than the existing energy management principles in T&D networks. Continuous development in the field of embedded system makes it possible to replace heavy and bulky solid-state devices with small and compact chip-based systems. Basic objective of HEMS is to reduce cost without sacrificing the comfort level. Generally, an effective HEMS addresses data monitoring, data logging, instrument controlling, device management and activate alarm if necessary.

Trend and future of HEMS

Concept and implementation of HEMS has become a great concern globally. Basically, adoption of any HEMS technique increases the flexibility of a smart grid system. However, the nature of development is different in different parts of the world. In Asia Pacific, implementation of energy management is generally carried out by an integrated interaction between local generation and emergency system. Generally, these systems are standalone by nature and mainly focuses residential sector. However, few developed countries adopted energy policy in PPP model for commercial as well as industrial sector. On the other hand, Europe, USA, Australia and New Zealand devised large-scale based smart techniques. HEMS in such countries are mainly utility led and is based on user-utility interaction.

To implement HEMS in residential sector, few basic parameters are considered. These are age and type of building, orientation etc. Also, the nature and number of occupants, their economic and cultural activity may affect the usage of energy. For proper integration and sustainability, the connection between HEMS and utility is an important consideration. Generally, the nature and pattern of energy usage is different in different locations. So, any specific model cannot be adopted globally. Hence proper energy policy is required for each part in the world. However, the ultimate objective should be to make the user aware about energy usage and help him/her to interact with the utility to achieve energy management.

Finally, it can be stated that the revolution in smart phone have connected all parts of the world through a common thread called internet. The concept of Internet of Things (IOT) has become a great concern today. There is a good potential for future work on the field of home energy management through IOT which will enable several devices running on a common platform like android to interact with each other which may be useful to achieve energy efficiency.

Implementation of energy management will find its usefulness only when all concerns from utility to the end-user will join hands together. The government also has to take part actively. Clear energy policy should be made. Utilities and HEMS developers need to interact mutually for proper control and monitoring of several electrical appliances. Basically, HEMS encourages shifting from centralized grid-based systems to smart grids for a residential sector specifically. Proper data processing, data monitoring and data transmission are necessary in an effective HEMS system [37].

Energy Management in Large Scale Installations

The discussion so far was analyzed for small scale energy management applications. On a similar note, as discussed earlier, effective energy management policy can be implemented in large scale also. This mainly focuses on smart grid-based research works.

According to The European Technology Platform [38] Smart grid may be defined as under:

A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it-generators, consumers and those that do both-in order to efficiently deliver sustainable, economic and secure electricity supplies.

According to the U.S. Department of Energy [39]:

A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electrical system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources.

From the discussed definitions it can be concluded that Smart Grid can be treated as a transparent and instantaneous bilateral path for the delivery of energy. Basically, Smart Grid empowers the users to increase their control on energy performance. One significant difference between traditional power grid and Smart Grid is that the later one is a bilateral medium for exchange of information between the consumer and the utility. Figure 2 shows a snapshot elaborating different components of smart grid [40].

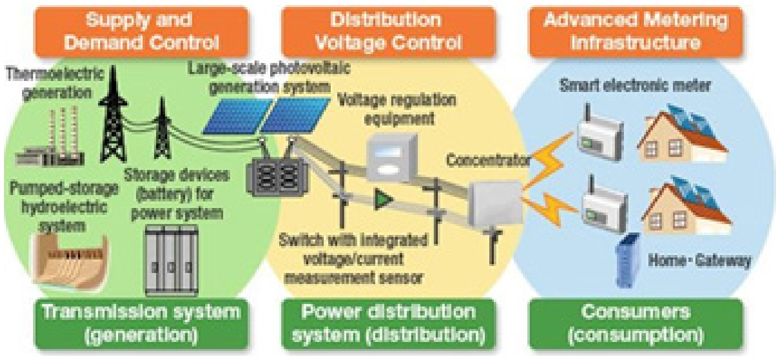

Figure 2: Components of Smart Grid [40].

Attributes of smart grid

According to different literature survey conducted, attributes of smart grid can be listed under as [40-45]:

A. Smart Grid empowers the consumer to optimize the energy usage at their end so that energy efficiency as well as sustainable development is achieved. Smart Grid activates demand response and demand side management through the integration of smart meters, smart appliances, micro level generation and storage of electricity.

B. Smart Grid establishes interconnection and intermittency among several generation and storage options.

C. It efficiently optimizes assets by effective delivery system (rerouting power, automatic operation) which decides when and what is needed at any instant of time.

D. Resiliency is an added advantage for Smart grid. Under any emergency situation such as disaster, physical or cyber-attack, energy is supplied reliably and securely if provided with self-healing mechanism.

E. Power quality supplied through such a system is very up to the mark specially for operating sophisticated equipment.

Evolution of smart grid

Different utility companies providing power in different geographical locations with the help of similar technologies thereby adopting inherent constraints. Smart Grid can overcome this situation by adopting demand specific methodologies thereby increasing system flexibility. Although, the implementation of traditional grid system is dominated by socio-economic, geographical, or political issues, their basic topology is same. Existing power system is basically a unilateral approach for delivering power form the power plant to the end user. But the problem with this system is that any unexpected surge in demand exhausting the designed limit across the distribution network which may cause several component failures or even blackouts. This was evident particularly in the distribution network. The concept of Smart Grid was adopted at the bottom of this hierarchy. Increasing rates of fossil fuels and lack of instantaneous generation at distribution line to meet sudden demands motivated utility companies to reorganize the distribution network in such a fashion so that demand side management is maintained along with revenue protection. Automated Meter Reading (AMR) system enabled the utility companies to read and monitor data related to energy usage of consumer from remote location. Figure 3 shows about the evolution of Smart Grid in a graphical manner [45].

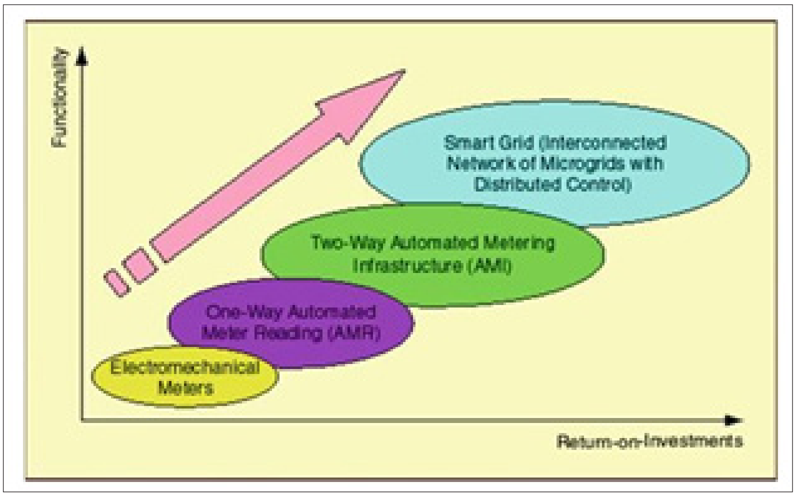

Figure 3: Evolution of Smart Grid in a Graphical Manner [45].

But the problem regarding the one-way communication was not solved by AMR. This problem was solved by adopting advanced metering infrastructure (AMI) [11]. This enabled an effective two-way communication system to access customer service level parameters on real time basis. The added advantage of such a system is that it can provide a limit to control energy consumption. The concept of distributed generation also helped to build up in achieving energy management. Saha et al. [46] conducted a study to integrate DG into distribution systems to meet the increasing load demand.

Components of smart grid

Components of a Smart Grid can be mentioned as under:

1. Monitoring and control technology component
2. Transmission subsystem component
3. Smart devices interface component
4. Intelligent grid distribution subsystem component
5. Storage component
6. Demand side management component

Generally utility owned energy management system is also known as distributed management system or DMS. Basic objective of DMS is to monitor and control the distribution network in a reliable as well as efficient manner [47]. Storey et al. [48] conducted a study to account different constraints such as unbalanced load flow, fault location, integration with transmission system, Volt/ Var optimization etc. Ipakchi et al. [49] reported that DMS fails to offer operational capabilities required for managing a large number of distributed and demand side resources due to distributed nature of system performance. In this context DMS may found its usefulness. Palensky et al. [50] classified DMS into following four categories:

A. Energy efficiency including permanent changes on equipment thereby improving physical properties of the system. Sometimes, energy conservation [51] focusing on behavioral activities to achieve efficient usage of energy may also know as energy efficiency.

B. Time of Use (TOU) enacts the concept for penalty as well as reward to the consumer. According to this, any customer drawing energy during high demand periods are penalized whereas may be rewarded at a discounted rate whenever the demand is low.

C. Demand Response (DR) optimizes load scheduling as per the following [52]: incentive-based DR: Direct Load Control (DLC). time-basedrates DR: Critical peak pricing or real time pricing.

D. Spinning Reserve (SR) gives a concept where loads are treated as negative. It can be related with droop control over the grid [53].

Few energy management systems were made to monitor the energy in distribution system by adopting the concept of Virtual Power Plant (VPP) [54]. Loads can act as virtual storage by proper demand shifting technique. Accumulation of several loads in considerable size can be an alternative to the traditional electricity storage system [55]. The main feature of VPP is increased reliability in terms of availability. However smart loads are required to implement such a development in order to shift virtual storage as and when required to avoid any problem arising during emergency situations. Nagesh et al. [56] conducted a study about real time architecture on Smart Grid to provide real time demand and price feedback based on aggregate load conditions in order to monitor smart appliances. The control procedure was done in such a way that in case of a peak demand, the demand was distributed in several directions to reduce load variability.

Energy management in electric vehicle

Recently, the concept of Electric Vehicle (EV) has gained attention to the researchers. Advancement in power electronics has revolutionized manufacturing of eco-friendly electric vehicles. But the inherent drawback in EV is its high cost due to battery. From its origin, transportation sector has been a significant contributor of Greenhouse Gases (GHG). Conventional vehicles operate with different types of Internal Combustion (IC) engines. EV is one of the promising solutions to decrease the global GHG emission. Inclusion of electricity- powered vehicle reduces operating cost than gas-powered vehicles. Generally, vehicles can be classified in three different classes: Internal Combustion Engine Vehicles (ICEV), Hybrid Electric Vehicles (HEV) and all Electric Vehicles (AEV). In hybrid vehicles, the concept of hybridization factor (HF) is used in which power developed in electric motor and ICE is taken into account [57,58]. For an EV, 33.7 kWh of electricity represents the same amount of energy as provided by one gallon gasoline [59,60]. Operating zone of vehicles should be considered during design. However, availability of energy resources, environmental factor and weather conditions should be considered. The basic objective behind EV is to utilize renewable resources as fuel either in form of fuel cell or by flywheel. Apart from transportation, EV can also be utilized as a mobile electricity storage system.

Conclusion

Implementation of energy management will be successful only if all concerns from utility to the end-user will join hands together actively. The government also has a major role to play in this matter. A clear and case specific energy policy should be formulated with a mandate of implementing energy management in all sectors with periodic energy audit according to the globally accepted standards. Proper awareness programs should be organized to make people understand that energy management is for the benefit for all. A governing body should be formed to monitor energy management scenario in different sectors. Utilities and users along with developers of energy management programs need to interact mutually for proper control and monitoring of different electrical appliances.

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