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Review: Home energy management system in a Smart Grid scheme to improve reliability of power systems

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Abstract Home energy management system (HEMS) concept rises from the development of smart homes that build interaction between users with their home appliances in order to operate automatically, multi-functionally, adaptably and efficiently. In line with technological developments and published regulations related to environmental issues, smart home applications evolve into HEMS applications which are not only to provide ease and convenience, but also to monitor and to make efficient energy use at home, thereby reducing peak power quantity and electricity bill. Smart grid is an intelligent power grid starting from its generation, transmission and distribution. It combines computing technology, artificial intelligence and communications technology which creates a smarter power system and is able to produce better power quality and lower generation cost. In the smart grid scheme, by means of HEMS applications, consumers can participate in improving the quality of power systems. This study will discuss about the development of HEMS in associated with smart grid technology particularly the role of HEMS application with its DSM (Demand Side Managment) and PEV (Plug-in Electric Vehicles) programs in the smart grid scheme to improve quality of power systems. Several studies have shown that the contribution of HEMS to the smart grid system can improve the power losses and voltage profile.

1. Introduction

The concept of home energy management system (HEMS) rises from smart home development which has been developing from 1990 [1]. This application was initially intended to facilitate users in operating and managing some household appliances so that they can operate automatically and optimally. In addition, the users can achieve a more comfortable room or environment condition which suits their preference [2]. In the smart home application, interaction between users with their home appliances will be formed thereby the devices can be operated and programmed interactively either directly or remotely. Therefore, these appliances can operate automatically, multi-functionally, adaptably and efficiently [3]. To be able to do that, smart home application is completed with several technologies like sensors, controllers, communications and programming languages.

In line with the development of technology, the emergence of environmental problems and regulations related to these problems encourage the smart home applications not only to provide comfort and convenience, but also to achieve energy efficiency. Afterwards, smart home applications evolved by developing home energy monitoring capabilities to achieve savings. Based on the results of the study, by monitoring the use of energy, psychologically users will change the behavior of the use of household appliances and it enables to save energy up to 30% [4]. The use of smart meters and AMI (Advanced Metering Infraestruture) assists in observing the use of energy. By providing feedback on the amount of costs that must be spent on energy consumption, users will more consider for their energy use, if they object with it. There are several information feedback techniques related to this smart metering technology described on [4].

In line with its function related to energy management, there appears derivative of smart home application--application of home energy management system (HEMS)--which manages household energy usage, thus reducing peak power and electricity bill. HEMS application is equipped with capability of data collection, data proccesing, data representation, and preparation of interactive operation with user to be able to perform energy management. Therefore, it can provide feedback in real time, daily, weekly or monthly.

The development of HEMS technology can be grouped into several categories: interface technology, smart hardware and software platform [5]. Some studies related to the development of HEMS are conducted from sensor technology [6], Communication devices [7], storage energy device [8], smart meter [4], smart home appliances [5] and the HEMS application itself. In brief, the HEMS development map is described on [9-11].

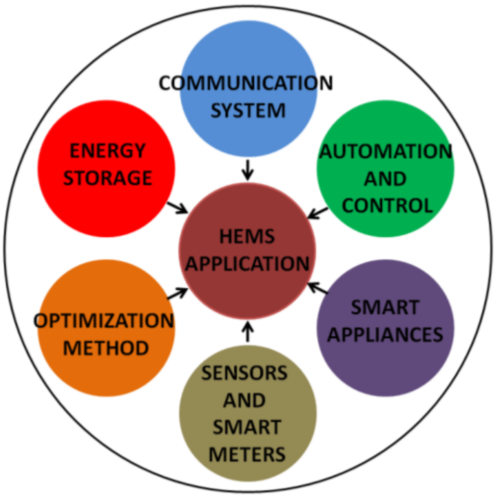

Figure 1. HEMS Technology Development

The increasing demand for electrical energy encourages the development of electric power technology, especially in large cities where the rapid population growth as well as the growth of the industry. The Increasing capacity demand of electrical energy, leading to the building of an electric power distribution becomes more complicated thus distributed generation as an alternative generation. Smart grid is a smart electrical network starting from the generation, transmission and distribution [12].

Smart grid technology combines the power system with computing technology, artificial intelligence and communications which make the power system smarter in order to produce better and cost effective electrical power [13]. One of the capabilities offered by smart grid technology is the ability of smart metering that is able to provide information about the amount of household power demand and self healing technology when there is a problem on the network either due to technical problems, sabotage or natural disasters, so as to increase Network reliability [14].

In the smart grid technology, the concept of generation changes from centralized to distributed and made it possible for consumers to become producers. With the support of computing and communications technology, consumers are allowed to participate/contribute in power system operation schemes through HEMS applications, as one of the entities of the smart grid system at the consumer level. In smart grid schemes, through HEMS applications, consumers can participate in improving the reliability of power systems. The presence of electric vehicle in the smart grid scheme connected in the HEMS application can participate effectively in helping to balance supply and demand by valley filling and peak shaving household loads [15].

This paper will review the development of HEMS and its relation with smart grid technology, particularly the role of HEMS in the smart grid scheme to improve the reliability of power systems.

This review is structured as follows. In Section II, we present HEMS position in smart grid system. In Section III, we review the power system infrastructure in smart grid concept, and last Section reviews the consumer contribution in improving power system reliability.

2. HEMS in Smart Grid

In the framework of smart grid, HEMS application is developed not only to manage energy use in households but also to conduct the management of energy supply, either from the provider of electrical energy or the own-generated one such as alternative energy sources through solar or wind power plant. The HEMS configuration consists of household loads that are divided into scheduled and unscheduled loads, energy storage, alternative energy sources, connections to grid, electric cars and HEMS control systems which is supported by communication technology and smart meter [16].

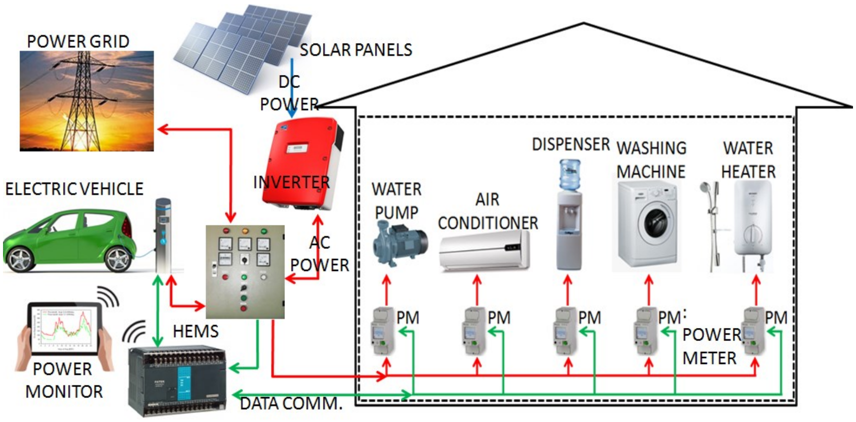

Figure 2. configuration of HEMS system

HEMS application performs managing operating time of the load, especially for scheduled loads so that minimum operating costs of electricity usage will be obtained. In HEMS the output power is generated from an alternative energy source rather than used to supply the household load; therefore, it can also be stored in energy storage and electric cars or supplied to grid. The presence of electric cars is not only intended to promote the use of environmentally friendly vehicles but also intended as energy storage; in addition, the vehicle itself can be used to contribute and maintain the reliability of power generated from the power grid.

In some countries, peak load rates and feed in tariffs are being applied. This led to research aimed at minimizing the costs to be paid for the electricity use. In general, the study related to the development of HEMS can be grouped into: problems of scheduling, automation and control, communication aspect and HEMS system [9]. Research development related to scheduling issues can be divided into modeling and optimization studies. The modeling study on schedule raises the problem of load modeling, pricing scheme, load forecasting and comfort level [17].

Optimization study uses heuristic and non heuristic approaches. Some heuristic algorithms developed for scheduling optimization problems include PSO, GA, taboo search and neural network. While for non heuristic optimization, among others, using LP and NLP [18-20]. The study on communications technology is aimed at discovering appropriate topology and communication media for use in HEMS. Several studies raised the use of sensor networks through wireless technologies as a communication medium such as zigbee technology. The communication architecture in HEMS is called home area network (HAN) used to gather information from each HEMS component beginning from household appliances, energy sources up to energy storage systems [21]. Comparison of some communication technologies on HAN are studied in [22] and some wireless network based on IEEE Standards as shown in table 1 [7].

The development of measurement methods on HEMS is directed to smart measurement. With the development of communications technology and micro-based processing, measurement devices have become smarter. Some studies related to smart measurements, are as follow [23] :

- Remote reading

- Bidirectional communication
- Support of advanced tariff systems and billing applications
- Remote energy supply control.

Table 1. Wireless Network Based on IEEE Standards.

Protocols / Specifications	ZigBee Over IEEE 802.15.4	WirelessHART Over IEEE 802.15.4	MiWi Over IEEE 802.15.4	Isa100.11 Over IEEE 802.15.4	Bluetooth (IEEE 802.15.1)	Wi-Fi IEEE 802.11
ISM Bands	2.4 GHz/915 MHz (USA)/868 MHz (EU)				2.4 GHz	5 GHz
Network Topology	Star, Peer-to-Peer and Mesh	Star, Peer-to-Peer and Mesh	Star, Peer-to-Peer	Star, Peer-to-Peer and Mesh	Star, Peer-to-Peer	Star, Peer-to-Peer
Modulation Scheme	BPSK (868-915 MHz) Q-QPSK (2.4 GHz)	O-QPSK (2.4 GHz)	FSK/OOK	O-QPSK (2.4 GHz)	GFSK/DQPSK 8DPSK (optional)	BPSK, QPSK, COFDM, CCK, M-QAM
Nominal Rate	250 kbps (2.4 GHz) 40 kbps (915 MHz) 20 kbps (868 MHz)				1 Mbps (v1.2/v4.0) 3 Mbps (v2.0) 24 Mbps (v3.0)	11-65-450 (IEEE 802.11 n) Mbps
Range (meters)	10–300	100	20–50	100–200	10	10–100
Application Areas	Demand Response, remote control and automation in residential and commercial buildings	Industrial Control, building control the sensory data conveying temperature, pressure or speed	AMR metering, consumer, electronics, home, automotive, industrial, automation, toys business and medical applications	Industrial and control market	Wireless connectivity between personal devices such as headphones, medical, sport & fitness, mobile phones or laptops	Wireless LAN connectivity, broadband Internet access
Advantages	Low Power consumption, several application profiles (home automation, smart energy) and topology flexibility	Communication Security, reliability and Environment with wired HART infrastructure	Flexible, cost-effective platform	Low energy consumption devices, Robustness in the presence of infrastructure, flexible and communication security	Speed and flexibility	Speed and flexibility

3. Power system infrastructure in smart grid

In a traditional power system, centralized generating stations generate bulk power which is supplied to the consumers through a one-way transmission and distribution system called the grid. The traditional bulk generation isa supplied power and then distributed to the consumers; at the same time, the integration of distributed generation is done at the bulk as well as distribution and customer levels [24]. As defined by the European Regulators' Group for Electricity and Gas (ERGEG), "*a smart grid is an electricity network that can efficiently integrate the behavior and actions of all users connected to it like generators, consumers and those that do both—in order to ensure an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety*" [25]. The comparison of the traditional power grid and the smart grid can be seen in table 2 [24].

Today the operation of electric power generation system is required to fulfill the consumers power demand. However, it must consider other aspects like the environment, output power quality and finance. To be able to compete in free electric trade era, generating systems must be able to operate efficiently in order to reduce the cost of generation. To comply with these requirements, the generation system requires generating equipment modernization with the latest technology so it can operate more reliably, efficiently, safely and with better power quality [26].

The power system infrastructure in the smart grid is supported by communication and data processing technology. It allows the generation side to control a more planned power generation due to load forecast to be more measurable, so that the generation can be more cost effective. Overall, power system infrastructure in smart grid can be divided into: Smart infrastructure system, Smart management system and Smart protection system [14].

Table 2. Comparison of Traditional Grid and Smart Grid [24]

Traditional grid	Smart grid
Customer calls when the power goes out	Utility knows when power is out and restores it automatically
Utility meets peak demand	Utility suppresses peak demand, thus lowering the cost
Difficult to manage high wind and solar penetration	Utility can manage distributed energy resources safely
10%+ power loss in T&D	Utility reduces power loss by 2+%, and reduce emissions and electricity bills of customers
All centralized control	Local control provides distributed generation

In the smart grid it is not only the information but also the power which can be exchanged in two ways. Meanwhile in conventional power system of generator system the energy is distributed through transmission system and being distributed to consumers through distribution network. In smart grid power systemconsists of distributed generation. In smart grid scheme consumers can also act as electric producers to produce electric power and supply it to the network.

Smart infrastructure includes the smart energy subsystem, the smart information subsystem, and the smart communication subsystem. Smart energy sub system handles mechanism of generation, distribution and consumption of electrical energy. Smart information subsystem is responsible for handling information exchange related to measurement, monitoring and management of smart grid system operation. Meanwhile, the smart communication subsystem handles communication infrastructure issues for data exchange between smart grid systems, devices and applications associated with smart grid. The smart management system is done by utilizing smart infrastructure facilities to achieve goals related to energy efficiency improvements, supply and demand balance, emissions control, reduced operating costs, and utility maximization. The smart protection system is the subsystem in smart grid that provides advanced grid reliability analysis, failure protection, and security and privacy protection services.

The distributed generation on the smart grid brings out the concept of managing multiple distributed generation in a cluster of power systems in smaller scale called microgrid. Power generation in microgrid concept can work either in the cluster or independently and not connected in a larger network or utility grid. This concept provides power grids more reliability, high penetration of renewable sources, self-healing, active load control, and improved efficiencies [27]. A study from the International Energy Agency pointed out that a power system based on a large number of reliable small distributed generations can operate with the same reliability and a lower capacity margin than a system of equally reliable large generators [28].

In smart grid, plug in electric vehicles (PEV) are not only intended to reduce pollution from vehicle exhaust gases, but also to play a role in power system operation, through the concept of vehicle to grid (V2G) and grid to vehicle (G2V). In the concept of V2G, electric vehicles act as energy storage that can supply power to the grid when parked and connected to grid [29]. While on G2V, electric vehicles act as energy storage that can contribute to handling power fluctuations through coordinated charging of EVs that can improve power losses and voltage deviations by flattening out peak power [30]. When electric vehicles are being parked at home, HEMS application handled power transaction of electric vehicles to grid. On the network side, the smart grid concept is aimed at improving network reliability through several integrated control systems consisting of smart control centers, smart power transmission networks, and smart substations. By adding sensors, communications and control to the existing network systems, then the network system can be smarter and able to do self-healing [31].

In the distribution level, the smart grid system application is conducted through smart metering in every consumer's houses integrated with HEMS and smart grid application, thereby from the side of the power system management there can be an analysis and planing of power system operation. From the side of consumers with HEMS application it is possible to control power usage and power source plan in the house either from solar or wind, in order to get cheaper and more efficient energy use [32].

4. HEMS Application Improving Power System Reliability

Smart grid technology has the potential to substantially improve electricity service by increasing reliability, reducing environmental impacts, and decreasing costs. In the electricity industry, reliability is often measured differently at the distribution level (retail service) and at the bulk transmission/ (bulk) generation level [33]. The reliability issues in modern power grids becomes more challenging. Factors contributing to the challenges include: aggravated grid congestion, transfers over longer distances, increasing volatility and reduced reliability margins and the grid is being operated at its "edge" [34].

In the smart grid system, the home load as one of the entities in the electrical power system can also participate in maintaining the stability of the operation and improving the power quality of the power system network. Through HEMS applications customers can participate in maintaining or improving the reliability of power systems. One of the programs on a smart grid system aimed at improving network reliability is Demand Side Management (DSM). Through the DSM program customers can make arrangements of the use of loads that can impact on the reliability of power systems. There are several categories of DSM programs, among others [35]:

- Energy Efficiency (EE).
- Demand Response (DR).
- Time of Use (ToU).
- Spinning Reserve (SR).

Energy efficiency (EE) is aimed at reducing energy consumption by improving the load so that the required energy consumption can be reduced because it becomes more efficient. Energy efficiency programs at the household level through HEMS applications can contribute to increased efficiency at the network level, this can occur due to the large number of household electrical customers [36]. EE activities, one of them, is done by installing electricity-efficient equipment. There are several electricity saving targets for household expenses, ranging from lighting, air conditioning, washing machines and others. Energy savings are also done by changing costumer's behavior in using household appliances [37].

Demand response, As defined by U. S. Department of Energy (DOE) is : Consumers conduct activities to change the operating pattern of electrical energy consumption, in response to the application of tariff provisions and incentives for the use of electrical energy. Consumers change the pattern of electric energy consumption from normal usage to the usage pattern by paying attention to the different electric prices based on the operating time or incentive value provided, in order to encourage lower electricity usage when peak load time or the reliability of the power system is threatened [38].

Included in Demand Response (DR) among others are Time of Use (ToU) and Spinning Reserve (SR). ToU is used for Non Dispatchable loads while SR is used for Dispatchable loads. In some countries tariffs for the use of electric power are differentiated for some time, especially at peak load times, where electricity rates are more expensive than out of peak load [39]. With time-based pricing schemes, application development is to implement Time of Use (TOU) programs such as Power shifting, load shifting and load shedding. Power shifting is done by moving an alternative energy source, such as from the sun, to be used when the electricity price of the network is more expensive [40]. Load shifting is done by moving the load operating time to another time outside the peak load. While load shedding is done by load termination or by not activating load during peak load. Beside that, it can be done through priority load mechanism in which peak load for less priority load will be off.

Spinning Reserve is meant to face disturbances and contingencies so that the power system remains operating optimally at the frequency of 59.97 Hz-60.03 Hz. Spinning Reserve is divided into regulating reserves and contingency reserves. Regulating reserves are to handle normal operational disturbances in the system. Contingency reserves (also referred to as reliability response) handle supply contingencies such as loss of generation [41].

PEV (Plug-in Electric Vehicles) in the smart grid scheme is to improve the power quality of power systems. Several studies have shown that the contribution of HEMS-PEV to the smart grid system can improve the power losses and voltage profile, one of the studies showed that voltage fluctuations resulting from large disturbances can be reduced up to five times [42]. This study proposes automatically controlled vehicle group (ACVG) as basic control units used in power system model. PEVs connected to the same substation are aggregated together to form ACVG. Increasing number of EV chargers will impact to value of current total harmonic distortion (THD).Transformer lifespan will decrease depending on the battery charging type and concentrated charging of electric vehicles [43].

5. Conclusion

The contribution of HEMS application to the smart grid scheme in improving the power system reliability is conducted through demand side management (DSM) program. DSM implements one of them with demand response and improved system power reliability. Penetration of electric vehicles in the smart grid scheme can also improve the reliability of power systems through V2G and G2V. When the electric vehicle is at home then HEMS application will handle the mechanism of V2G or G2V. Contribution of HEMS to the smart grid system can improve the power losses and voltage profile; one of the studies showed that voltage fluctuations resulting from large disturbances can be reduced up to five times.

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