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A Survey on Smart Home Energy Management Systems

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Abstract: The recent development in IT infrastructure has provided the researchers with more options to design new energy management solutions. The steep increase in energy usage requires attention in controlling the pollution which is a result of traditional methods of generating power. Alternative energy generation using solar and wind energy is gaining attention. An efficient means to harness this green electricity and utilizing it with maximum efficiency requires a good smart grid architecture which generates, delivers and monitors the usage of this clean electricity. This paper provides detailed structure of various Home Energy Management techniques for researchers in a great way.

Key words: Cloud Computing · Wireless Sensor Networks · Smart Grid · Renewable Energy Sources

INTRODUCTION

The global climatic change and hasty increasing population have resulted in growing demand for abounding, sustainable and green energy on universal basis. Today in most of the nations, the rapidly raising energy demand refers to larger burden on already aged, tensed and fragile electricity infrastructure. In US, for example age of the electric transmission lines is over 50-60 years [1]. According to the report produced by the US Department of Energy [2] shows that the consumption and demand for electricity has increased by 2.5% per year over the last 20 years. The rising demands for electricity with complication power distribution system have caused complex network issues. Moreover, the mismatch between the supply and demand for energy and lack of monitoring and automatic systems have cause severe blackouts over most of the countries. The negative impacts to the increasing energy consumption are more clearly congregating greenhouse gases and degrading fossil fuels. Furthermore, the rapidly rising usage of renewable energy sources has introduced lot of issues to power grid such as energy storage, system monitoring and system management has brought additional challenges. To meet these challenges Smart Grid (SG) has been emerged.

The Smart Grid(SG) [3] is an electric system that uses information, two way secure data communication and artificial intelligence over power generation, distribution, transmission, power consumption to bring an advanced and efficient system that is secure, clean and more reliable. The SG [4] can be explored in three major systems.

Smart Infrastructure System: This system supports the power generation, power delivery, smart monitoring, management and efficient communication technologies.

Smart Management Subsystem: This subsystem provides efficient control and management services to the modern electric system.

Smart Protection Subsystem: This subsystem provide system protection, security and reliable and privacy services to the Smart Grid.

Role of Renewable Energy in Energy Management: On global basis the change in electricity generation is desired to oppose the climatic change and increase energy efficiency. The usage of renewable energy sources [5] and its distributed generation plays a vital role among

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its users. And the integration this renewable energy sources to the traditional electric system brings a major challenge to the power grid .As the traditional electricity grid tends to accommodate higher percentage of renewable energy there is larger need for conventional back up power and huge energy storage. The introduction of renewable to the modern electric system reduces the usage of traditional power and thus saves the energy.

Enabling the usage of renewable energy sources to facilitate a cost effective system [6] while improving the power consumption ratio, quality of service and provides better reliability.Integrating theuse of renewable energy source to the power grid to enable a dynamic system that reduces peak hour loads as well as improves the energy efficiency and reduces the emissions of greenhouse gases.

Home Energy Management: Smart Home Energy Management system is a method which exchanges command between the households and the energy providers to minimize the energy consumption. This reduces the consumer's electric bill and manages well the household utilities at the peak hour. The design of the Home Energy Management system consists of resources from electric grid and renewable energy sources such as solar energy, wind power etc. The conventional Home Energy Management System (HEMS) [7] provides smart metering, sub metering and monitoring function to reduce the energy consumption.

With the demand of intelligent services, context-aware systems have been used in green home with different mechanisms such as learning, thinking and reasoning [8]. This context-aware system offers intelligent services with respect to the service patterns and the user activities. To the user's requirement the system can provide adaptive services by reasoning and analyzing events [9]. Context-aware systems have been used to improve energy efficiency and user satisfaction [10]. Further more modern home energy management systems exploit lot of embedded sensors to support large complex application.

Review of Varioushome Energy Management Techniques: In this section we going to review various Home Energy Management techniques.

Optimal Residential Load Control (ORLC) Scheme: AnOptimal Residential Load Control (RLC) scheme [11] that is suitable for grids with real-time pricing is and focuses on an automatic controller [12] which helps to predict the price of electricity to different scheduling categories. This automatic controller schedules the modern home appliances to reach the optimum cost and to give less waiting time for other electric appliances.

Coordinated Scheduling of Residential Distributed (CSRD) Energy Resources: This Decision support tool [13] was proposed for energy management in smart homes. This system concentrates on the heavy current consuming electric appliances such as a PHEV space heater, water heater, PV system and schedules them using particle swarm optimization technique to various TOU tariffs.

Optimal Consumption Schedule (OCS) for Residential Energy Management: This OCS system [14] focus to reduce peak hour electricity usage ratio using an Optimal Consumption Schedule (OCS).This system is a game theoretic approach. An energy management protocol [15] is used in this system to provide the users a set of maximum electric consumption value and a gateway is used to turnoff automatically the home appliances which are in standby mode. However defining a maximum consumption value is not practical and results in discomfort to the consumers.

TOU-Aware Appliance Coordination Scheme (TACS): The TOU-aware Appliance Coordination Scheme [16] gives the consumer a suggested time that is when they can turn on the home appliances to reach the minimum energy consumption level. The suggested time is calculated based on criteria such as TOU rates, electric power generation capacity, energy stored in the storage unit and the current demands.

Optimization Based Residential Energy Management (OREM): This OREM [17] focuses to minimize the total cost of the electricity usage at home. In this OREM scheme one day is divided into number of equal length time slots. Each of this time slots have varying electricity consumption charges. This system reduces the total electric bill of the home by scheduling the appliances to different time slots which have low prices. In this model the consumer's requirement are taken as input and the optimum scheduling [18] is done to provide the output. As a result the appliances that are scheduled create a time delay. To reduce the cost of electricity usage the appliances are scheduled to less expensive time slots. In OREM scheme the user's request should be given in advance.

Smart Home Energy Management System (SHEMS): The SHEMS [19] describes smart green home device applications, descriptions and standards for smart home control and load management. This green home control system provides application domains such as sensing device, control system pricing domain, load management and demand response system. This also defines green energy home interfaces and device applications that share the Zigbee devices [20] that are produced by producers of various electric equipments, smart meters and smart green energy products. In this work smart home control system is designed in a way that it can assign various control tasks to its related components. Wireless Sensor Network (WSN) with actuator function [21] is used to sense the smart home control information to efficiently control the home appliances.

A Smart Energy Distribution and Management System (SEDMS) for Renewable Energy Distribution: This Smart Energy Distribution and Management System (SEDMS) [22] operate through the interaction of a smart green energy distribution unit and smart control and monitoring subsystem. This smart system efficiently monitors and gives information about power consumption, consumer's situation and the user environment and controls the home appliances using the dynamic patterns. As SEDMS is connected with the traditional electric grid and with the renewable energy sources [23], the integration of this renewable energy sources brings some novel features to the SEDMS such as

Renewable Energy Management and Distribution: As the use of renewable energy sources has increased certain issues have been arisen to the electric power system. The key issue is the power system is the difference in the voltage and frequency. Therefore research should be considered in the smart energy distribution system.

Dynamic Demand Management: In the traditional electric grid system, the demand response (DR) is to efficiently manage the power consumption with respect to the market price and the user environmental condition, is to reduce the user consumption at peak hours. Thus tis system schedules the home appliances to consume less power not only based on users environmental situation.

System Control through Dynamic Patterns: The traditional power grid system manages and controls the smart home appliances by means of fixed and static values. That is they control the appliances in home by means of predetermined events. However this system manages and controls the home appliances through dynamic rules based on the environmental situation.

Smart Heating and Air Conditioning Scheduling Method (SHASM) for Home Energy Management: In this work the authors present smart a heating and air-conditioning scheduling [24] method for HEMS that considers the users convenience as well as the properties of high power consuming appliance in a smart green home. In order to save the energy and to reduce electric price optimal scheduling is done among the resource in the smart home. And this system defines an efficient heating, ventilating and air-conditioning (HVAC) model for the user convenience and an advance technique for solving the scheduling model for the Home Energy Management system [25] with this heating, ventilating and air-conditioning model. The HEMS based on this technique is used to resolve the least price schedule traditional electric system, as well as reduces the inconvenience of the user in the smart home system. The numerical result analysis of this HVAC system installed at various houses proves that it has reduced the percentage of power consumption.

Digital Environment Home Energy Management (DEHEM): This domestic energy monitoring and management system [26], [27] has been introduced, which defines direct feedback of percentage of power consumption and gas energy consumption in over 250 Bulgarian and UK homes. In this work, five living labs have been designed with novel features to create an interactive and effective environment for the participants. Diverse data visualization techniques and inducing interfaces are used for monitoring, controlling and sensing information in smart homes for energy management [28]. For the better results and quantitative and qualitative analysis of data is done. The numerical result analysis for this system shows the appliances in home have consumed less energy. And 92% of the users participated have declared positive behavioral changes in this DEHEMS work.

Intelligent Cloud based Home Energy Management System (iCHEMS): iCHEMS [29] assign a dynamic priority to the smart home appliances based on the type of appliances and the environmental condition. In accordance to the dynamic priority, the appliances in the smart home are scheduled to both the traditional power system and the renewable energy capability. The iCHEMS

Table 1: Comparison of various Home Energy Management Schemes

Approaches	Method	Communication	Quality of Service	Renewable Sources	Energy Efficiency	Pricing	Coverage
ORLC	Automated Load Control Scheme	No	Low	No	Poor	Real time Pricing	Local
CSRD	Swarm Optimization based technique	No	Low	No	Better	Time Of Use	Neighborhood
OCS	Game theoretic based scheduling	No	Low	No	Better	Based on Load and Generation cost	Local
TACS	Optimal scheduling	No	Low	No	Better	Critical Peak Pricing	Local
OREM	Optimization based scheduling	No	High	No	Good	Real time Pricing	Neighborhood
SHEMS	Distributed scheduling	Yes	High	Yes	Better	Time Of Use	Neighborhood
SEDMS	Interactive Demand Shifting	Yes	High	Yes	Better	Real time Pricing	Neighborhood
SHASM	Optimal scheduling	No	Low	Yes	Good	Time Of Use	Local
DEHEM	Dynamic scheduling	Yes	High	Yes	Good	Time Of Use	Neighborhood
iCHEMS	Dynamic scheduling	No	Low	Yes	Good	Time Of Use	Local

considers the concept of cloud computing to enhancethe usage of the renewable energy sources and utilization of more storage for computation.

To maximize renewable energy the iCHEMS assigns dynamic priority to the household appliances to make of renewable energy sources more to reduce the electric cost of the smart home [30] and to reduce the usage of the traditional electric power.To efficiently manage the infrastructure in the cloud iCHEMS defines the cloud computing techniques to offer the home energy management schemes. The architecture of this iCHEMS is well defined in the cloud as it provides more storage space.To efficiently manage the smart home appliances, the household appliances are optimally controlled and managed based on patterns such as user's behavior, energy consumption and resident's profiles and so on.

The numerical results of this iCHEMS shows that 6.5% of power consumption has been improved in stand-alone type and 8.1% in server based type, when compared to the predetermined schemes.

Table 1 Gives the comparative features of various Home Energy Management Schemes used in this section.

Research Directions: Number of papers in Home Energy Management has been reviewed for power management .However some of the issues to be solved are as follows

Voltage and Frequency: The quality of power delivered to the intended device plays a significant role in generation of power. Power Quality is a term used to describe the power that needs to drive a load. A device may fail to deliver desired output without good power. Quality of power depends upon the current that is produced and the voltage delivered. The steep spikes in the voltage due to excessive power generation beyond the load capacity can cause problems and so does the low voltage delivery. The variations in the frequency also play a major role in determining the quality of the power. A renewable power generation system needs to deliver the voltage with correct frequency for the load to accommodate.

High Cost: The raw materials required to build equipment to generate clean electricity requires very high initial investment. The return of investment is also is very high when compared to alternate methods. New source to harvest renewable energy must be developed for cheaper solution.

Service Response Time: The load requesting for service from an alternate energy source must be optimized to reduce the demand response time. The work flow patterns must be built is such a way to accommodate maximum utilization of power from renewable energy source at minimized response time. The peak generation time provides maximum output which can be utilized for operating heavy loads. The load shifting can be automatically shifted based on the power produced.

Power Consumption Ratio: The ratio between consumption of traditional electricity to the clean energy generated must be optimized to maximize the utilization of energy harvested from renewable energy sources. Work flows and scheduling algorithm has to be designed to maximize the utilization of clean energy.

Location Based Context Aware Service: The production of electricity by renewable energy source is much dependent on environmental and climatic zones distributed around the globe. Suitable designs to accommodate the drastic change in weather and climatic conditions should be deployed for optimal extraction of useful energy.

CONCLUSION

Home Energy Management is one of the major critical issues that have been addressed through various proposed schemes presented in various papers. This paper outlined different techniques and different critical issues in HEM, each of which has different merits and demerits. From the study of home energy management

schemes in still have more research opportunities in the future. New trends of a home energy management system will require interoperable user-centric services to the green home domains as well as extended service domains where new innovative pervasive services are available by network and service convergence.

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