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Smart Home Energy Management Systems Survey

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***Abstract*— Different kinds of system components including hardware elements, software algorithms, network connections, and sensors are required to cooperate with each other to provide various services in smart home. With the development of smart grid providing a two-way communication infrastructure, residents have the opportunity to schedule their electricity usage pattern to reduce their electricity cost. The energy management of a household level must take into consideration how to reduce the environmental burden, while supporting human's life style. The incentive and motivation to manage energy at the household level is influenced by commercial and technical reasons. Commercially, it offers the passive residential customer to be active in the energy market. The technical aspects include peak shaving, valley filling, load shifting, flexible load curve, strategic conservation and strategic load growth. Another important aspect of energy management systems is the socio-economic impact of such system. This paper reviews the concept of energy management systems for residential customers and looks into the background of smart home energy management system technologies. It highlights the major components, and comparatively analyzes various technological approaches. It also discusses some of the concerns and challenges such as cost, implementation and privacy issues of smart technologies.**

Keywords*— *Demand-Side management, Demand response, Energy management systems, power scheduling, Home Area Networks

I. INTRODUCTION

Since electricity is economically non-storable, wholesale prices (i.e., the prices set by competing generators to regional electricity retailers) vary from day to day and usually fluctuate by an order of magnitude between low-demand night-time hours to high-demand afternoons. In general, almost all retail consumers are currently charged some average price that doesn't reflect the actual whole sale price at the time of consumption [1]. As a remedy to this problem, various time-differentiated pricing models have been proposed: real-time pricing (RTP), day-ahead pricing (DAP), time-of-use pricing (TOUP), critical-peak pricing (CPP), etc. In all of these variations, the main idea is twofold: first, allowing retail prices to reflect fluctuating wholesale prices to the end users so that they pay what the electricity is worth at different times of the day; second, encouraging users to shift high-load household appliances to off peak hours to not only reduce their electricity costs but also to help to reduce the peak-to-average ratio (PAR) in load demand [2-5].

Demand-Side management (DSM) mostly refers to utility companies implemented programs to control the energy consumption at the household side [6]. These programs are employed to use the available energy more efficiently without installing new generation and transmission infrastructure. DSM programs include conservation and energy efficiency programs, fuel substitution programs, demand response programs, and residential or commercial load management programs [4,5,7]. Residential load management programs usually aim at one or both of the following design objectives: reducing consumption and shifting consumption [8]. The former can be achieved among users by encouraging energy-aware consumption patterns and by constructing more energy efficient buildings. However, there is also a need for practical solutions to shift the high-power household appliances to off peak hours to reduce the peak-to-average ratio (PAR) in load demand.

In the U.S. and in many parts of the world, there is a persistent problem of inefficient use of electric power generation and transmission assets. For example, in the Dominion Virginia Power' service area, roughly 20 percent of generation assets are used 5 percent of the time [9].This problem has partially been tackled by demand side management, which was introduced in the early 1980s [10], [11]. With the introduction of the smart grid, it is now possible to perform demand response at customer premises to get a finer control of the available resources. Demand response (DR) is defined as "changes in electricity use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" [12]. According to Federal Energy Regulatory Commission (FERC), DR activities in the U.S. are classified as either incentive-based (e.g., direct load control) or time based (e.g. dynamic pricing, critical peak pricing) programs. FERC has also pointed out that almost 80 percent of the total U.S. peak load reduction potential comes from incentive-based DR programs [12].

Due to this reason, and the fact that there hasn't been amateur time varying tariff for residential customers, the DR concept for our hardware demonstration is based on the incentive- based DR program which involves a customer receiving some sort of load control signals from a service provider. This DR concept is thoroughly discussed in [13], in which an algorithm is presented to manage multiple power intensive loads in a house to meet certain peak reduction targets, taking into account house-owner preset load priority and comfort level preference. In this case, a house-owner has the freedom to choose what loads to manage and for how long. This is different from a pre-set load (kW) reduction target set by a local electric utility company in direct load control programs. Note that for this kind of DR programs, economic incentives should have already been written into the contract between consumer and the utility. In order to realize the proposed DR feature, it is necessary to deploy a fully automated DR solution, or auto-DR [14], which can be made possible through the use of a Home Energy Management (HEM) system. Today, interests in HEM systems have grown significantly.

The rest of the paper is arranged such that section 2 gives a brief introduction about the home energy management system. While, section 3 presents a survey on the energy consumption scheduling. Then section 4 concludes the papers describing the home area networks. Finally section 5 contains the conclusion of the paper.

II. Smart Home Energy Management System

Energy management systems (EMS) have been in existence in the energy sector for several decades. The key functions of such systems are to monitor, control, and optimize the flow and use of energy. In general, energy management systems have formidable applications in the generation, transmission and distribution systems of the electrical network. Early EMS operations were based on analogue meters with skimpy, but fast, easy to understand information. They were however limited in scope and application [15]. The application developed rapidly in the early 1970s. Most of the systems delivered before 1975 were based on Xeros Sigma 5 and Sigma 9 [16]. The technological evolutions in the 1980s further changed the EMS, particularly with the advent of personal computers. Early developments of EMS, from manufacturers such as General Electric (then Harris Controls), Hitachi, Siemens and Toshiba, were based on proprietary hardware and operating systems [17].

Software- based system such as UNIX, LINUX and Windows-based systems added many possibilities to the EMS solutions in the early 2000s. Recent developments in embedded systems technological have further enhanced EMS functionalities. Many of the bulky, space-consuming solid state technologies have given way to more compact, small and efficient embedded or chip-based systems [17]. EMS also has age-long application in the residential sector. The use of workable night thermostat as a form of automated energy control dates back to the early 1900's. However, energy management became a real concern especially with the multiple energy crises, increasing cost and with the idea of energy conservation in the 1970's [18]. Developing a functionally and customer-friendly EMS at residential level requires a relatively different approach from the existing EMS in the distribution and transmission networks. Honeywell developed a unique solar energy managed system in the last 1970s based on microprocessor systems as a significant contribution to solving energy crisis [19]. Like any other EMS, home energy management systems have the end-goals as to conserve energy, reduce cost and improve comfort. Basically, HEMS offer five key services defined in [20], being monitoring, logging, control, management and alarms.

Home Energy Management Systems (HEMS) for residential customers are of recent important development. Demand response (DR), demand side management (DSM), peak shaving and load shifting which are considered to offer solutions to the network operator have further boosted the drive for more robust and intelligent HEMS. The U.S. Department of Energy classifies DR as having two options: price-based options and incentive- based options [21]. The price-based options and Direct Load Control (DLC) (one of the incentive-based options) are listed as follows since they are primarily offered to residential customers.

- Time-of-use (TOU): a rate with different unit prices for usage during different blocks of time, usually defined for a 24 hour day.
- Real-time pricing (RTP): a rate in which the price typically fluctuate hourly reflecting changes in the wholesale price of electricity. Customers are typically notified of RTP prices on a day-ahead or hour-ahead basis.
- Critical Peak Pricing (CPP): a hybrid of the TOU and RTP design. The basic rate structure is TOU. A much higher CPP price is applied when the demand is very high or system supply is limited.
- Direct Load Control (DLC): a program in which the utility remotely switch off a customer's electrical equipment (e.g. air conditioner, water heater) on a short notice

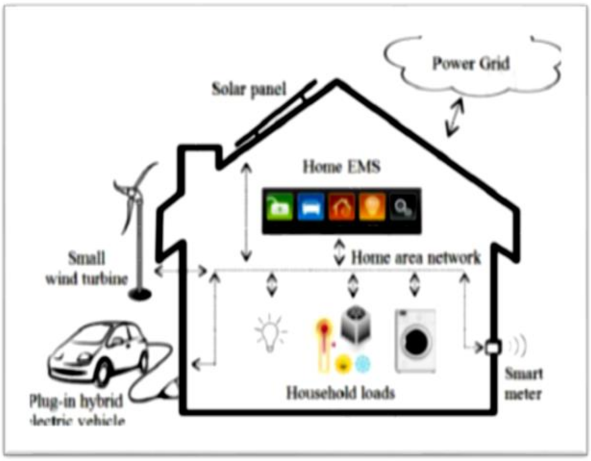

Fig. 1: A smart home with a home EMS

In residential sectors, the DR enable technologies usually related to smart home, which features an equipment of a home Energy Management System (EMS) that intelligently controls household loads with association of smart meters, smart appliances, Plug-in Hybrid Electric Vehicles (PHEVs), and home power generation and storage equipments as shown in Fig. 1. In the research work of a home energy management, it was noticed that it can be classified into either energy consumption scheduling or home area networks.

III. Energy Consumption Scheduling

The problem of smart scheduling from the consumer's point of view or side mainly is considered in this section. Like in ref. [22], it proposes a power scheduling approval based on RTP combined with IBR prices and it was effective for electricity cost reduction in residents' houses and the PAR reduction in the utility. Several optimization algorithms were compared in ref. [23] which addressed the scheduling of energy resources in a smart home and the comparison results showed that linear programming (LP) algorithm get the best solution with less complexity but not suitable for extensions and the Action Dependent Heuristic Dynamic Programming (ADHDP) got closer performance in the case study. In [24] the author compares between some optimization techniques for energy resources. Scheduling in smart homes with focusing on the attainable performances independency on battery features and also the ADHDP gives more benefits in battery model by battery size reduction with keeping other features and total energy cost unchanged. As proposed in [25] the optimization algorithm had an overall cost objective function for household user incentive compatible and the algorithm was efficient in first cost saving second energy peach shaving that take shift ability depending on a day ahead prices.

In ref. [26], the author had some objectives and he categorized them into: Minimize over all electrical energy consumption by scheduling the devices and shift-appliances use to off peak periods without user comfort disturbs, manage grid energy storage and household renewable energy sources. Authors in [27] presented scheduling scheme for home appliances operating over a consumer-praise communication network incorporated with smart pricing-based or DLC-based of other respond DR schemes. The model of direct load control was evaluated as 2-dimensional Markov chain protocol. Ref. [28] purposed time series method for electrical consumption of individual households by using Service Location Protocol (SLP). This method generated realistic time series of standard load profiles electrical demand with a high resolution up to 1 second.

The authors in [29] present a stochastic scheduling technique that based on the utility comparing time varying pricing information. The scheme achieved monitoring a precise reduction up to 41 percent over the traditional scheme and it is able to generate effective schedule with 10 seconds. The author of [30] proposed a Privacy enabled Home Energy Management System (PeHEMS) based on a simple algorithm to provide flatten load profile and lower consumption cost. The algorithm is less saving as compared with TOU.

A scheduling algorithm based on the assumption of algorithm energy prices, based on the requirements of user and he applied it on dimmable shift able and interruptible loads are discussed in [31]. An Adaptive Neural Fuzzy Interface System (ANFIS) based on master controller was proposed in [32] for cost power demand of the users depending on their life style and the environmental social factors are impacting power consumption. The designed scheduling algorithm for managing the appliances was based on the break and bound algorithm. The Micro Controller (MC) used to optimize the scheduling of the appliances communicates with the customer based on the TOU pricing.

Reference [33] purposed a consumer energy portal and HEMS which enable the consumer to understand their electricity use and bill with controlling them. It was presented by simulation that load shifting technique and TOU pricing can make up to 12 percent for saving monthly and 50 percent of peak. A hardware design of a smart home energy management system (SHRMS) is presented in [34] with a communication, sensing technology and machine learning algorithm application. The design helped the consumers to achieve a RTP responsive control strategy over residential loads and interact with suppliers or load serving entities (LSEs) to facilitate the management of the supplier side. A home area network used in [35] as EMS for power scheduling by combining both RTP and Inclining Block Rate (IBR) with residents preferences which gave cost reduction of electricity and delay time rate of home appliances operation as a result, a reduction of PAR from utility side that increase the stability of entire electricity system and it gives better results when compared to RTP approach.

The white good appliances has been scheduled in [36] based on a consumption measurements and dynamic prices. Reference [37] has a main objective for the Reactive-Home project which is creating an intelligent optimization system for production, storage and use of energy in homes. To activate this project the author used the cycle-based indicator. Authors in [38] described smart metering pilot project technical solution which is called 3e-hours project that was aiming to decrease, the energy use though ICT alone by 20 percent. About 100 hours were used as practical experience and the technical approach is built upon transporting of data between smart meter in hours and a remote collector server. A Smart Home Management System based on Power Line Communicator protocol is presented in [39]. A PLC Power Controlled Outlet Module (PPCOM) was developed for integrating AC powers socket. The power consumption concept parameters and exercise control over the devices are measured by PLC and microprocessor. Reference [40] used PSO in scheduling the tasks with operational constrains specified by domestic user and the algorithm was capable to reduce PAR in energy demand. An algorithm called a real household load priority scheduling which based on prediction of RES. Availability has been proposed in [41] and the results improved both energy and cost efficiency.

In [42] an event driven Model Predictive Control (MPC) frame work was established for solving load shifting problems. The consumer was allowed by the optional control to keep minimum daily energy cost in scenarios characterized by a TOU pricing model and DSM. Authors in [43] presented and implemented a programmed load manager for households that allows the user either to program a schedule, or put load schedule for multiple loads, that was tested and gave about 14 percent household efficiency and gave the ability to the owner to select daily operational hours for non intermediate loads in the house. A practical implementation algorithm that called Observe, Learn and Adopt (OLA), that achieved about 79 kWh potential saving for 30 days when compared with OLA disabled houses in ref [44]. The authors in [45] proposed load shift and load curtailed scheme that cope with multiple operators and different types of appliances and represent a suitable solution to handle the price fluctuation under real time pricing and reduce the energy cost by shifting some loads to low price periods and limit the consumption at higher prices.

The mixed integer linear programming (MILP) has been described in [46], which dealed with real situations of products and storages and domestic thermal model to achieve comfort level to its consumer and it was able to work in both static and dynamic cases maintaining the continuity of the task and the thermal comfort between schedules. The proposed versatile convex programming (CP) DR optimization techniques for automated load management in [47] showed that the start-up decisions of Schedule-based Appliances (SAs), that unavoidably lead to mixed integer problem conventionally but could be handled efficiently, and most of appliances could be presented as convex function which support its CP-DR to wider variety of appliances. The home energy controller based on MILP in [48] was able to control and optimize the energy use of the home grid components that lead to economic saving and PAR redacts through demand curve flatting. HEM proposed in [49] allowed the consumer to monitor, manage and control the usage of these appliances and reducing the electricity bill. It is a Wireless Enabled Electricity Manger (WEEMAN) and it is efficient in generating load schedules. Reducing both the operational cost and the equipments reliable use is achieved by coordinated optimal scheduling of controllable loads techniques and time of day electricity rate for operational cost calculations applied in smart homes by the authors of [50].

IV. Home Area Networks (HAN)

Moving towards the smart energy management will require changes not only in the way energy supplied, but in the way it is used or controlled, and reducing the energy consumption. All these goals will need networks to achieve it. As a result a lot of researches are trying to apply networks to the smart home. As in [51], an Open Service Gateway initiative (OSGi)-based gateway system integrating Non-Intrusive Load Monitoring (NILM) smart meters, sensors and actuators was proposed to provide more information such as appliance and appliance states in a house and building and the power consumption of an individual appliance to home automation and energy management applications and services. The association mining algorithm was developed to extract the relationships between appliances, sensors and actuators and it gives information that enhance the functionality of automation and energy management for smart home. The proposed gateway system and association algorithm were implemented and verified and the experimental results shows that the system and algorithm can be provided and significantly reduce the cost and effort of user configurations for smart home and building system.

A clustering method of one minute circuit current data was proposed using Self Organization Map (SOM) clustering method was estimated in [52]. To estimate the appliance operation condition, clustering results were connected to possessed appliances' information. The clustering method applicable to the waves including spiking loads was also developed. A new method has been discussed by authors in [53] based on smart meter data. The method was developed to identify and track home appliance by modeling the entire operating cycle of a load and make identification based on event windows. Another proposition of a novel method was customized for individual houses to create signature databases. After testing it was shown that the successful rate of identification is above 90 percent for all appliances also this technique makes nonintrusive monitoring more applicable for complicated loads and it reduce ordinary house owner's efforts to apply NILM.

Due to clustering high accuracy, a successful identification of the operating states of the household appliances plugged-in to a multiple sockets extensions was achieved and so we got a strong evaluation criterion for data clustering of power consumption data. Due to two applied criteria, the technique allows clusters with arbitrary shapes and size. The first criteria treats minimum distance from the most distance point from the cluster in the Euclidian space it was considered for optimization in a timely manner. The second criteria is based on self similarity and it was integrated because of the nature of the problem fractional dimension is defined as a measure of self-similarity. HEMS was designed in [54] to control power sockets based on precise identification of the plugged in appliances. The energy management panel in [55] is the link between the energy management system and the resident which supplies a visual representation of any electrical and thermal energy flow in the smart home to enable the resident to configure the EMS with her individual constraints. The Energy Management Panel (EMP) represents an interactive interface for an integrated EMS which manages electrical and thermal energy flows so it takes dependencies into account. The user is able to define constraints for the EMS like charge for specific time. The EMS is able to provide an optimized schedule of any consumer, supplier, and storage complying with the specified constraints.

A ZigBee sensor networks are proposed in [56] to build up Smart HEMS (SHEMS) to make homes more intelligent and automatic in managing the use of energy. The authors in [57] presented architecture of home gateway (HGW), the management system was crucial for realizing a better ecological home network. Electricity saving and CO2 reduction are aims reached by the authors in [58] by implementing EMS based on cloud platform and depending on Zigbee hub to collect data from appliances. The cloud computing system and software development project in [59] proposed study of a lightweight electronics appliance recognition method for designing smart meter. The average recognition rate of a single electronic appliance reaches 96.14 percent, while the parallel is about 84.14 percent. The Zigbee packet monitor and control panel was developed in [60] to record the transmitted messages, establishing protocol that is feasible for SHEMS.

To enable addressing the unbalance between consumer and utility, a wireless sensor network (WSN) was found for the renovation of the power grid by the integration of ICT. Wide spread of adoption of renewable energy sources, monitoring utility assets and self healing under failures, all this work was presented in [61]. In [62], a wired smart home is an application of Machine to Machine (M2M) with European Telecommunications System Institute (ETSI) activities on its standardization, open metering system specification and emergency communication with using a new web tool. The authors in [63] show a HEMS on web and determine the role that status of the remote browsing control web from practical stand point which enables user to configure or operate his smart home. The energy reduction and efficiency were confirmed by the actual test of the system and improved effectively. An approach based on secured web services was used to build up HEMS to allow remote interact with home elements for managing energy consumption using Zigbee wireless network was presented in [64].

The E2 Home novel application is proposed in [65] for fusion of electricity consumption data and location of residents. Then convert the data to charts and maps using web based application. Using calculations of the instantaneous power by authors of [66] helped in solving the case of activating new loads using priority criteria depending on Zidbee technology forming the HEMS, then advanced control level has been implemented considering more variables as temperature, timing, luminosity forming a decision control application. In [67] the performance evaluation of 5 different wireless HAN techniques have been discussed. The evaluation takes place depending on two objectives parameters. Firstly, required transmission energy per packet. Secondly, the reliable indoor coverage range.

Due to the bad suited sensors in dynamic HEM systems, the authors of [68] present a novel scheme which is Zigbee based intelligent self adjustment sensor (ZiSAS) scheme. The authors compared their scheme to sensor magnet agent (SMA) as percentage of energy consumption reduction. The result was 8-34 percent to 3-12 percent. The authors in [69] depended on a device free Radio Frequencies (RF) to extend the outlets and light switches to be human detectors to increase the user awareness and improve human computer interaction in smart homes. Their application was more efficient and successful than Passive Infrared (PIR) sensors. The Energy Sni_er system discussed in [70] can use the capability of sensing in the smart phones to monitor energy consumption of appliances at home. They use the sound sensing frame work represented in the microphone sensor of the smart phone as a practical test to monitor consumption of energy of the home machines and the results gives a good accuracy in detecting and monitoring.

As in references [69], [71] also used the RF as energy source to show that the field strengths availability for the Very High Frequency (VHF) radio band is usable for the application of sensor modules with energy harvesting functions, but with two disadvantages. First the operation illegality and second the antenna size. The new idea was to allow householders to monitor and control their appliances in the smart houses through a web browser. However, in [72] a new intelligent power socket (IPS) module has been acheived. The IPS was connected to system based home gateway to connect to internet and store the data in cloud. The authors in [73] presented an innovative remote control system that can control the appliances by email using X-10 power line communication protocol. As many governments encourage ’green home’ so it means to control the demand energy inside the home. One of the most important loads is lighting energy. Ref. [74] presents a ubiquitous home scenarios using sensor network to achieve the objective of cost energy reduction and energy saving. Authors in [75] introduced a sensor network to build up an energy monitoring system. The system components are smart power strip nodes, sink nodes, gateway, data base server and web server. The considered SHEMS gives a high accurate data and easy interface with user.

The Real Time Location System based on Ultra Wideband Radio Frequency technology was used in tracking and identifying occupant location to monitor their activities in different times as a type of energy use prediction had been discussed in [76], while the author of [76] also showed that the disadvantage of this system is its high cost.

V. CONCLUSION

The home energy management systems are used to reduce the environmental burden, and supporting human’s life style. The technical aspects of management include peak shaving, valley filling, load shifting, flexible load curve, strategic conservation and strategic load growth. Another important aspect of energy management systems is economic impact of such system. The paper reviewed the definition and explanation of energy management systems for residential customers. It gave background of smart home energy management system technologies, and highlights the major components, comparatively analyzes various technological approaches. Also some of the concerns and challenges such as cost, implementation and privacy issues of smart technologies and makes suggests a framework for future systems have been discussed.

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