Demand Side Management inside a Smart House

Review

Mario Šipoš
Croatian Armed Forces,
Zagrebačka 2, 43000 Bjelovar, Croatia
mario.sipos86@gmail.com

Mario Primorac
J. J. Strossmayer University of Osijek,
Faculty of Electrical Engineering, Department of Power Engineering
Kneza Trpimira 2b, 31000 Osijek, Croatia
mprimorac@etfos.hr

Zvonimir Klaić
J. J. Strossmayer University of Osijek,
Faculty of Electrical Engineering, Department of Power Engineering
Kneza Trpimira 2b, 31000 Osijek, Croatia
klaic@etfos.hr

Abstract *– The upgraded traditional grid, also known as the smart grid, that incorporates information and communications technologies will change not only electricity production but also consumption. In combination with Photovoltaics (PV) and electrical storage, demand side management (DSM) is a promising solution for net-zero energy building (NZEB). NZEB will be able to produce energy for its own needs and also feed a surplus back to the grid. In scientific papers, it has already been proven that the use of electrical energy storage can improve the power quality and store variable production of renewable energy. Smart meters are a step forward because they enable a two-way communication between a customer and a utility. In this way, it will be possible to monitor consumption and electricity prices on the market in real time. Furthermore, this will enable the consumer to turn off devices that are large loads, or let the DSM system known as load management do its job such to reduce energy consumption in a given period. DSM will automatically switch off a big load in a manner that does not disturb user comfort. Smart appliances at the end-user level such as the Internet protocol (IP) addressable appliance controlled by external signals from the utility or end-user will enable load shifting to off-peak periods. Solar radiation is prevalent everywhere and can be used to generate electricity at the point of consumption, thereby reducing the losses in transmission. Only one hour of solar radiation is sufficient to cover the annual consumption; this shows that the future of low-carbon energy production lies in the use of solar radiation.*

Keywords *– demand side management, energy storage, load management, photovoltaic, smart grid.*

1. INTRODUCTION

Growth of global energy demands has the potential to cause a significant increase in greenhouse gas emissions. More than three-quarters of the world's population lives in cities [1]. Between 1970 and 2010 electricity demand for domestic properties increased by more than twice [2]. Increased demand will have to be covered with environmentally friendly technologies such as renewable energy sources, to reduce carbon dioxide (CO2) emissions.

Since the 1990s, smart homes have been studied, with a primary focus on resident comfort. Studies on efficient energy management in residential buildings have shown a 30% reduction of consumption when the end-user is provided with real-time information on consumption. The smart grid will enable integration of renewable energy sources such as solar radiation [3], [4].

Studies on solar radiation to solve environmental problems have become an important issue [5]. World energy needs for one year can be covered by the amount of energy released by the Sun during one hour [4].

In a split second, the Sun releases more energy than our civilization has used during its development. This interesting fact shows the importance of utilizing solar energy. Annual solar radiation is fifty times greater than the sum of all fossil and nuclear fuels. World energy consumption is significantly smaller than the technical potential energy of solar radiation [6].

Evolution from typical electromechanical meters to modern smart meters will enable a reliable communication link all over the grid system making it easy to monitor and control. Smart meters will be capable of handling real-time information to improve the efficiency of power delivery and usage. A smart meter can set the temperature value below the reference value at off-peak demands for home appliances (refrigerators or air conditioners). Italy, the United States of America, the Asia-Pacific region, China and Japan are some of the countries that started smart metering pilot projects [7]. Smart meters will support demand side manage-ment [8].

Demand side management will enable customers to make decisions when they will use electricity and how much. The major impact areas of demand side management are load shifting (Figure 1) and load reduction (Figure 2).

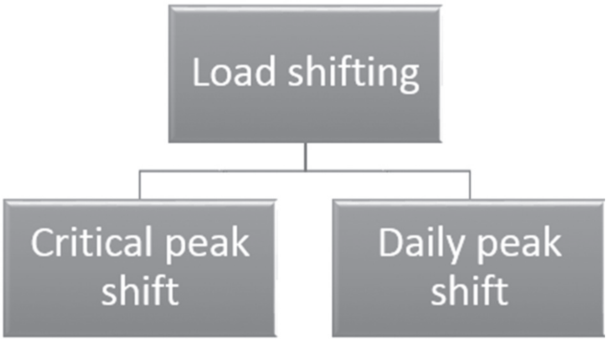

Fig. 1. Load shifting impact of demand side management

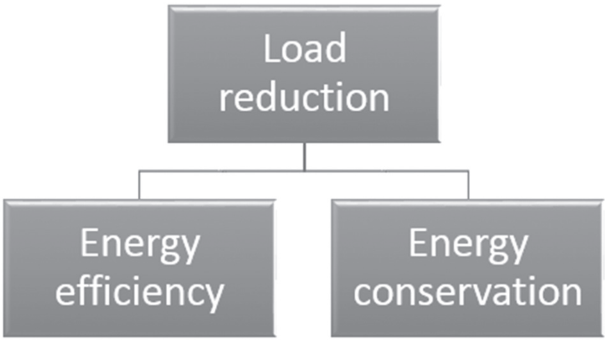

Fig. 2. Load reduction impact of demand side management.

Load shifting or demand response (DR) programs shift consumer load to off-peak periods. Energy efficiency and conservation encourage customers to smart consumption, for example, to set the thermostat on the air conditioner up a few degrees in the hot day to minimize energy bills [9].

2. SMART HOME

Residential homes on smart grids usually have local electric power generation from photovoltaic systems, micro combined heat and power (micro-CHP) systems [10]. Storage systems are used to reduce the impact of output power fluctuation of renewable energies on the grid voltage and frequency [11].

Next-generation grid researchers put focus on smart homes. At Yildiz Technical University, the Smart Home Project with appliances used in the average house was started in 2012. The proposed smart home concept consists of different renewable energy sources and an electrical energy storage system. With smart plugs and sensors, the data about temperature, humidity and the lighting level was transmitted to the central computer. In the central computer, the proposed algorithm can perform load control aiming primarily at reducing consumer bills [12].

The Gator Tech is a single-family smart house developed at the University of Florida for the purpose of experimenting and analyzing the application of intelligent technologies. The primary focus of this smart house is to enable better quality of life for users with special needs and elderly people by using smart sensors and intelligent appliances, but this smart living environment is suitable for everyone. The Gator Tech intelligent lab-house can ensure user privacy and comfort, notify the user of the medication and much more. Matilda Smart House is an experimental lab developed at the University of Florida. It consists of basic rooms in a family house, such as kitchen, living room, bedroom, and bathroom. The primary focus is set on automation of a smart living environment with smart technology and applications. A smart house similar to the Gator Tech Smart House was developed at the Duke University experimental laboratory. Its purpose is to provide a better, comfortable living environment for elderly people and disabled users with smart devices and appliances. The Drexel Smart House is a living laboratory dedicated to the quality of life. It is an example of how an old building is transformed into a smart house with smart appliances and an intelligent living environment. The Aware Home was developed at the Georgia Institute of Technology. It is a smart environment aware of user needs and. It uses sensors and intelligent cameras to fulfill user needs through automated response [13].

A smart home is equipped with smart devices and modern technology that can control consumer appliances. In [14], simulation of 100 homes for 100 days with the neural fuzzy system developed in the MATLAB/ SIMULINK to control electrical appliances showed a reduction in electrical power consumption by 15.6%.

In [15], electrical energy storage (EES) is presented as a solution to voltage rise from large-scale PV integration. The test network consists of five LV feeders emanating from the HV/LV substation. In the simulation, when PV generation injects maximum output power into the network, the three-phase voltages increase above the statutory voltage limit. When EES stores power from the network, the voltage decreases below the limit.

The embedded system that provides and manages a smart home energy requirement with solar and storage energy resources in the smart home was proposed in [16]. In terms of two-way communication, the home gateway (H-Gateway) single chip embedded system integrated with the GSM modem was installed at the end-user side and the utility server (U-Server), a high-end PC was installed at the utility headquarter. Test results of this PV system connected to the grid showed that-two way communication between the H-Gateway and the U-Server can manage peak and lower energy bills by about 33%.

Household appliances must be linked via a communication network that allows control of smart appliances to carry out load management. The task of a home automation system is to achieve load management taking into account user comfort at low cost while satisfying technological constraints of equipment [17]. In a typical home automation network (HAN) architecture, smart appliances enable intelligent decision making. These devices report their energy consumption to the Home Energy Controller (HEC) and respond to its commands, such as on/off signals, or DR command to operate in an energy saving mode. For example, after receiving DR signals, smart dishwashers can delay wash cycles until off-peak periods. Smart meters send user data to the utility network and real-time pricing (RTP) with DR signals to the HEC at the home area network [18]. The smart house can become part of the smart city. The demonstration project, IssyGrid, aimed at reducing energy use, located in the French town of Issy-les-Moulineaux. It consists of four commercial buildings and 200 test homes. The citizens were provided with real-time energy consumption. The results show that consumption and energy bills on the end-user side arere reduced by 10 to 20% [19].

3. DEMAND SIDE MANAGEMENT (DSM)

It will soon be possible to modify consumer's use of energy by demand side management (DSM) strategies in smart grids that will enable shifting from peak times to off-peak times to smooth out daily demand. Key components to develop demand side management strategies are smart home technologies and smart meters [20], [21].

DSM is focused on minimizing peak load. End-users are willing to reduce their electricity bills but also to maintain comfort in this process. Waiting reflects user comfort for DSM, and it is desirable to keep it as short as possible. Expensive power generation can be avoided by shifting electricity usage from peak periods to off-peak periods.

A system architecture and an algorithm for user-friendly DSM (UDSM) using ICT is proposed in [22]. UDSM will minimize user's energy bill and peak load, and maximize user convenience by using the previous user pattern. Smart appliances send a request to a load aggregator (LA). The LA receives time-varying price information from an advanced metering infrastructure (AMI) and sends the price with reserved appliance information to the demand response manager (DRM). The DRM receives the previous user pattern from the database (DB), then the DRM sends an optimal scheduling result and rescheduling request to the load controller (LC). The LC also receives a real-time monitoring scheduling request. Moreover, in the end, the LC sends a signal that turns smart appliances on. Simulation in MATLAB 2013a shows that the load balancing algorithm shifts time to avoid peak load and reduce the electricity bill.

An intelligent home energy management (HEM) algorithm for demand response that takes into account load priority and customer comfort level settings was proposed in [23].

HEM receives external signals from the utility; load priority and customer comfort preference were considered. In the proposed HEM algorithm, some loads can only be monitored and some can be both monitored and controlled. Simulation results show that the proposed HEM algorithm can effectively control the appliance operation, but to some extent, at the expense of customer comfort.

The My Home load control management system manages load control by automatically disconnecting the least important appliances in case of overload. The system can control up to 63 loads. It can display actual consumption of the controlled load on the display interface, e.g. Local Display, Touch Screen and Webserver. The user plugs a home appliance into the socket with the actuator creating a hierarchy of importance of the appliance used. In this example, during peak periods, the first device that disconnects is the oven, which is considered least important by the user. The second device that will disconnect is the washing machine and finally the microwave that is considered most important by the user.

The user can reactivate the disconnected device by using the actuator push button or the touch screen. In this case, if a pick period still exists, the central unit will disconnect another load according to the hierarchy of importance of the used appliance that is set by the user [24].

Computer technology can make common load become smart load that will improve power quality form [25]. In most DSM programs, the key focus is put on interactions between the consumer and the utility company. In [26], an autonomous and distributed demand-side energy management system among users was proposed. Each consumer is equipped with an automatic energy consumption schedule (ECS) deployed inside smart meters connecting the power line and the communication network. In the proposed DSM system, game theory and formulation of an energy consumption scheduling game was used; the players were the users and their strategies were the daily schedules of their household appliances and loads. Simulation results showed reduction in total energy demand and total energy costs.

A home energy management (HEM) scheme based on appliance coordination is proposed in [27]. The ZigBee protocol is used for communication among home appliances, a central energy management unit (EMU), the smart meter and the storage unit inside the home. Simulation results showed efficient shifts of loads from peak hours to off-peak hours.

In [20], three occupied homes with a wireless smart home platform EnOcean, for demand side management in fully monitored "life-labs" located at the University of Nottingham, UK, were part of an experiment. The aim was to investigate consumer reactions to shifting appliances that use a considerable amount of energy, such as dishwashers (DW), washing machines (WM) and tumble dryers in the off-peak period.

Six case study methods lasting between two and four weeks were performed. Four tariffs, i.e., the cheapest Green, Orange, Yellow and the most expensive Red, were used. At the beginning of each study, the Green tariff was selected, users were able to select any other of the above tariffs; if the Red tariff were selected, smart control would be turned off. The user was able to override the system if desired. Three levels of engagement were available: first - the Web only, accessible from personal devices to access a website to select a tariff, second - appliance tablets, there was a tablet on every device that enabled easy access to the same website, and third – an override switch, an EnOcean switch that can cancel the currently active smart program, was fitted with each appliance. The following case study methods were applied:

1. BASF house with the washing machine & the dishwasher, the method – the Web only and the duration of four weeks.
2. BASF house with the washing machine & the dishwasher appliance, the method – the Appliance tablet, and the duration of four weeks.
3. Tarmac 10 house, the washing machine, the method – the Appliance tablet, and the duration of four weeks.
4. Tarmac 10 house, the washing machine, the method – the Override switch, and the duration of two weeks.
5. Tarmac 12 house, the washing machine, the method - the Web only, and the duration of three weeks.
6. Tarmac 12 house, the washing machine, the method – the Override switch, and the duration of two weeks.

Users accepted well the Web only in two case studies. The average delay was 9 hours and start time was between midnight and 3:00 a.m. The main problem was that dirty laundry was left to sit in the washing machine for too long for the Green tariff to begin. In case study 1 and case study 5, the house had washer dryers, the green period did not last long enough to wash and dry the laundry. Because of that, 65% of users used the Red tariff.

Users accepted appliance tablets well; they had easy access to the website and the ability to control devices. Users were more engaged in system management, but the study shows that the introduction of tablets increased use in high demand periods.

The override switch was used in case study 4; a misunderstanding about the override button resulted in 71% of use in high demand periods. In case study 6, 58% of use took place in high demand periods.

In [28], a new demand-side bidding mechanism with Price Elasticity Matrices (PEM) in an hourly Day-Ahead (DA) wholesale electricity pool is proposed. The proposed system was examined on a 6-bus system with three generation units and three retailers, under real-time pricing in a 24 hourly DA wholesale pool. Actual load data from Long Island, New York State, on August 9, 2008 was used. A numerical analysis showed more accurately the capture of real-time load behavior when the proposed demand-side bidding mechanism was used in comparison with the Single Hourly Bidding (SHB) mechanism.

In [29], a new real-time pricing demand response model was proposed. This model consists of two levels; the first level is electricity market price and the second level is control of battery storage and air conditioner units on the end-user side to reduce its electricity cost. The proposed model was successfully tested on the IEEE 14 bus system.

In [30], the authors proposed a water-filling based algorithm for charging a plug-in electric vehicle and flattening the load curve. Simulation results proved the effectiveness of the proposed algorithm.

4. CONCLUSION

An advanced communications network, the revolutionary transition from old electricity meters to smart meters that will enable two-way communication between the utility and the end-user will make a dream of DSM come true. The DSM system is now a well-researched field that can avoid or delay the need for new power plants. DSM benefits for the end-user are lower electricity bills with retention of comfort or sacrifice to some extent.

With the arrival of smart grid variability of renewable energy sources will no longer be a problem and they will be easily integrated into the network using electricity storage. The smart home is one of the key components of the smart grid. The PV technology with energy storage is a promising solution for the production of electricity in the household. Another advantage is that PV can be mounted on the rooftop, the facade and windows, so there is no need for additional space.

EVs will improve the reliability of the network, bring balance between supply/demand and achieve goals of reducing greenhouse pollution. The smart grid is necessary to meet the growing demand and reduce environmental pollution caused by the production of electrical energy by burning fossil fuels. Pilot projects around the world show that it is smart to invest time and money in the smart grid.

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