Energy Management Policy with Demand Respond Method for a Smart Home

Win Thandar Soe, Cécile Belleudy
Department of Electronics
Laboratoire d'Electronique, Antennes et Télécommunications (LEAT), Université Côte d'Azur
Nice, France.
e-mail: win-thandar.soe@unice.fr, cecile.belleudy@unice.fr

Abstract**—**The increasing energy consumption increases the underlying environmental impacts. Hence, designing a more efficient energy management system is a vital research topic to address. A more innovative system for energy management makes energy consumption smarter and more efficient and reduces electricity bills. Several researchers proposed different home energy management systems with only grid supply as the source of energy. This study proposes a new online energy management approach that takes into consideration renewable energy sources coupled with battery autonomy. It is based on a novel architecture for collecting information on the energy consumption in a smart home via a wireless sensor network. In this approach, the first step is to identify the load type of each appliance based on its consumption. The second step consists in defining an energy management policy that utilizes the energy provided by the battery using a demand response method. These results show a reduction in the electricity bill for a smart home.

Keywords- demand response; energy management; load profile; smart plug network.

I. INTRODUCTION

In recent years, as the world's energy consumption has increased alarmingly, energy management systems have a critical role to contribute to the efficiency of modern smart homes. Many electrical devices used in homes do not optimize energy consumption, or to automatically or semi-automatically turn ON or OFF. From the electrical point of view, we can determine the total power consumption for a home, however, we cannot identify and observe the energy consumption of the different devices. To collect data from and manage the consumption individual appliances, smart plugs must be attached to each appliance. The plug then sends information to a gateway to be visualized on a dashboard. This collection data firstly identifies the appliance depending on its consumption. Using this classification, we will design an energy demand response system that reduces the required energy from the grid by using renewable energy to power one class of appliances.

The process of energy modeling and management in the smart home is based on three concepts:

- Energy harvesting [1][2]: local power resources, battery autonomy/charge, energy harvesting profiles according to the geographical climatic position,
- Home energy consumption [3][4]: classification and daily usage of appliances, lifestyle, load profiles during the day, time shifting, prediction and estimation of load analysis,
- Novel functionalities in Home Energy Management (HEM) approach [1][2][5]: integration of renewable energy sources and efficient battery management based on data collection and load profile classification, peak shaving energy management.

The aim of this article is to describe the load profile classification and the peak shaving energy management. This paper is organized as follows: First, Section II gives an overview of the related work. Section III describes a novel infrastructure for energy management system that classifies home appliances according to their power consumption. In Section IV, we propose and discuss an innovative energy management approach for a smart home that uses renewable energy sources to decrease the energy obtained from the grid. In Section V, we present the results of our preliminary experiments which are obtained by using our energy management approach. Finally, in Section VI, we conclude the paper and give some future work.

II. STATE OF THE ART

Electricity is the most inconstant and widely used form of energy. Therefore, electricity generation and consumption demand are growing globally. It is evident that among many other sources, the electricity generation is currently the largest single source of greenhouse gas emission, which is considered a significant contributor to climate change [6]. To mitigate the consequences of climate change, the current electrical system needs to undergo adjustments. The solution to these problems is not only in generating electricity more cleanly but also in optimizing the use of the available generating capacity. To achieve such optimization, the smart home could be an alternative. The intelligent control system inside a house introduces the concept of the smart home. Smart home technology provides an optimal alternative to its use for their security, comfort and energy saving as well. Previous studies have introduced different methods of home-based energy management system; however, most of these methods have considered grid supply. In the smart home environment, there are two primary methods to modify home energy consumption; total energy reduction with a price-based option and peak demand shedding or shifting method of Demand Response (DR) activities.

A. Problem Description

To fulfil the requirement of exceeding demands of energy consumption, different energy sources are installed in France. According to the study made in December 2016 [6] out of total capacity of 130 GW, approximately 48.3% installed energy is taken from nuclear sources, 35% is obtained from renewable energy sources and the fossil fuels and thermal energy sources contribute only 16.7%. Following the increased CO_2 emission in 2016, the nuclear power generation decreased due to the closure of several plants to conduct tests at the request of French nuclear safety authority. The energy generation from renewable sources covered nearly 20% of demand in France [6]. According to statistics presented by [6], the residential sectors are one of the main energy consumers which accounts approximately for 36% of the total French energy consumption. Seasonal variation and weather patterns reflect the energy consumption in France; for example, the use of energy is different during days of the week and time of day. France is the most temperature sensitive country in Europe. The demand for electric heating is higher in winter than in summer. Temperature below 15°C ultimately causes higher energy consumption. Similarly, the demand for user's activity is higher on weekdays than on weekends.

Energy consumption is one of the indices in determining the levels of development of a nation. The availability of energy supply to all sectors of life in any country causes the shortage of all kinds of energy, particularly electricity which is badly needed for economic development. Energy Management System (EMS) has been in existence in the energy sector for several decades. EMS also has age-long application as a vital role in the residential sector. Monitoring, controlling and optimizing the flow and use of energy are the key functions of energy management system [7]. HEM system also takes part in an essential role in performing residential demand response methods in the smart environment. It affords a homeowner the ability to automatically perform smart load controls based on utility programs, customer's preference and load priority.

B. Demand Response Approach

According to Federal Energy Regulatory Commission [8], demand response is defined as: "Change in electric 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". Time-of-Use (TOU) pricing is one of the price-based options under the classification of the U.S. Department of Energy [9].

- TOU pricing: a rate with different unit prices for usage during different blocks of time, usually defined for a 24-hour day. TOU pricing provides an incentive to shift loads from higher priced (On-peak) to lower-priced (Mid-peak) or (Off-peak) periods.

For example, Ontario Electricity TOU price periods [10] based on the schedule shown in Figure 1 follow: (i) Off-peak: 6.5 cents per kWh, (ii) Mid-peak: 9.5 cents per kWh, (iii) On-peak: 13.2 cents per kWh. TOU rates are typically reflected in the user's energy bill. In this study, we don't consider this price-based option.

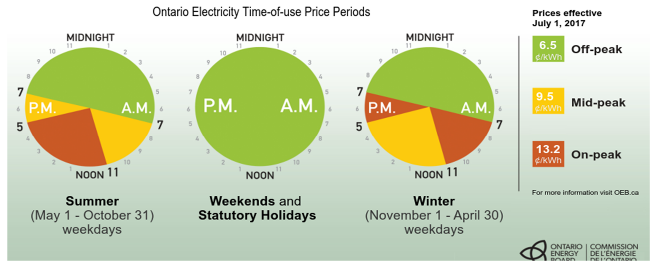

Figure 3. TOU Schedules and Rates **[10]**

Several HEM systems are based on different methods, such as load shifting, peak shaving etc.

- Load Shifting: a technique is used in demand-side management shown in Figure 2. It can be shifted the demand for a high power consumption of home appliances at different times within an hour or within a day when the price is lower.

Boynuegri et al. [1] have proposed HEM algorithm using load shifting method for the smart home. This algorithm includes the predefined criteria which combine grid ON/OFF situation, multi-rate electricity tariffs and the State of Charge (SoC) of batteries for all smart home platform with/without renewable energy sources.

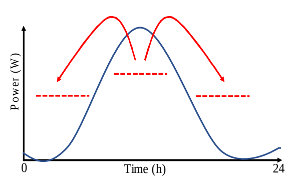

Figure 1. Load Shifting

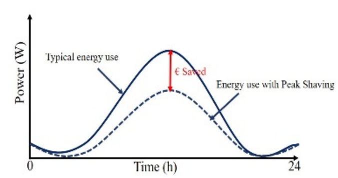

Figure 2. Peak Shaving Procedure

- Peak Shaving: a method which decreases total energy consumption, reduce the cost of electricity bill from the electricity grid due to the usage of renewable energy sources and shifting the higher power load to the night where the electric price is lower [5].

The procedure of peak shaving method is shown in Figure 3. Al-Saedi [5] presented the smart home peak shaving energy management system with a wired network that connects the house applications to a personal computer via USB port using K8055 interface board. Based on the peak shaving method in [5], the proposed policy with wireless network manages the household loads according to their preset priority and fixed the total household power consumption under a certain limit.

III. Energy Management Infrastructure and Load Classification

The home automation system has been used for the remote control of devices in the home since the 1990s and has formed the basis of the smart home building comfort [8]. A smart home system is divided into three main parts: a communication network, intelligent control and home automation [11]. The communication network can be created by wire, wireless or mixed communication technique between sensors and actuators. Many existing, well establishment home automation systems are based on wired communication. At present, the evolution and benefits of wireless technologies, such as Wi-Fi, wireless system are used every day and everywhere. The intelligent control intends to manage and monitor the entire house by internet services. Home automation that connects to the relevant smart components by using Home Area Network (HAN). Wireless sensor network system for smart home enables easy EMS construction. In next section, we described data collection and control architecture in the future smart home. Base on the principle of energy management infrastructure, we collected the data from home appliances by using the smart plug and classified the load.

A. Data Collection and Control Architecture in Smart Home

The smart home is a technology integration for greater comfort, autonomy, reduced cost, and energy saving as well. Figure 4 schematically illustrates the data collection and control architecture in the future smart home.

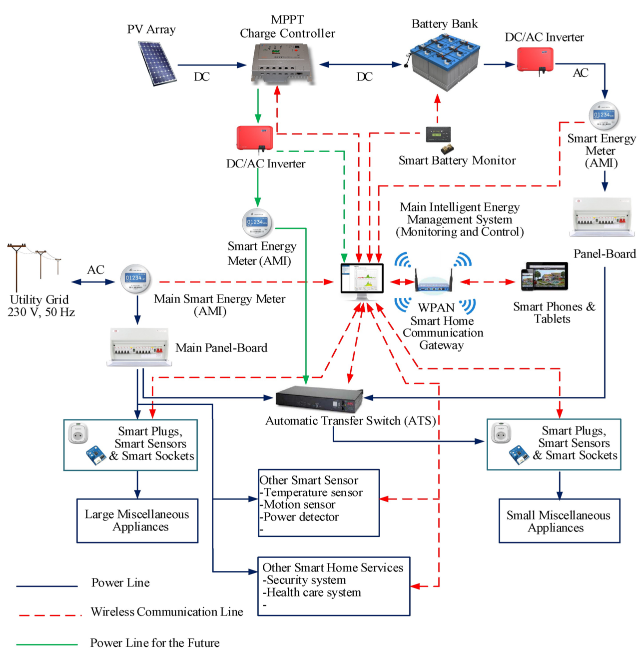

Figure 4. Data Collection and Control Architecture in Future Smart Home

In our proposed smart home, there are two supply sources for the household appliances: one source comes from the power grid and other from the renewable energy source, such as solar energy via battery. In this model, household appliances relate to an intelligent control system to communicate to the database and to manage the energy by Wireless Personal Area Network (WPAN), the smart sensors, the actuators and the smart plugs. The system can operate both in grid parallel mode and in stand-alone mode. All appliances are plugged into the wireless-enabled smart plugs. Thus, energy and power consumption for each appliance is monitored and stored in a distant location. Similarly, we can identify load profile of appliance by using the smart plug. Moreover, the smart plug can turn appliances ON/OFF remotely based on the commands from the central control. For example, the activation time of the appliances can be shifted if necessary.

To realize first measurements and validation of the proposed approach, we decide to use Fibaro smart plug [12]. The wireless communication protocol is Z-Wave technology. Fibaro smart plug is a bi-directional wireless system: current sensing and remote control. This plug has one function to check its status whether they are active or not. Each Fibaro network has its own unique network identification number (home ID), which allows identifying the different appliances and their activities. After Fibaro system is switched on, the location of its individual components is automatically updated in real-time through status confirmation signals received from devices operating in a mesh topology network. The unique feature of this smart plug is real-time energy consumption measuring through color changing, crystal LED ring.

B. Home Energy Management Database Structure

Information from energy harvesting (E_H), state of the battery charge (E_b), power and energy of each appliance (E_c) are collected and stored in the database. This collection is based on smart suitable sensors and actuators. Weather information, forecast or current, are derived from OpenWeatherMap service. The user activity is depending on the occupant's action plan and we propose to classify the underlying consumption according to load profile presented in next section. To achieve that, real-time consumption gathered by using smart plugs with proposed wireless communication technology. Energy management policy work on the database that contains real-time and prediction values by slot time. Slot time has been defined as part of a day according to the user activity. This slot time is to predict energy consumption and harvesting to propose a schedule of the usage of the battery according to energy sources status. The aim is to avoid energy harvesting loss, peak power, and prevent the outage. Figure 5 shows the principles of the proposed energy management infrastructure in a smart home.

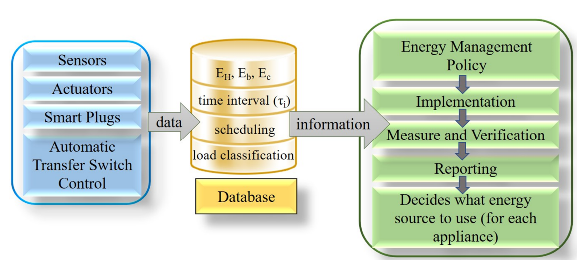

Figure 5. Principle of Energy Management Infrastructure

 ISBN: 978-1-61208-635-4

C. Data Collection from Smart Plugs

Fibaro smart plugs (Figure 6), which use a Z-Wave communication protocol, are in charge to collect power and energy consumption for the different home appliances. Real-time consumptions of appliances during each slot-time are collected and stored with Domoticz home automation application. This application allows visualizing and stored load profile for each appliance depending on the user's activity. On this base, our approach consists in determining a suitable classification of these load profiles with the aim to facilitate energy management.

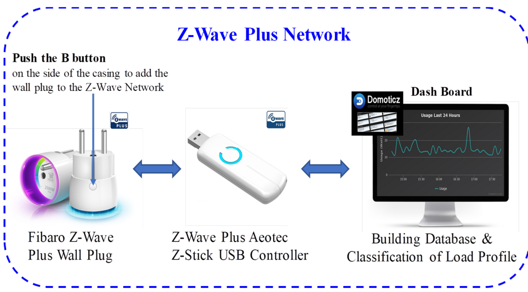

Figure 6. Installation to collect data from Fibaro Smart Plug

D. Load Profiles and Classification

The load profile is the variation in power consumption of an electrical load with time. The load profile is a specific concept in a smart home system that can vary depending, for example, on the user activity, season and weather condition etc. Appliances are drivers of residential power demands. Figure 7 demonstrates the aggregated load profiles of different appliances in a typical day. Our aim is to propose a suitable classification of these profiles to facilitate the energy management. As power consumption prediction is the main base for efficient energy management, the periodic load must be clearly identified and quantified. So, the proposed classification of loads is the following: intermittent load, phantom load, and continuous load [13].

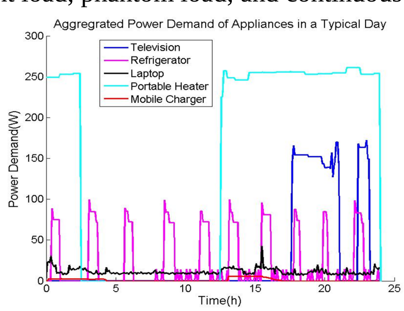

Figure 7. Aggregated Power Demand of Appliances in a Typical Day

1) Intermittent Load: The power consumption occurs occasionally or at a regular interval when an appliance is ON state. An appliance only operates a fraction of 24-hours periods depending on the user's activity. If the home appliances are active at a regular interval, these appliances' power consumption can be predictable but can present some variations which must be estimated with the confidence interval and degree. This load can be delayed eventually when the consumption of an appliance is lower than the total power consumption during peak hours or not enough energy.

2) Phantom Load: The phantom load or standby power also called wasted power occurs when the appliance is plugged into the socket and is not active (OFF/Idle states). In this state, the power consumption of home appliance is low almost zero. This function can define as a phantom load. After a while, this small amount of consumption tooks effect for the electricity bill.

3) Continuous Load: The certain appliances operate continuously or semi-periodically during a 24-hours period. The consumption can be variable according to appliance consumption mode. The characterization of each power mode must be done. This kind of load is highly predictable.

We defined a classification based on three kinds of load that can be combined to characterize the global power consumption. Each appliance is viewed as a combination of loads: one of the two main loads (continuous or intermittent load) and the phantom load which represents the small amount of power consumed in idle mode. Each load is defined by different parameters:

- Phantom Load: duration, the period with an interval of confidence, average maximum power. (Figure 8)
- Intermittent Load: duration with degree of confidence, the regularity with an interval of confidence, average maximum power. (Figure 9)
- Continuous Load: average duration, the period with an interval of confidence, average maximum power. (Figure 10)

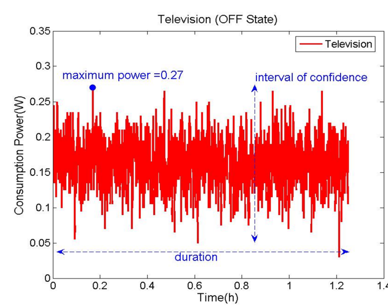

Figure 8. Measurements and Interpretation of Phantom Load

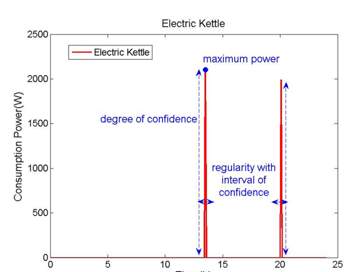

Figure 9. Measurement and Interpretation of Intermittent Load

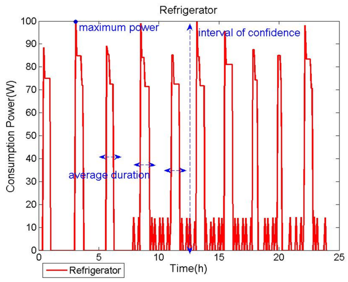

Figure 10. Measurement and Interpretation of Continuous Load

An automatic detection of the load has been implemented for real-time identification of data collected on the smart plugs. The first day for identification is needed. For instance, the home electricity usage of television at OFF state is represented in Figure 8. Where we analyzed the measurement and interpretation of the phantom load. Similarly, the intermittent load during a day as an example: Electric Kettle (ON state) is shown in Figure 9. The load profile of a refrigerator as an example of the continuous load is presented in Figure 10.

IV. ENERGY MANAGEMANT POLICY

In this paper, we propose an energy management policy using the peak-shaving method. The energy management policy is based on the different interval of time on which the schedule of battery charge, harvested energy and power consumption of appliances is built. On this basis, decision/action to reduce energy consumption from the grid are determined. The next subsections present the different parameters used and the proposed HEM policy concepts.

A. Analysis of Measurement

The energy management policy considers different sources of energy like grid and energy harvesting. To quantify the last quoted energy source, weather conditions are needed, and real-time and forecast data can get from web service or data center as like OpenWeatherMap service. Energy management can be based weather condition and occupants' action, real time or predictable. The associated parameters are:

- Weather condition (real-time and forecasted): Sunny hours per day and its irradiance, external temperatures (maximum, minimum),
- Kinds of the day: weekday/ weekend or holiday,
- Occupant's activity according to day: go to work or school at daytime or stay at home or not at home for the whole day based on the user's activity, prediction and motion detector.

By e-learning, different profile activity per day like wake up, small activity, lunch, non-activity, dinner, night, etc., are identified. This schedule is built at first on prediction and actualize on real time.

B. Proposed Home Energy Management Policy

In each time interval, the proposed HEM policy starts by gathering information, which includes the status (ON/OFF) and the power consumption of all appliances (watt, W), load priority (level) with its associated duration and the usable energy of the battery. A preliminary schedule is built based on the different prediction. When the decision is made, the HEM sends control signals to change the selected appliance status. In our study, we consider the three cases depending on the battery and electricity supply.

In the following, small appliances are defined by the fact that they can be powered by the battery. We assume that the customer fixes a priority for small appliances if he accepts to delay or not their activation. According to the level of energy in the battery and the expected energy consumption as described in Table I, different cases are feasible: (*b* = *battery*, *g* = *grid*)

TABLE I. SUMMARY OF PROPOSED HEM POLICY

Case	Conditions	b	g	Load Priority
1.	$E_{cs}(\tau) < [E_{b,\,usable}(\tau) + E_H(\tau)]$ SoC condition $\geq$ 70%	*		All small appliances are ON
2.	(a) $E_{cs}(\tau) > [E_{b,\,usable}(\tau) + E_H(\tau)]$ 50% $\leq$ SoC condition $\leq$ 70%	*		From the highest to lowest (with delay)
	(b) $E_{cs}(\tau) > [E_{b,\,usable}(\tau) + E_H(\tau)]$ 25% $\leq$ SoC condition $\leq$ 50%	*	*	From the highest to lowest
3.	$E_{cs}(\tau) > [E_{b,\,usable}(\tau) + E_H(\tau)]$ SoC condition < 25%		*	All appliances are ON

Case 1: If the total energy consumption of small miscellaneous appliances $[E_{cs}(\tau)]$ is lower than the usable energy of the battery $[E_{b,\,usable}(\tau)]$ plus the total harvested energy $[E_H(\tau)]$ for and during a time interval, all small appliances are powered by the battery. The HEM will force the status of small miscellaneous appliances $[A_{s,i}$ (i= 1,2,3,…,n)] to be "ON". Assume that the state of the charge of the battery (SoC) is greater than equal to 70% condition. No action is taken from the grid.

Case 2 (a): If $[E_{cs}(\tau)]$ is greater than $[E_{b,\,usable}(\tau)]$ plus $[E_H(\tau)]$, some small appliances can be delayed or powered by the battery. In this state, SoC assumes between 70% and 50% condition. HEM will perform the lowest priority load to turn OFF and determine primarily the highest priority load to turn ON. To keep the total power consumption under the usable energy of the battery, some of the lowest priority load will delay for the next time interval until enough energy of the battery.

Case 2 (b): If $[E_{cs}(\tau)]$ is greater than $[E_{b,\,usable}(\tau)]$ plus $[E_H(\tau)]$ and SoC condition assumes between 50% and 25% condition, some small appliances will be powered by the battery and others by the electricity grid. In this case, the supply source for home appliances can be dual. With the performance of automatic transfer switch, some of the highest priority load will shift to use electricity supply due to the insufficient energy of the battery.

Case 3: If $[E_{cs}(\tau)]$ is greater than $[E_{b,\,usable}(\tau)]$ plus $[E_H(\tau)]$ at the SoC condition is below 25%, all appliances will

 ISBN: 978-1-61208-635-4

be power from the grid to be more efficient energy and keep the usage of battery charge.

The proposed policy calculates the power of selected appliances and it will define state of each appliance either it is active or inactive. If the total power of these appliances exceeding the power limits, the use of this policy classifies the appliances and prioritize them in ascending order.

V. Preliminary Experiments

To process HEM, we recognize and identify different home appliances when coupled with smart plugs and monitor the progress at first day. We have collected data from appliances, such as quality of prediction and degree of confidence and classify different kinds of loads in our database. Table II describes the preliminary results of selected home appliances. We discussed the different parameters of appliances and defined in section III. The experimental time for each appliance was 24 hours. Quality of prediction is denoted by numbers from 0 to 5 indicating from lower (0) to high (1) priority. *(C = Continuous Load, P = Phantom Load, I = Intermittent Load)*

TABLE II. Results from Preliminary Experiments of Different kind of Loads

Plug No.	Appliances	C	P	I		Quality of Prediction
				(Regular)	(Irregular)	
1.	Refrigerator	*	*			5
2.	Light		*	*		4
3.	PC, Laptop		*		*	3
4.	Multimedia		*		*	2
5.	Coffee Maker		*	*		1
6.	Charger		*		*	0

These preliminary tests have been made to support home appliances for standard size family and this proposed HEM system allows approximately 28% reduction in total grid energy consumption. These results could be extended to larger HEM systems to provide and prove the energy efficiency of this proposed approach.

VI. Conclusion and Future Work

To measure the energy consumption in the smart home and analyze their features, we propose a data collection architecture base on smart plugs and the definition of three types of load. The aim is to improve the prediction of the energy consumption which is estimated at intervals of time that compose a day. According to these different load profiles, we propose to modify the functionality of the energy management policy for a smart home to integrate with renewable energy sources with the aim to optimize the use of the battery. Although much demand response methods are widely implemented by commercial and industrial side, nowadays it is enabled in the residential sector. Depend on the user activity and current electricity policy, to integrate peak shaving method with the smart appliances for the smart home. The goal of our research is to solve outage of electricity from the grid, to seek energy from the local power resources and reducing of electricity bill by using per month.

Base on the above conditions, the next step of work is to validate our approach with wider experiments. The second aim is to couple the energy management policy and a simulation framework which will represent the sensor network in charge to identify the load activity. The final aim is to provide a tool to realize a conjoint architecture exploration on suitable wireless sensor network and energy management policy in the smart home.

Acknowledgment

The authors would like to acknowledge by the mobility funded by Erasmus Mundus Mobility with Asia (EMMA) in the framework of EU Erasmus Mundus (Action 2). We also express our gratitude to Laboratories d'Electronique, Antennes et Télécommunications (LEAT).

References

[1] A. R. Boynuegri, B. Yagcitekin, M. Baysal, A. Karakas, and M. Uzunoglu, "Energy management algorithm for smart home with renewable energy sources," 2013, pp. 1753–1758.

[2] A. Saha *et al.*, "A Home Energy Management Algorithm in a Smart House Integrated with Renewable Energy," p. 6.

[3] T. Zhu, A. Mishra, D. Irwin, N. Sharma, P. Shenoy, and D. Towsley, "The case for efficient renewable energy management in smart homes," in *Proceedings of the Third ACM Workshop on Embedded Sensing Systems for Energy-Efficiency in Buildings*, 2011, pp. 67–72.

[4] M. Pipattanasomporn, M. Kuzlu, and S. Rahman, "An Algorithm for Intelligent Home Energy Management and Demand Response Analysis," *IEEE Trans. Smart Grid*, vol. 3, no. 4, pp. 2166–2173, Dec. 2012.

[5] F. A. T. Al-Saedi, "Peak shaving energy management system for smart house," *Int. J. Sci. Eng. Comput. Technol.*, vol. 3, no. 10, pp. 359–366, 2013.

[6] "2016 Annual Electricity Report: Bilan électrique 2016." [Online]. Available: http://bilan-electrique-2016.rte-france.com/mon-bilan-electrique-2016-en/. [Accessed: 05-Mar-2018].

[7] M. Amer, A. M. El-Zonkoly, A. Naamane, and N. K. M'Sirdi, "Smart Home Energy Management System for Peak Average Ratio Reduction," *Ann. Univ. Craiova Electr. Eng. Ser.*, vol. 38, pp. 180–188, 2014.

[8] D. Wight *et al.*, "2010 Assessment of Demand Response and Advanced Metering - Staff Report," *Fed. Energy Regul. Comm.*, vol. 2, pp. 1–117, 2011.

[9] Q. Qdr, "Benefits of demand response in electricity markets and recommendations for achieving them," *US Dept Energy Wash. DC USA Tech Rep*, no. 2, pp. 1–122, 2006.

[10] "Electricity rates | Ontario Energy Board." [Online]. Available: https://www.oeb.ca/rates-and-your-bill/electricity-rates. [Accessed: 05-Mar-2018].

[11] O. Elma and U. S. Selamoğullari, "A home energy management algorithm with smart plug for maximized customer comfort," in *Electric Power and Energy Conversion Systems (EPECS), 2015 4th International Conference on*, 2015, pp. 1–4.

[12] "Wall Plug | FIBARO Manuals." [Online]. Available: https://manuals.fibaro.com/wall-plug/. [Accessed: 13-Oct-2017].

[13] W. T. Soe, I. Mpawenimana, M. Di Fazio, C. Belleudy, and A. Z. Ya, "Energy Management System and Interactive Functions of Smart Plug for Smart Home," *Int. J. Electr. Comput. Energ. Electron. Commun. Eng.*, vol. 11, no. 7, pp. 884–891, 2017.