Modeling and Simulation of Smart Home Energy Consumption

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Abstract
The Smart home energy consumption represents much of the total energy consumed in advanced countries. For this reason, the main objectif of this paper is to study the energy consumption profile by day for each home appliances: controllable appliances for example Washing machine, Tumble dryer and Air conditioning and uncontrollable appliances for example TV, PC, Lighting, Refrigerator and Electric heater. In this paper, we start with presentation of a smart home energy management systems. Next, we present the modeling and simulation of controllable appliances and uncontrollable appliances. Finally, concludes this paper with some prospects. The modeling and the simulation of a Smart home appliances is based on MATLAB/Simulink software.

Keywords:
Smart home, smart home energy management, energy consumption, controllable appliances, uncontrollable appliances

1. Introduction

Smart grids are electricity distribution networks. They collect information from consumers and producers and adjust their operations accordingly automatically. The objective being, on the one hand, to ensure a balance between electricity supply and demand at all times and, on the other hand, to provide consumers with a secure, sustainable and competitive supply [1]. They aim to achieve customer satisfaction. It operates to supply the required quality of electricity every second and with very high quality.

In fact, a large number of electric appliances installed at home. This paper has the same goal of several works presented in the literature which is the decrease of power demand. To achieve the objective, this paper proposes the modeling and simulation of domestic appliances based on Matlab/Simulink software.

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Domestic appliances are divided into two categories: controllable appliances and uncontrollable appliances [2], [3], [4].

The controllable appliances can be totally or partially switched off by a controller for example Washing machine, Tumble dryer and Air Conditioning.

The uncontrollable appliances are passive loads that cannot be switched off or partialized for example TV, PC, Lighting, Refrigerator and Electric heater.

2. Smart home energy management systems

The smart home energy management is an essential home system to achieve the successful demand-side response in smart grid. It is used to monitor and control various home appliances in real time.
Therefore, smart home energy management is defined as “a system that is used to provide different energy management services such as monitoring, controlling and managing energy generation, energy storage, and energy consumption in smart houses” [5].

Figure 1 illustrates the five main functions of smart home energy management systems, including monitoring, logging, control, management and alarm.

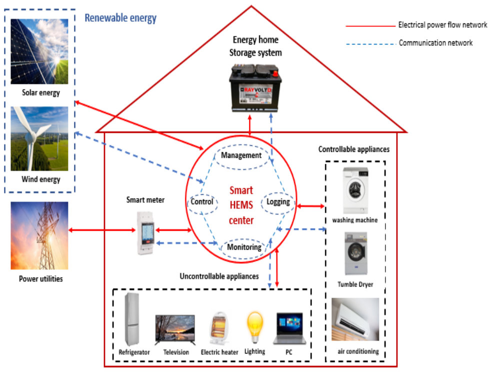

Figure 1. Smart home architecture

There are four main functions of smart home energy management, monitoring, logging, control, management and alarm [6]:

- Monitoring: This function offers consumers easy access to their consumption of electrical energy in real time. In addition, it offers services for the operating modes and the energetic state of the home appliances.
- Control: This functionality classified into two types namely direct control and remote control. Direct control is applied on both the appliances and control system. Remote control enables consumers to monitor and control their appliances on line via a personal computer or smart phone from outside the home.
- Management: Is the most important function of smart home energy management, in order to optimize the power consumption in the smart home. This functionality includes renewable energy system management, energy storage management and home appliance management.
- Logging: Smart home energy management aims also to collect and save data on power consumption of appliances, generation from renewable energy resources, and the energy storage state of charge.

3. Modeling of the Smart home appliances

The simulation model of smart home appliances developed in this work is depicted in Figure 2. The key components in the model are [2], [3], [4]:

- Domestic Appliances: These are divided into two categories: controllable appliances (Washing Machines, Tumble dryers and Air Conditioning) and uncontrollable appliances (TV, PC, Lighting, Refrigerator and Electric heater).
- Appliance Energy Controller: This block performs the load scheduling for the loads based on the results from the optimization and sends out instructions to the appliances to determine their operation time.

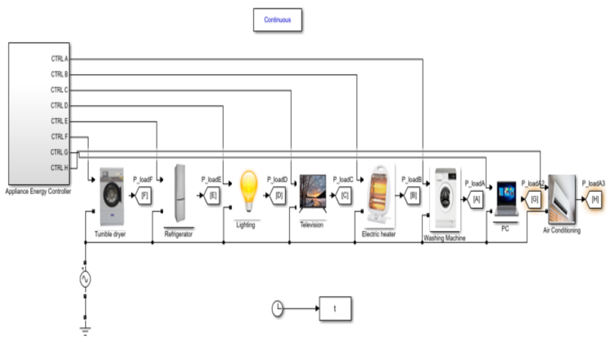

Figure 2. Simulink model of the Smart home appliance

4. Modeling and simulation of controllable appliances

In this section, we are modeling the controllable appliances which are Washing machine, Tumble dryer and Air conditioning.

a. Washing machine model

The washing machine is a device with multiple operation phases [7], [8], [9]. For the purpose of simplicity, the washing machine model for this paper is lumped into three phases; the heating and prewash phase, the washing and cooling phase, and the rinsing and spinning phase. Each phase of the washing machine consumes a specific amount of power and its operation last for a specific duration of time.

After simulation of the washing machine, the output of the washing machine shows the different operation phases with their corresponding power consumption and operation times. This is shown in

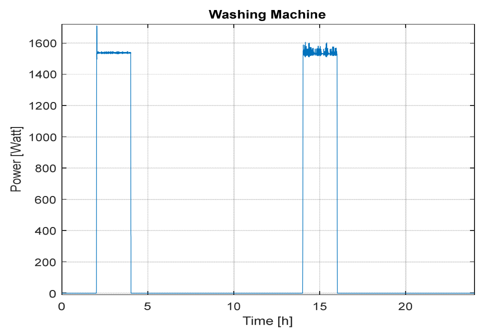

figure 3 below.

Figure 3. Energy consumed during the day for Washing machine

According to the proposed model, we can reduce the power of washing machine. We have to reduce the degree of the temperature, the amount of clothing, the rotation speeds and choose the most economic program for the seconds fuzzy [17].

b. Tumble dryer model

In this work, we use the Tumble dryer. It is modelled to consume a power value of 1000 Watts. The simulation of the synthetics program in MATLAB is presented in figure 4.

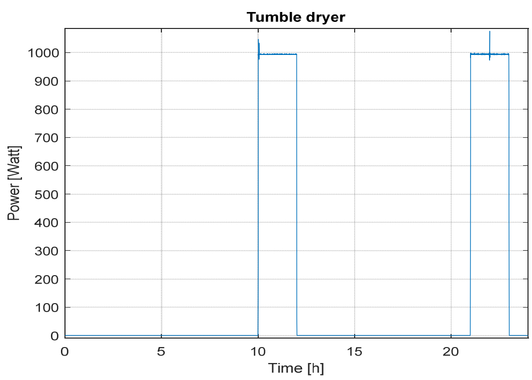

Figure 4. Energy consumed during the day for Tumble dryer

c. Air conditioning model

Modeling of air conditioning systems is necessary for studying and regulation of energy consumption and quality of indoor environment [18], [19], [20].

The Air Conditioning model is used in the summer when the temperature is very hot. In this work, the model is simulated from 11h to 18h and the figure 5 is the energy used in these seven hours at the day.

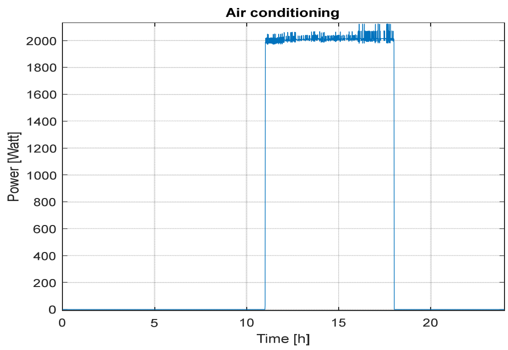

Figure 5. Energy consumed during the day for Air conditioning

d. Total energy consumption for controllable appliances

Figure 6 shows the demand of the controllable appliances during the day. It is clear that the most important peak consumption is about 3.6 kW between 14am and 16am and 3.3 kW at 11am due to the activation of most appliances in the same period.

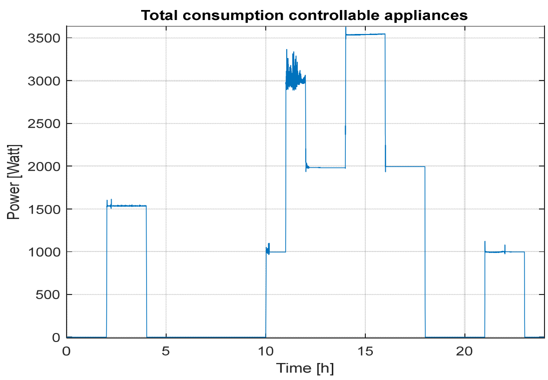

Figure 6. Total energy consumed during the day for controllable appliances

5. Modeling and simulation of uncontrollable appliances

In this section, we are modeling the uncontrollable appliances which are Electric heater, Television, PC, Lighting and Refrigerator.

a. Electric heater model

The electric heater is single phase appliance which is modelled and operated using an ideal switch to switch the appliance on and off as at when required. It is modelled to consume a power value of 800 Watts and the duration of operation can vary depending on specified on and off times [16]. This is shown in figure 7 below.

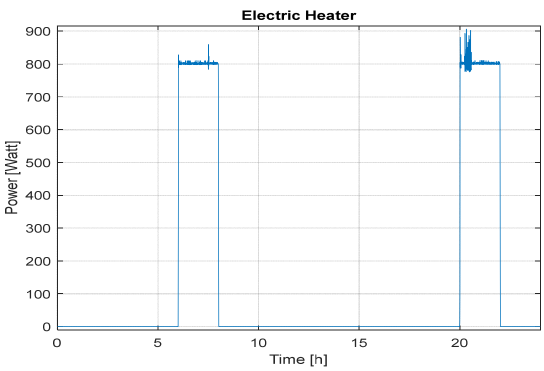

Figure 7. Energy consumed during the day for Electric heater

b. Refrigerator model

The refrigerator model presented in figure 8 is modeled by equation 1 and 2 with the hypotheses of: homogenous materials, linear cooling cycle with constant COP and neglect of the freezer compartment.

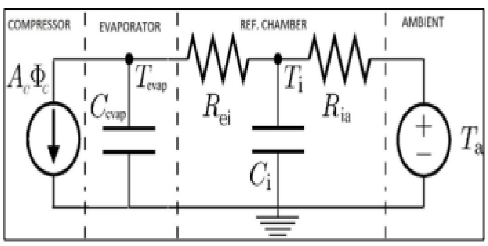

Figure 8. Refrigerator mode

$$\frac{dT_i}{dt} = \frac{1}{C_i R_{ia}}(T_a - T_i) + \frac{1}{C_i R_{ei}}(T_e - T_i) + \sigma_1 d\omega_1 \quad (1)$$

$$\frac{dT_e}{dt} = \frac{1}{C_e V_{ap} R_{ei}}(T_i - T_e) - \frac{1}{C_e V_{op}} A_c \varphi_c + \sigma_2 d\omega_2 \quad (2)$$

With: A_c= COP, Overall Coefficient of Performance.

The refrigerator is a single-phase appliance which is also controlled by a single ideal switch receiving instructions from the appliance energy controller [10], [11], [12].

However, the operation of the refrigerator differs from the electric heater, as the refrigerator is an appliance modelled to operate throughout the day. It is modelled to switch on and off continuously as typical refrigerator controlled by a thermostat to maintain a certain temperature. This is achieved using a pulse generator which sends instructions to the ideal switch to continually switch the appliance on/off throughout the simulation period. The refrigerator is modelled for a typical small household and consumes a power value of 110 Watts. Figure 9 illustrates the output simulation of the refrigerator as simulated from the model.

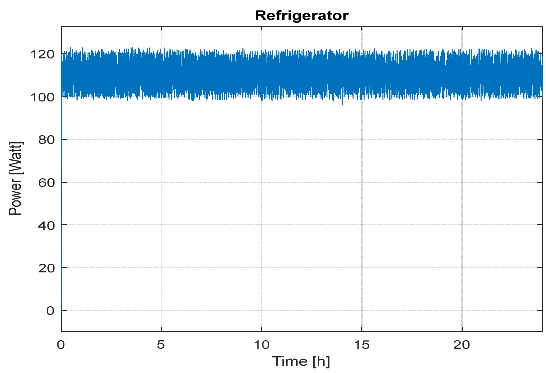

Figure 9. Energy consumed during the day for Refrigerator

c. Low power device

The lighting, the PC and the TV energy consumption are modeled as a constant amount of electricity used during a given time period [13], [14], [15].

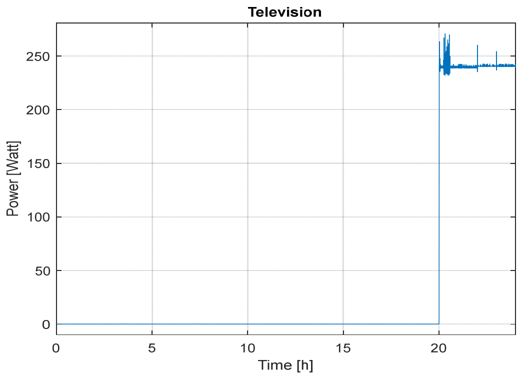

Figure 10. Energy consumed during the day for Television

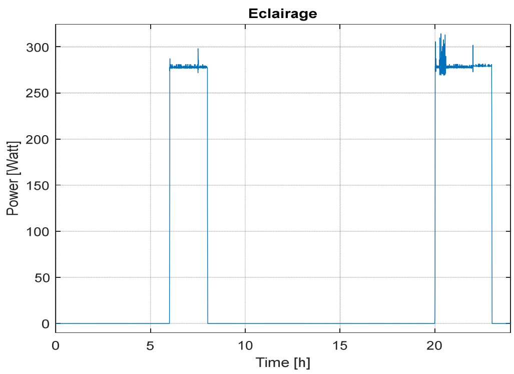

Figure 11. Energy consumed during the day for Lighting

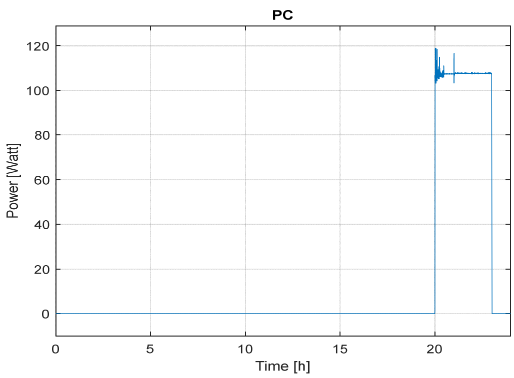

Figure 12. Energy consumed during the day for PC

d. Total energy consumption for uncontrollable appliances

Figure 13 shows the demand of the uncontrollable appliances during the day. It is clear that the most important peak consumption is about 1.7 kW between 20pm and 22pm.

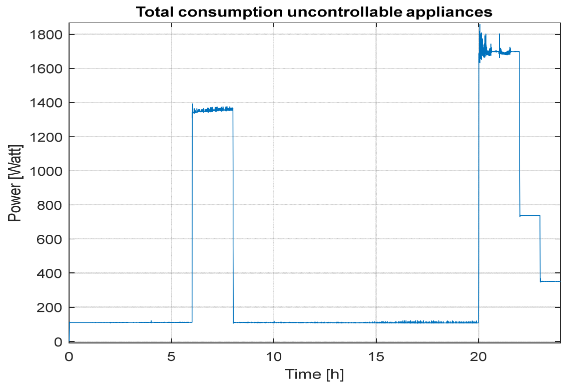

Figure 13. Total energy consumed during the day for uncontrollable appliances

6. CONCLUSIONS

Currently, Smart grids are aiming for profound changes to be able to improve and find the right balance of energy distribution in real time.

In this paper, we proposed a modeling and simulation of the home appliances: controllable appliances and uncontrollable appliances. We notice that the major areas of energy consumption in smart home are controllable appliances (washing machine and air conditioning).

By studying the modeling and simulation of smart home energy consumption presented in this paper, we will study the development of the fuzzy logic control strategy for household appliances to reduce power consumption and electricity costs.

REFERENCES

[1] A. Belgana "Distributed generation in a smart grid: a Game Theory Approach," thesis by Maîtres sciences (M.Sc.) in telecommunications, Université du Québec, 2015.

[2] Ahmed, M. S., Mohamed, A., Homod, R. Z., Shareef, H., & Khalid K, "Modeling of electric water heater and air conditioner for residential demand response strategy", international journal of applied engineering research. 11, 2016.

[3] Fanti, M. P., Mangini, A. M., & Roccotelli, M, "A simulation and control model for building energy management", Control Engineering Prectice. 72, 2018
[4] Mirakhorli, A., & Dong, B. "Market and behavior driven predictive energy management for residential buildings", Sustainable cities and society. (38), 2018.
[5] Zhou, B., Li, W., Chan, K. W., Cao, Y., Kuang, Y., Liu, X., & Wang, X," Smart home energy management systems: Concept, configurations, and scheduling strategies". Renewable and Sustainable Energy Reviews, 61, 30-40, 2016.
[6] F. Alfaverh, M. Denaï, Kh. Alfaverh, "Demand-Response Based Energy Advisor for Household Energy Management", IEEE, 2019.
[7] Demetgul, M., Ulkir, O., & Waqqr, T., "Washing machine using fuzzy logic", Automatic control and intelligent systems, 2014.
[8] Hatagar, S., & Halase, S. V, "Three input-one output fuzzy logic control of washing machine", International Journal of scientific research engineering and technology (IJSRET). 4, 2015.
[9] Ahmed, T., Ahmad, A., & Toki, A, "Fuzzy logic controllet for washing machine with five input and three output", International Journal of latest Trends in Engineering and Technology (IGLTET). 7. 2016.
[10] Costanzo, G. T., Bacher, P., & Madsen, H, "Grey-box modeling for system identification of household refrigerators: a step toward smart appliances". 4th International Youth Conference on Energy (IYCE). Hungary. 2013.
[11] Glaa, R., Lakhoua, M. N., & El Amraoui, L, "Using SA-RT method and SCADA for the analysis and the supervision of a hydrogen circuit", Journal of Electrical Engineering. 16(3). 2016.
[12] Sossan, P, "Grey-box modelling of a household refrigeration unit using time series data in application to demand side management", Sustainable Energy. Vol.5, March 2016.
[13] Bissey, S., Jacques, S., Chaeles, J., & Bunetel, L, "The fuzzy logic at the heart of an algorithm for optimizing the electrical energy consumption of an individual home", the Conference of Young Researchers in Electrical Engineering (JCGE). 2017.
[14] Glaa, R., Lakhoua, M. N., & El Amraoui, L. "Analysis and System Modeling of a Smart Grid: Case Study of the Operations Domain", GECS'2017, Hammemet, 23-25 March. 2017.
[15] Ciabattoni L., Grisotomi M., Ippoliti G., & Longhi S. "Fuzzy logic home energy consumption modeling for residential photovoltaic plant sizing in the new Italian scenario", Energy, (74). 2014.
[16] Ogwumike, C., Modibbo, A., & Denaï, M. "Optimized Residential Loads Scheduling Based on Dynamic Pricing of Electricity: A Simulation Study". 2013.
[17] Thinzar, K., & Soe, T. Z. "Operation system of washing machine with fuzzy logic control system and construction of detergent box", International Journal of science, engineering and technology research (IJSETR). 5. 2016.
[18] Zuñiga, K. V., Castilla, I., & Aguilar, R. M. "Using fuzzy logic to model the behavior of residential electrical utility customers", Applied energy. (115), 384-393. 2014.
[19] Dejvises, J., & Tanthanuch, N. "A simplified air-conditioning systems model with energy management", International Electrical Engineering Congress. Procedia Computer Science. 86, 361-364. 2016.
[20] Issi, F., & Kaplan, O. "The determination of load profiles and power consumptions of home appliances", Energies. 11. 2018

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