Chapter 7

Fuzzy Logic Energy Management for a Residential Power System Using Renewable Energy Sources

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Additional information is available at the end of the chapter

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Abstract

A fuzzy logic energy management algorithm is proposed for a hybrid wind/photovoltaic (PV) power generation unit, an electric vehicle battery, and a heat pump for household applications. The proposed concept refers to two independent power systems—a light electric vehicle and a household that interact through light, interchangeable batteries; moreover, they are powered from a renewable energy system comprising PV panels, wind generator, and appropriate MPPT-based converters. The main features of the concept are the heat pump load that produces thermal energy, as the main electric load of the system, and the storage element that is alternately used by the vehicle, which can be recharged from renewable sources. The presented algorithm allows the implementation, by means of fuzzy tools, of an appropriate energy management control system in order to obtain maximum utilization of the renewable energy. The results show that most of the energy required to charge the battery and to feed the heat pump can be covered from renewable sources.

Keywords: fuzzy logic energy management, PVs, wind turbine, heat pump, electric vehicle, battery

1. Introduction

Over the last decades, renewable energy sources have witnessed major (annual) growth rates, mainly the solar energy ones, which offer competitive, environmental friendly, low-cost solutions, accessible at a mass production level. The renewable energy producing units located close to energy loads are advantageous as the transportation energy losses are practically eliminated. The energy needed for a typical residential home is relatively small and can be covered mainly from renewable sources.

Considering the two major renewable energy sources, such as the wind and sun, the efficient energy harvesting from these sources is one major target of the energy industry. Although these energies seem to be free, with low negative impact, only the way these energies are extracted and used can state if the system is a sustainable system or not. In view of this, one can state that a system is efficiently harvesting the energy from these sources in a sustainable way if the overall efficiency of the system is high and if the energy produced is managed in such a way that these systems have minimum negative effect on the power grid. In other words, it is more efficient to use or store locally the energy produced from renewable sources instead of injecting the energy into the grid. In this way, the power grid is not perturbed by a small production facility with high dynamic behavior. Moreover, if the system is designed in an overall cost-efficient way, the number of PV panels, the wind turbine power, and battery storage capacity can all be minimized in order to obtain an optimized solution in which the power grid can be used only as an energy buffer supply.

The renewable systems of the future will have to integrate all the energy-dependent applications into a system that can be centrally controlled to obtain the best cost-performance balance. In view of this, one interesting way is to combine the electric car and the home electric systems. Concepts like vehicle-to-grid are recently being introduced [1], imposing that the energy storage of the electric vehicle can be integrated into the home electric system to maximize the overall system performance. An overview on solar heat pump systems is presented in Ref. [2]. Garcia et al. [3] present an optimal energy management system for standalone wind turbine/photovoltaic/hydrogen/battery hybrid based on fuzzy logic. Also, Ben Salah et al. [4] and Athari and Ardehali [5] are using fuzzy logic to facilitate the integration of renewable energy into residential or decentralized small power grid applications. Several papers, written by the same research group, present optimal control of different combinations of power sources that feed a heat pump and other loads. A wind/PV + power grid combination is used in Ref. [6], whereas a PV/diesel/battery + power grid combination and a fuel cell/wind/PV + power grid combination are used in Refs. [7] and [8], respectively. These three papers present cost savings derived from optimal control strategies.

The following sections present the power system under study, the presentation of the fuzzy logic energy management, the simulation results, and a conclusion.

2. Power system under study

This chapter proposes a concept in which two power systems interact by means of two interchangeable small batteries: a lightweight electric vehicle and a household partially powered from renewable energy sources. The overall schematic of the studied system is represented in **Figure 1**. The power generation system is composed of renewable energy conversion equipment: PV panels and a wind generator, both components being connected at the outputs on a DC-Link by means of MPPT-based converters. This DC-Link can be considered the main power line of the system on which also all the DC house loads are connected. This power system is also connected to the grid with a bidirectional DC-AC converter. The

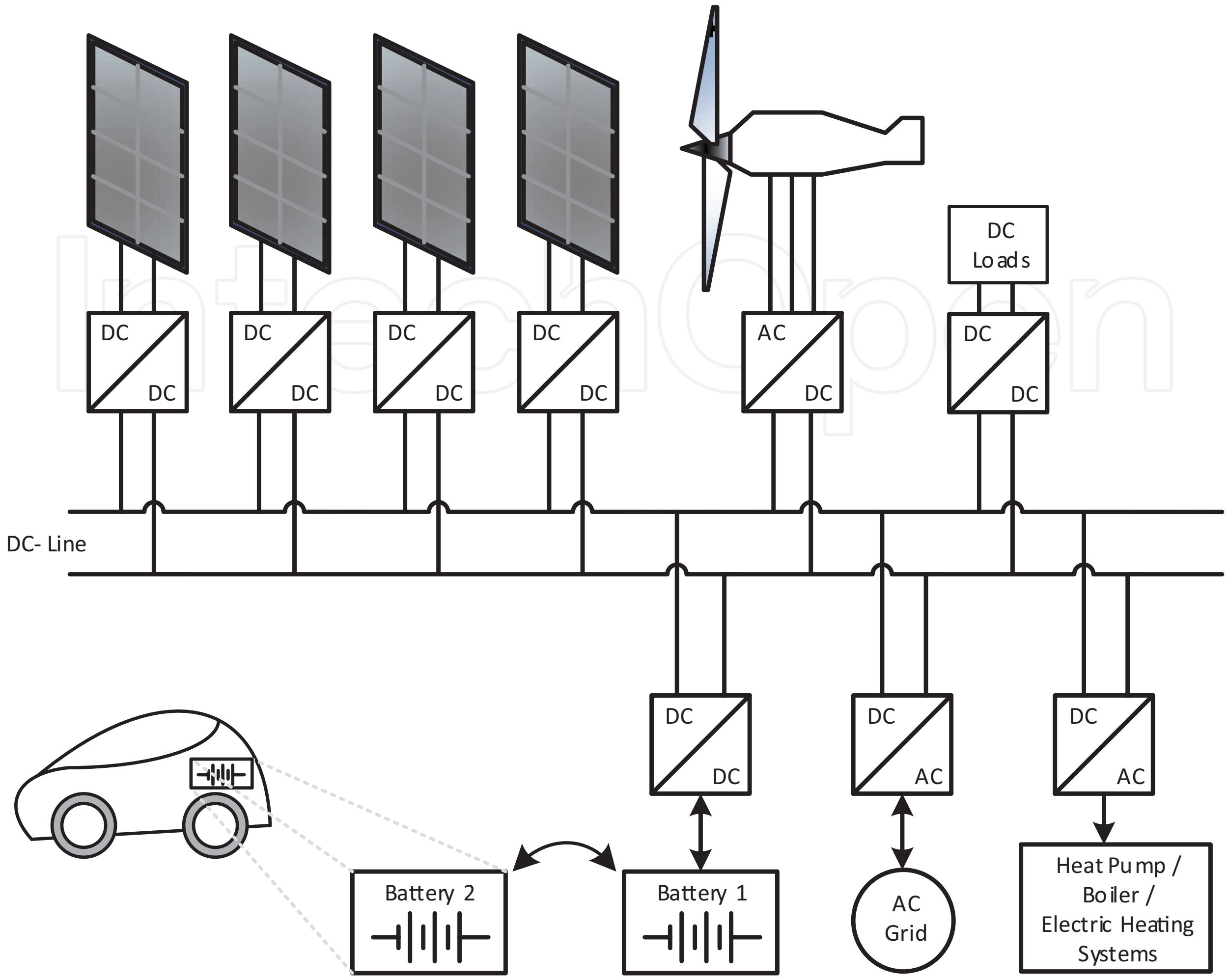

Figure 1. Schematic of the power system.

storage element is a battery from a lightweight electric vehicle. This small capacity battery is exchangeable with a second battery that is installed in the vehicle. The heat pump load is a key element in the proposed system, mainly because it will be the main electric load in balancing the energy from the renewable sources. Also, a key element of the proposed system is that the battery storage capacity is kept to a minimum; the two batteries are alternately used by the vehicle and are recharged mainly from the renewable sources. The battery can be used by the home electric system only when the power grid is unavailable. It must be stated that, to obtain a feasible approach, the battery has to be as light as possible in order to be easily exchanged.

The main objective of this study is to develop an energy management control system, based on fuzzy logic, which performs in such way that all the energy from the renewable sources is used, with minimum or no energy injection into the power grid and with a small energy storage capacity. The electrical energy can also be obtained from the power grid. In this way, the best cost-performance tradeoff with minimum storage capacity and maximum utilization of the renewable energy can be obtained.

3. Fuzzy logic energy management

The fuzzy logic energy management is developed with the aim of splitting the renewable energy power to be either stored into the battery or transformed into thermal energy, with a multiplication factor by a heat pump. The fuzzy algorithm is using as inputs the battery state of charge (SoC) and the required heat energy (hot water and heating during cold periods). The output is the battery power (P_{batt}), the heat pump power (P_{hp}) being calculated with the simple Eq. (1):

$$P_{hp} = 1 - P_{batt} \tag{1}$$

Figure 2 presents the two inputs and one output of the fuzzy logic supervisor.

Figures 3–5 present the membership functions (MFs) of the two inputs and output. The implementation of the fuzzy logic supervisor is done using Fuzzy logic toolbox and Matlab/Simulink® software from Mathworks®. It should be noted that those membership functions are built considering that the sum of them is on the entire interval 1 and the variation on both axes is expressed in per unit.

The rule base of the fuzzy algorithm is presented in **Table 1**. It contains nine rules according to the fact that each input has three MFs, all of them being considered in the rule-editing phase.

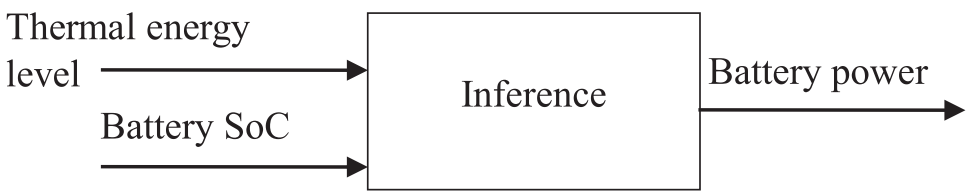

Figure 2. Fuzzy logic energy management inputs and output.

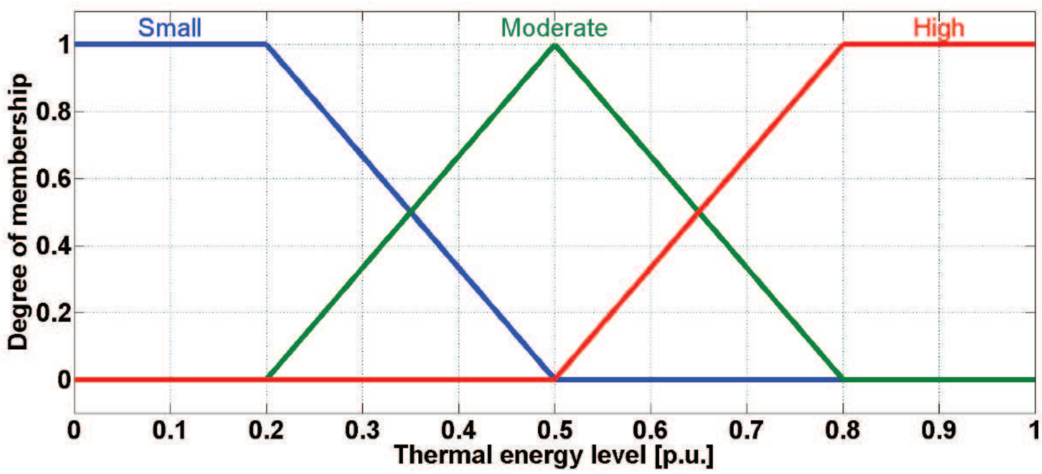

Figure 3. MFs for the first input of the fuzzy logic management system.

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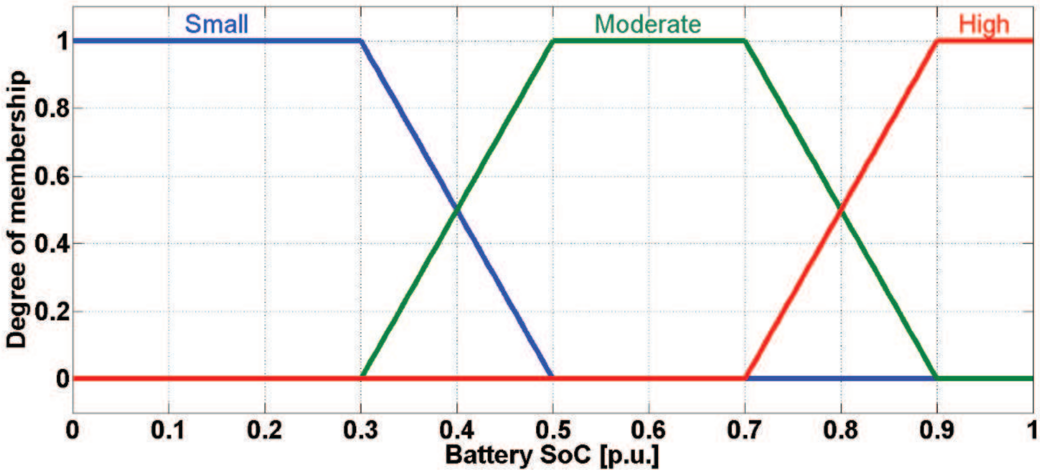

Figure 4. MFs for the second input of the fuzzy logic management system.

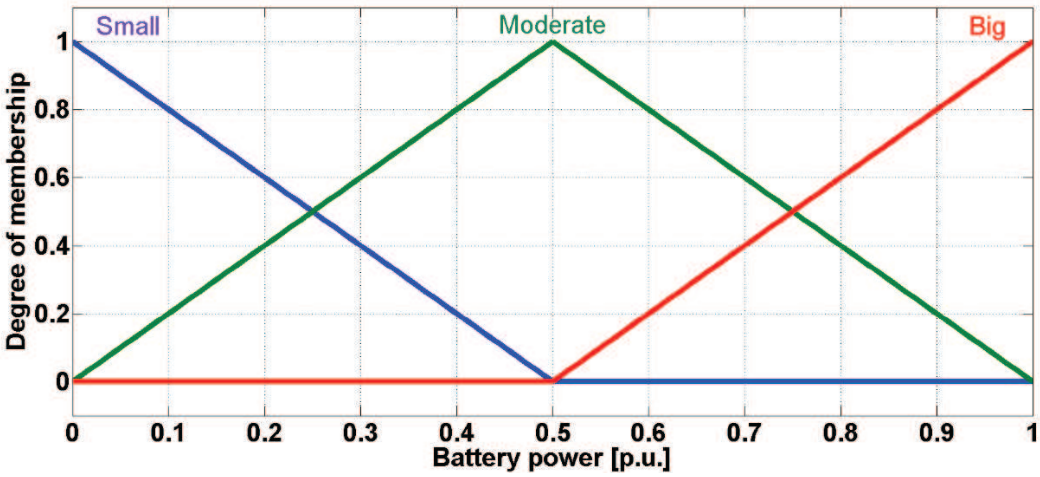

Figure 5. The output of the fuzzy logic management system.

Battery power		Battery SoC		
		Small	**Moderate**	**High**
Thermal energy level	Small	Moderate	Small	Small
	Moderate	Big	Moderate	Small
	High	Big	Big	Small

Table 1. Rule base of the fuzzy logic power management.

These rules were established considering the next principle: the thermal energy level and the battery SoC should increase similarly if they have a similar level (in per unit), but if one is lower than the other, it will be favored in order to reach a similar level (in per unit).

The defuzzification method used is centroid, which returns the center of area under the response surface. **Figure 6** presents the response surface generated for this fuzzy logic supervisor. As it can be seen from this figure, the output variation does not reach the full range between 0 and 1 (its range is between 0.163 and 0.837). Thus, in order to extend the output range, the output result is subtracted with 0.163 and then multiplied with 1.485.

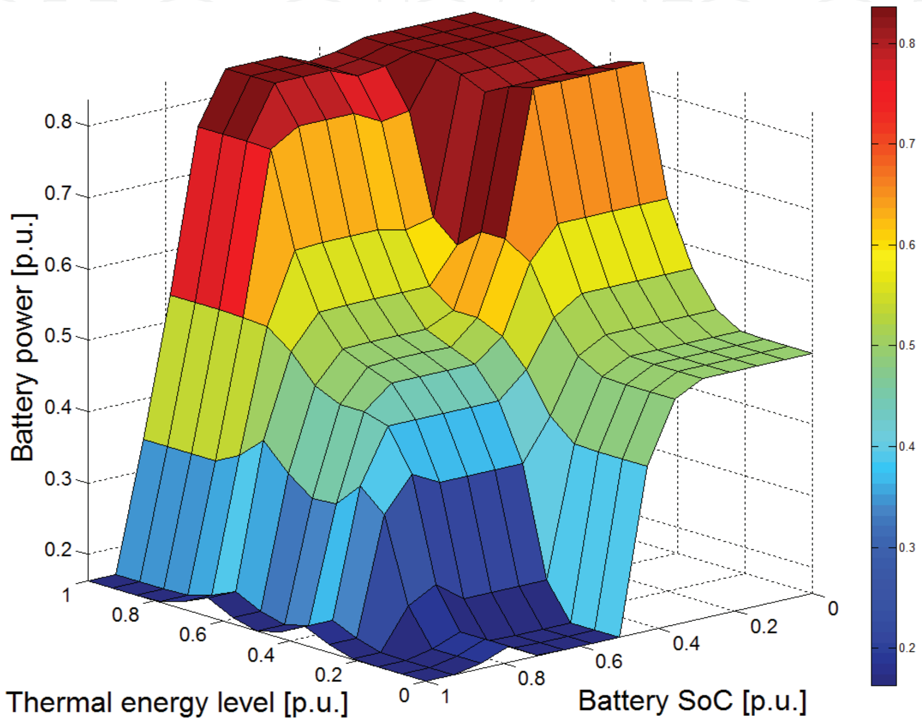

Figure 6. Response surface for the fuzzy logic supervisor.

4. Simulation results

The following figures present the simulation results for a power system with the following assumptions:

- Wind turbine and PV panels have an installed power of 1 kW each.
- The electric vehicle battery has a capacity of 1 kWh with an SoC of 40% when the charge process starts.
- It is considered that the vehicle is an ultralight version having two interchangeable batteries: one that equips the vehicle and the other left at home for charging.
- The heat pump has a coefficient of performance (COP) of 3, thus it consumes one-third electrical energy and generates three times more heat energy.

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- The necessary heat energy considered is 30 kWh, thus a 10 kWh of electrical energy is required for the heat pump.
- The heat pump has the possibility to adjust power according to renewable energy production.
- Simulations are made for 1 day (24 h).

Figures 7 and **8** present the power and energy produced by the wind/PV hybrid system. The PV power curve has similar variations with some classic production curves for a sunny day, and the wind power has approximate variations according to a wind measurement from Brasov area (Romania).

The necessary electrical and thermal powers required are presented in **Figure 9**. The electrical power consumption is taken from a figure presented in Ref. [9] and the thermal power is estimated considering 30 kWh of needed energy (for a cold period) and no energy consumption during workhours.

Figure 10 presents the power grid failures. Even if it is unlikely to have two grid voltage drops during 1 day, it was considered in the simulation for demonstration purposes. Each voltage drop has a period of 15 min, first, from 14h30 to 14h45 and second from 21h30 to 21h45.

Figures 11 and **12** present the thermal energy level and the battery SoC, respectively, of the heat pump and battery powers, for the considered application. Both the thermal energy level and the SoC have an initial level. Due to the fact that at 18h00, the thermal power consumption restarts, and even if the heat pump is still working, the thermal energy level decreases (**Figure 11**). At the same time (18h00), the batteries are switched, the charged one is placed on the electric vehicle and the discharged one is put to charge. In order to use mainly the renewable energy to charge the battery and considering that the thermal energy demand is high, during the remaining hours of the day (18h00–24h00), the charging of the battery is stopped.

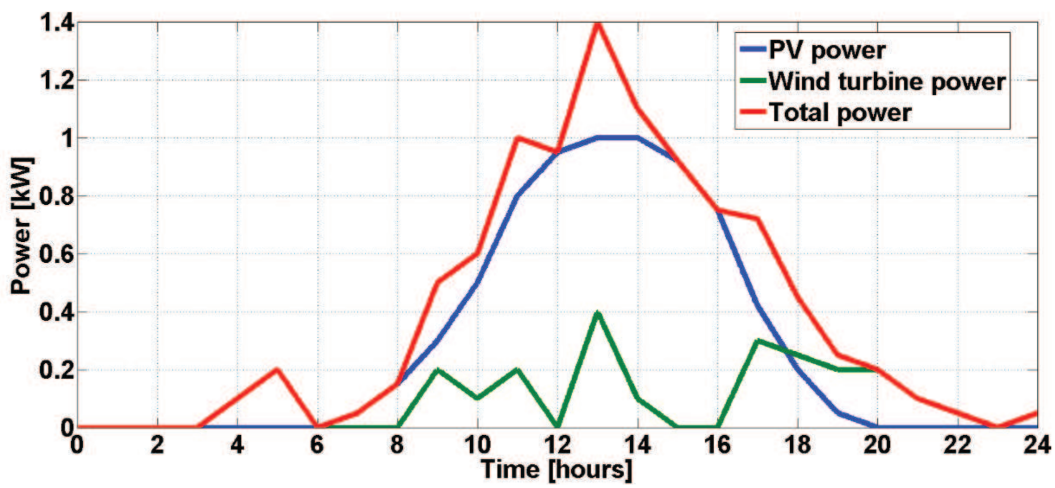

Figure 7. Renewable sources power curves.

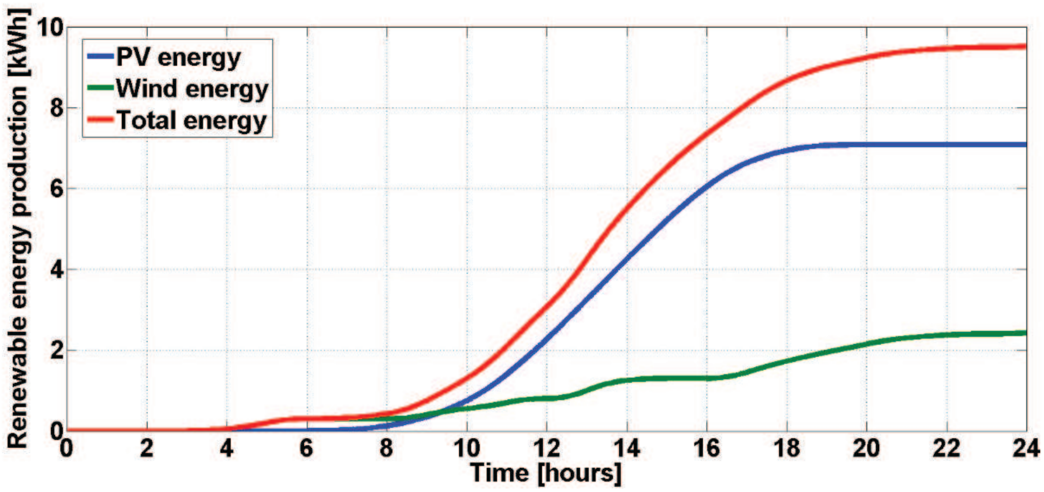

Figure 8. Renewable energy production.

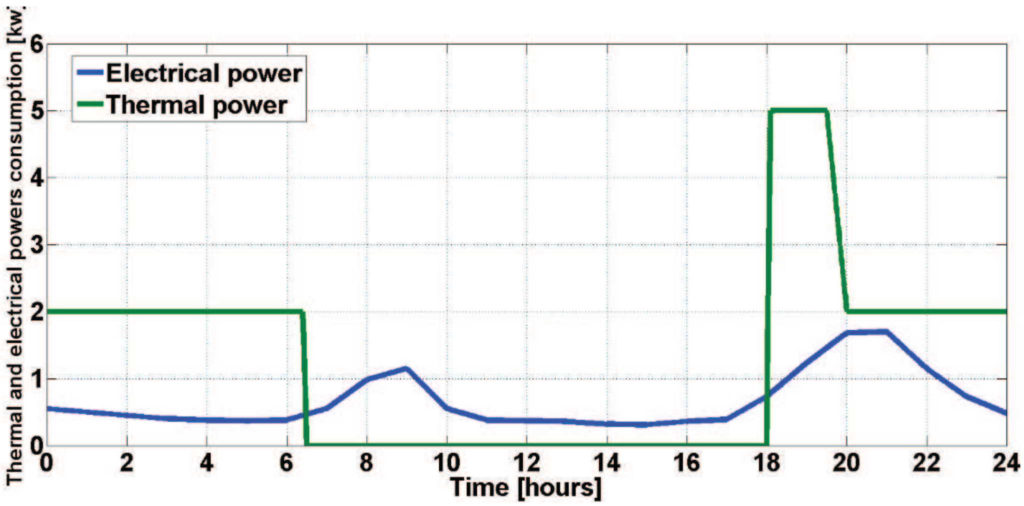

Figure 9. Estimated consumption of thermal and electrical powers.

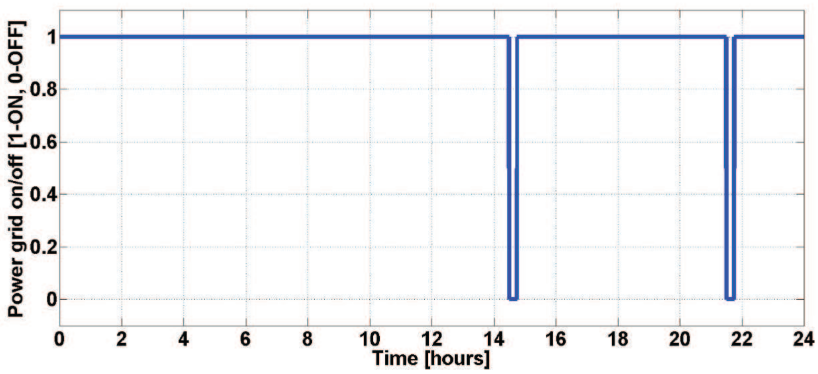

Figure 10. Power grid failure.

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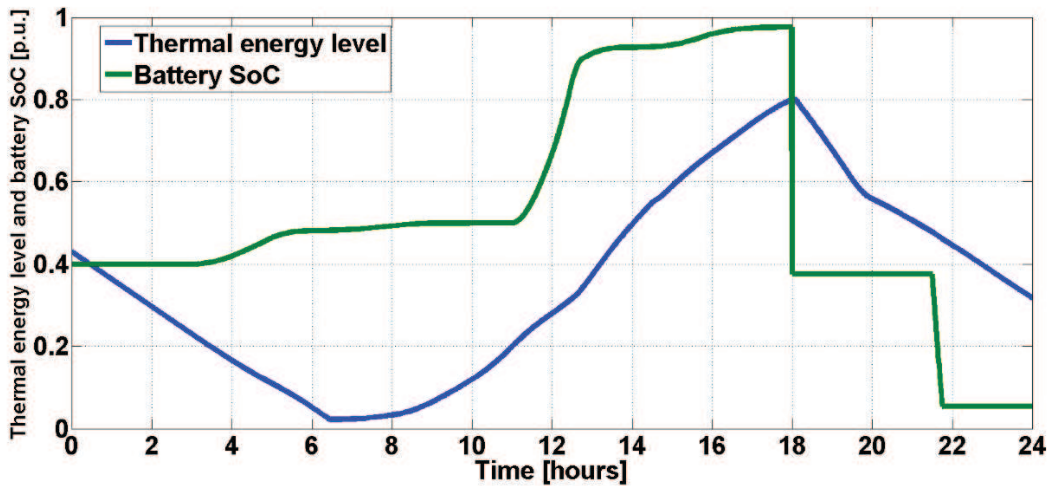

Figure 11. Thermal energy level and the battery SoC.

By the end of the day, the thermal energy level and the battery SoC are lower compared with the situation at the beginning of the day. It is clear that not all required energy can be obtained from the renewable sources, thus, some has to come from the power grid to arrive to the necessary level. From **Figure 12** one can observe that the first power grid drop is easily covered from renewable energy sources, just a sudden drop in the heat pump power can be observed. But the second one takes a lot of energy from the battery, which arrives to an SoC of about 5%. If the power grid loss would be longer, the feeding of all the loads would not be possible, and if considered appropriate, only the mandatory loads (pumps, lighting, etc.) should be fed. Or, if charging the discharged one is started at 18h00, the SoC would not decrease that much (**Figure 13**). Of course, in this case, the thermal energy level will decrease. For this situation, the heat pump and battery working powers are changed (**Figure 14**).

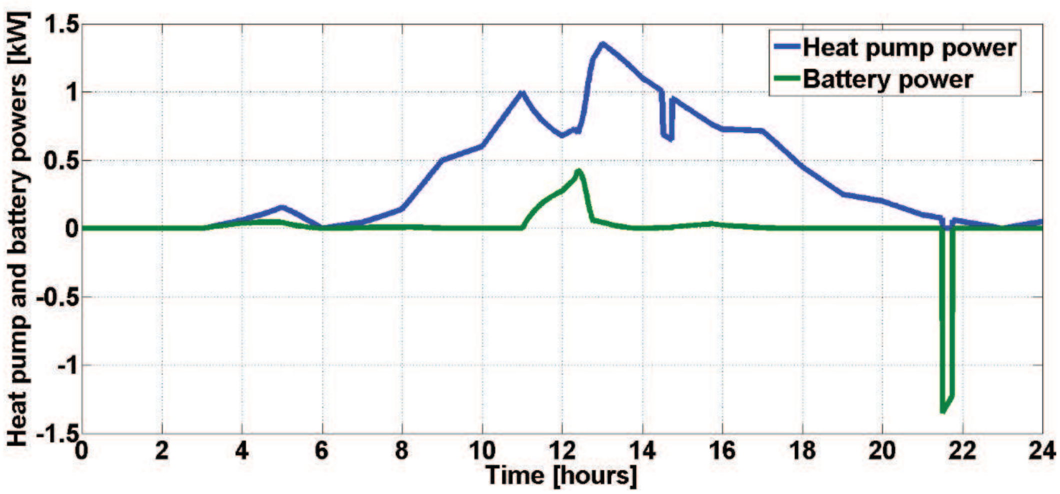

Figure 12. Heat pump power and battery power.

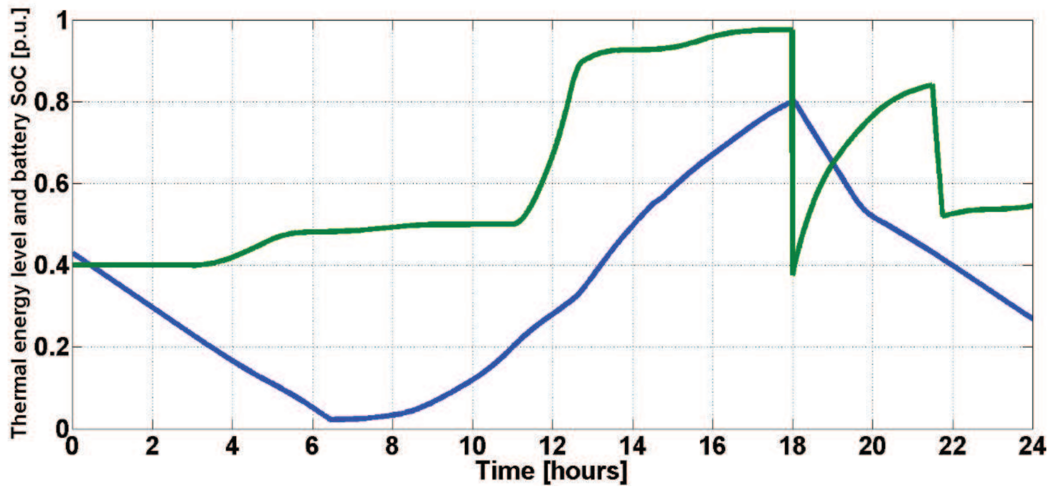

Figure 13. Thermal energy level and the battery SoC for the immediate charging of the discharged battery.

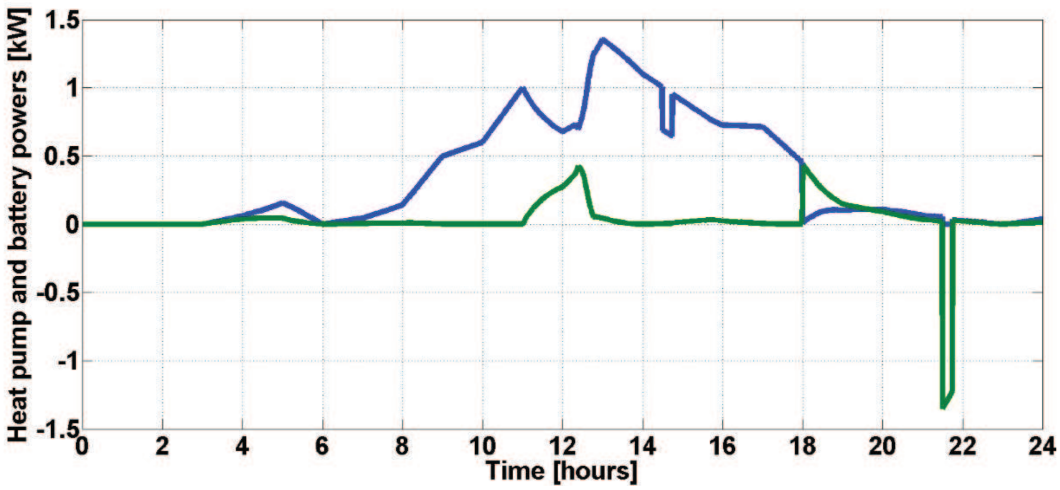

Figure 14. Heat pump and battery powers for the immediate charging of the discharged battery.

5. Conclusion

A fuzzy logic energy management algorithm has been proposed and validated by simulations, for a household application. This algorithm allows the distribution of the renewable energy to charge a battery and also to feed a heat pump that produces thermal energy. The results show that the battery charges to around 97%, and the thermal energy level from renewable sources is around 88% for the first case (discharged battery is not charged during the evening) and around 83% for the second (discharged battery is charged during the evening). The rest of the needed energy should be covered from the power grid.

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References

[1] Guille C, Gross G. A conceptual framework for the vehicle-to-grid (V2G) implementation. Energy Policy. 2009;**37**(11):4379-4390. ISSN: 0301-4215

[2] Sparber W, Vajen K, Herkel S, Ruschenburg J, Thür A, Fedrizzi R, D'Antoni M. Overview on solar heat pump systems and review of monitoring results. In: ISES World Solar Congress, 28 August -2 September 2011, Kessel, Germany; Published by International Solar Energy Society, Freiburg Germany:1-12

[3] Garcia P, Torreglosa JP, Fernandez LM, Jurado F. Optimal energy management system for standalone wind turbine/photovoltaic/hydrogen/battery hybrid system with supervisory control based on fuzzy logic. International Journal of Hydrogen Energy. 2013;**23**:14146-14158

[4] Ben Salah C, Chaabene M, Ben Ammar M. Multi-criteria fuzzy algorithm for energy management of a domestic photovoltaic panel. Renewable Energy. 2008;**33**(5):993-1001. ISSN: 0960-1481

[5] Athari MH, Ardehali MM. Operational performance of energy storage as function of electricity prices for on-grid hybrid renewable energy system by optimized fuzzy logic controller. Renewable Energy. 2016;**85**:890-902

[6] Sichilalu S, Mathaba T, Xia X. Optimal control of a wind–PV-hybrid powered heat pump water heater. Applied Energy. 2017;**185**:1173-1184

[7] Sichilalu S, Xia X. Optimal energy control of grid tied PV–diesel–battery hybrid system powering heat pump water heater. Solar Energy. 2015;**115**:243-254

[8] Sichilalu S, Tazvinga H, Xia X. Optimal control of a fuel cell/wind/PV/grid hybrid system with thermal heat pump load. Solar Energy. 2016;**135**:59-69

[9] Arif MT, Oo AMT, Ali ABMS. Estimation of energy storage and its feasibility analysis. In: Zobaa AF, editor. Energy Storage—Technologies and Applications. InTech, Rijeka, Croatia; 2013: 41-78. ISBN: 978-953-51-0951-8