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An intelligent strategy for hybrid energy system management

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Abstract.

This paper proposes an advanced energy management system (EMS) to control the power flow in a hybrid generation energy system connected to grid and with energy storage. The main contribution of the paper is related to the inclusion of energy forecasts in the control strategy to manage the resources of the system. The EMS is implemented using fuzzy logic technology and will define the battery charging policies and the use of grid energy when necessary. Inputs to the decision system includes current system variables and energy forecast. Some simulations scenarios are considered to test the proposed strategy. Results are compared to existing energy management strategies to attest the potential of the proposal.

Key words

Renewable energy, EMS, Fuzzy logic, energy storage.

1. Introduction

The penetration of renewable energy sources in the traditional energy mix is a fact that is not discussed at the present, however, there are still points to improve for their complete integration. One of the main features of renewable energy sources is the variability and intermittency. This makes it necessary to create hybrid energy systems (HES) in which they can combine production with photovoltaic panels, wind turbines, hydrogen electrolysis, battery banks, hydrogen storage systems, etc. [1]–[3]. This makes necessary the introduction of energy management systems (EMS) [4], which can manage the resources to guarantee the continuous supply and the charge state of the batteries at each moment, depending on the demand, energy resources and costs. The EMS has to take account, in addition, that each energy sources provides energy at different costs. In addition, if the HES is connected to the grid, the EMS have to do its management according to the grid code [5], in addition contributing to the grid stability and providing system-wide cost and performance efficiencies.

Previous works have demonstrated that the Fuzzy logic control can manage complex systems as HESs [4], [6], [7]. However, there are few applications focused on the use of these kind of methodologies to control the power flow and behaviour of the HES components. In particular, the use of predicted power balance has not been intensively studied in the literature.
In the present work, a Fuzzy logic-based energy management system is designed to improve the efficiency of the HES. The main contribution will be focused on the use of short-term electricity generation and demand forecasts in the inference system. The proposal is based on a simple and efficient method to include the predictions in the decisions on the energy resources.

The paper starts with a description of the proposed problem. Then a solution based on fuzzy logic will be presented to deal with the energy management. The simulation scenarios considered in this work will be explained in the next section. Finally, the results are presented together with a discussion on the performance of the proposed solution.

2. Problem description

In the present study, we have considered a hypothetical hybrid solar power generation plant which is also connected to the distribution grid. This power plant is compounded by (Figure 1):

- Solar PV generator.
- Battery bank.
- Interior loads.
- Connection to a distribution grid.
- EMS.

The solar PV generator is aim to satisfy the load demand of a building electrical installation. A backup battery bank will be installed to storage surplus energy and give it back to the system

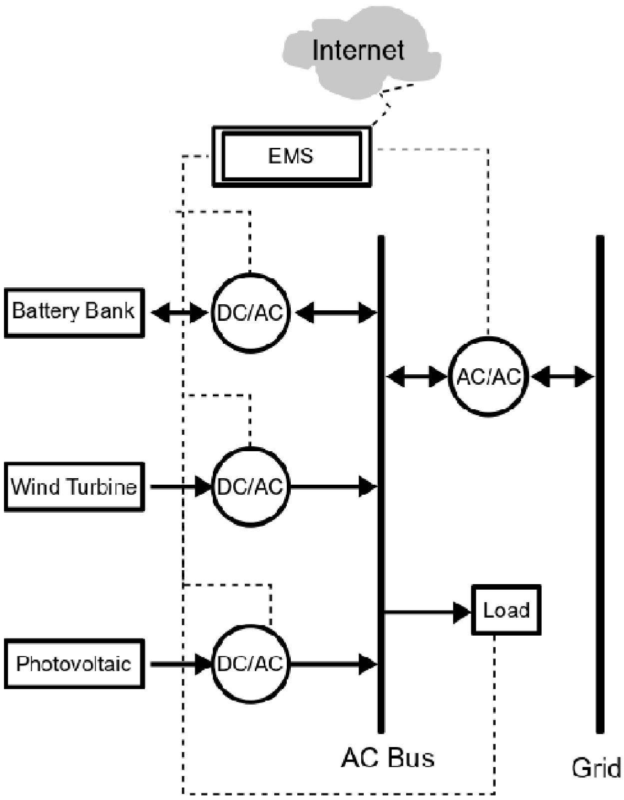

Fig. 1. Schematics of the HES.

when necessary. Additionally, there will be possible to receive energy from the distribution grid. Several considerations must be done by the EMS in order to operate over the system to distribute the energy. In this way, a set of goals will be established to improve the performance of the energy management, as well as the strategies the EMS has to follow to achieve them.

3. Fuzzy logic-based energy management

As commented, the proposal in this paper is to develop a smart in a hybrid generation system consisting of renewable generation (PV and/or wind energy), a battery storage system and a connection to the grid. The EMS will communicate with the several elements to monitor the current state of the system (generated energy, state of charge, demanded load). The information of the costs of energy will also be provided to the EMS. In addition, short-term energy demand and generation forecasting will be also available (24h.) With all this information, the smart EMS will take decisions on the power flow and on the battery management. On one hand, the system will decide when to use energy from the grid or when to feed it into the grid. And, on the other hand, the system will define the battery when to charge the battery and the charging intensity and when to use battery energy.

The proposal presented here considers the general structure for the EMS depicted in Figure 2. As observed, the inputs are the current system variables, the information about costs and the load prediction. While the outputs of the system are the grid breaker (depending on the state of the system, costs, and forecast, grid can be used or not) and the battery usage (defined by the charging intensity). The universe of discourse for the charging intensity varies between -1 and 1. Positive values refers to a battery charge while negative values to a battery discharge. Charging values can be asymmetric, that according to recent studies, increase the battery life as discharge currents can be greater than charge currents [8].

The intelligent EMS will be based on fuzzy logic. The global aim of the system will be to optimize the energy use in terms of costs. More precisely the design criteria are:

- Maximize battery life by a proper SOC management. In the simulations considered a reference value of 70% will be considered for the SOC.
- Costs minimization: if the cost of grid energy is expensive, use energy from the battery system, otherwise, use energy from the grid.

For this, a Mamdani type fuzzy inference system will be considered. The tuning procedure will be done by simulation in different conditions and scenarios.

4. Simulation scenarios

Several simulations have been performed with the purpose of checking the EMS performance. In this way, several scenarios have been considered in order to deal with a wide range of likely situations. These scenarios include power generation above and under demanded load, different costs for the energy taken from the grid, as well as the use of a power ratio (*Pr*) input or either a weighted power balance ratio (*WPB*) which is calculated based on the predictions of the power generation and consumption along a prediction horizon.

A 5-day simulation interval experiment was carried out as it was presented in [6]. Daily solar power production and consumption used for this study are shown in Figure 3. We have also considered several costs for the energy consumed from the grid (kWh price rates of 0.5, 1 and 2) and two different initial states of charge (SOC): 100% and 30%.

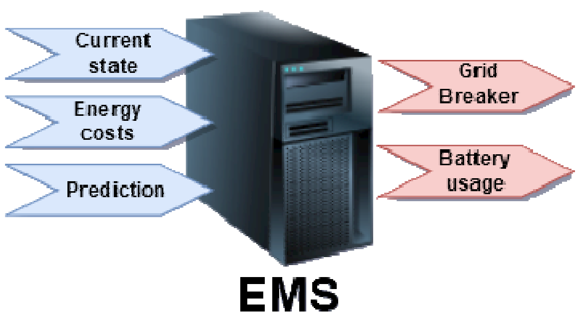

Fig. 2. Input/output diagram of the EMS.

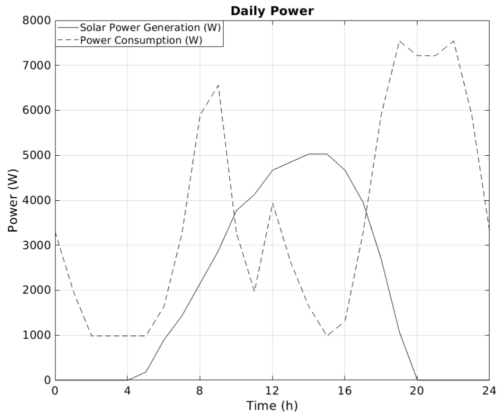

Fig. 3. Daily power generation and consumption.

It is expected that the use of prediction variables as inputs to the EMS input will cause an improvement in the overall behaviour of the control system. Generated and consumed power have been predicted 24 hours in advance to determine the *WPB* signal which is used in the EMS input. Thereby, an EMS with *Pr* input has been compared with an EMS version which uses *WPB*.

The predictions used to calculate *WPB* match perfectly with the generated and consumed power which have been finally obtained. At this point, the current research is focused on the advantages that these predictions introduce into the control quality and how much it varies depending on its accuracy.

5. Results

The EMS uses three input variables:

- SOCr: ratio between actual SOC and its reference value (70%).
- *Pr* or *WPB*: power ratio between generated and consumed power or weighted power balance ratio calculated along a prediction horizon.
- ECr: constant cost of the kWh obtained from the grid.

Figure 4 shows the *Pr* and *WPB* variation along 24 hours. These ratios just depend on the generated and consumed power, so it will be the same for all 5 days in all scenarios as long as the power balance keeps the same. These values are limited to 2 at the EMS input. A value greater than 1 means higher generation than consumption. Notice that *WPB* is always greater than zero. It is due to the fact that any instant along the prediction horizon in which there is power production contributes increasing this value. In the same way, *WPB* is greater than one in some situations in which the power generation is lower than the load in the actual moment. It means that the *WPB* ratio foresees a change in trend in the near future.

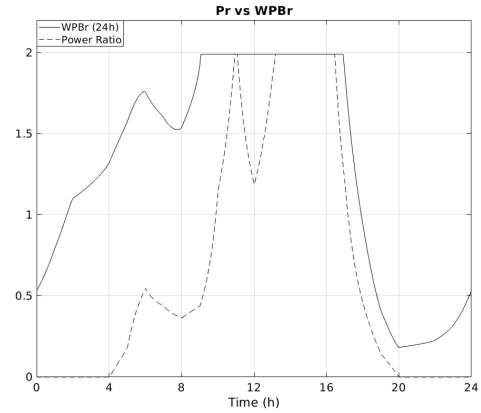

Fig. 4. Power ratio (*Pr*) and Weight Power Balance (*WPB*) used in the simulations.

Consequently, the EMS with *WPB* will use the energy stored in the battery if it estimates that there will be enough power in the system to satisfy the demand, considering that the battery charge will be recover if it is low.

Figures 5 to 8 show the SOC comparative of 12 different situations using combinations of three different price rates (0.5, 1 and 2), two SOC (100% and 30%) and both *Pr* and *WPB* inputs.

The introduction of the *WPB* ratio results in a wider use of the battery energy. Its SOC presents a bigger deviation from the target (70% of SOC) as well as a more oscillating response. However, it tries to keep the desirable SOC when possible. This power balance forecast causes a better use of the energy stored in the battery or taken from the grid.

Accordingly, the total cost of the energy consumption from the grid has been taken as a proper quality index to measure up the controller performance.

The evaluation of the system in terms of costs is illustrated in Figures 9 to 12. As can be seen, the strategy that includes the weighted power balance reduces the total cost of the energy consumption for all the studied cases. Thus, in the first case where initial SOC is 100%, and considering a price rate equal to 0.5, the energy consumption was reduced from 550 KWh to 420KWh. This means a reduction close to 25%. In the first case where initial SOC is 30%, and considering a price rate equal to 0.5, the energy consumption was reduced from 630 KWh to 510KWh. This means a reduction close to 20%.

Deviation from the reference values of SOC as part of the quality index will be also considered in future studies to assess the performances of the EMS in terms of cost of battery usage.

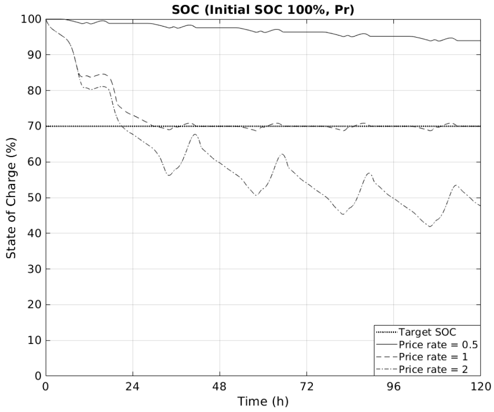

Fig. 6. SOC comparative (*Pr*, SOCi = 100%).

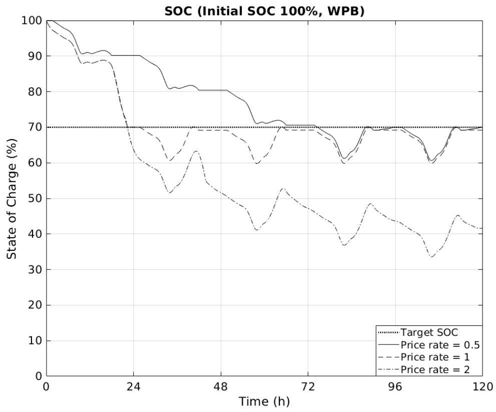

Fig. 7. SOC comparative (*WPB*, SOCi = 100%).

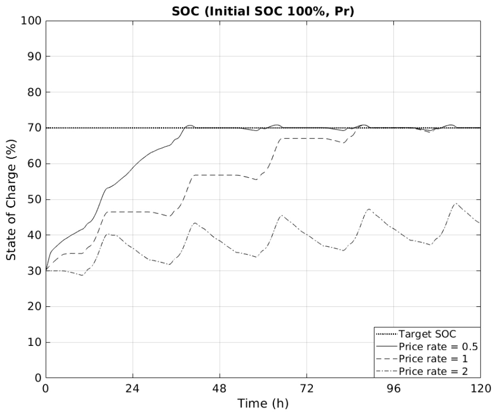

Fig. 8. SOC comparative (*Pr*, SOCi = 30%).

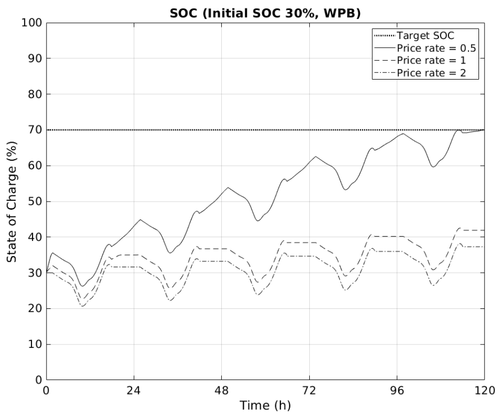

Fig. 9. SOC comparative (*WPB*, SOCi = 30%).

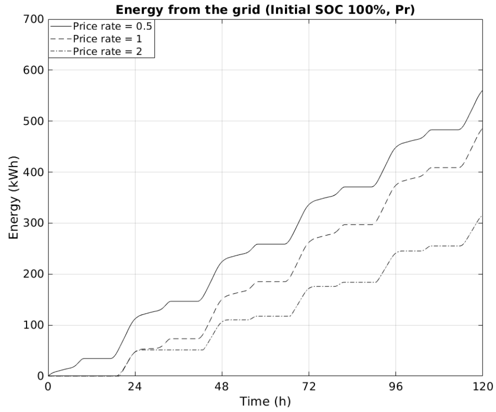

Fig. 10. Grid Energy (*Pr*, SOCi = 100%).

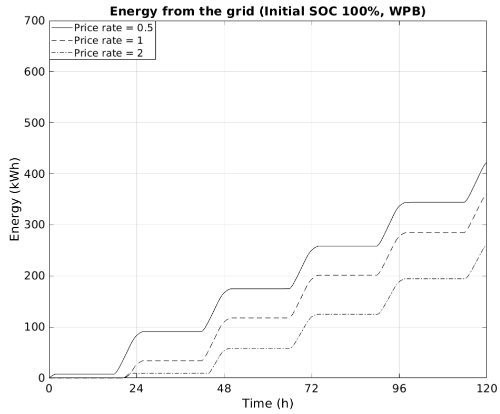

Fig. 11. Grid Energy (*WPB*, SOCi = 100%).

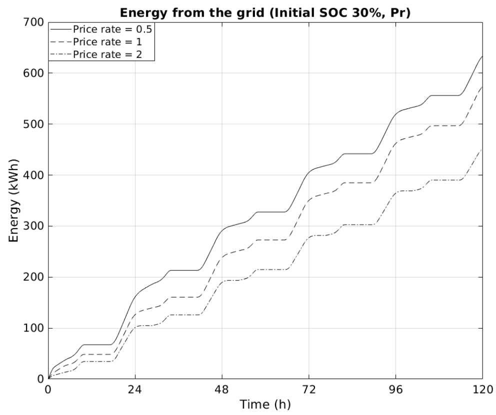

Fig. 12. Grid Energy (*Pr*, SOCi = 30%).

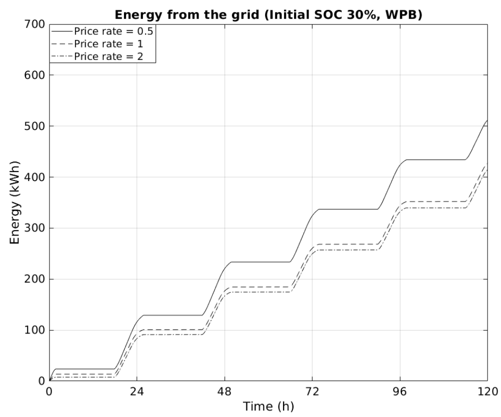

Fig. 13. Grid Energy (*WPB*, SOCi = 30%).

5. Conclusion

The success in the deployment of renewable energy systems lies on the availability of efficient energy management systems. In particular, when energy storage is considered in the system, it is critical to count with tools to take decisions related to flow of energy.

In this work, a new strategy to monitor and control the power flow in a renewable energy system was considered. The main contribution of the proposal is related to the inclusion of prediction variables in the energy management system. Both generation and load short-term forecasts were added as inputs to the EMS. Different scenarios are considered to attest for the efficiency of the proposed strategy.

The results showed that the proposed strategy improves the performance obtained without load and generation forecasts. Future work should be directed towards more complex targets as the inclusion of battery usage costs, energy price variations and actuations in loads.

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