Improved Fuzzy Controller Design for Battery Energy Management in a Grid Connected Microgrid

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***Abstract*— An improvement of fuzzy logic controller strategy for a grid-tied domestic microgrid is presented. The fuzzy logic controller takes onto account the microgrid power flux trend in order to minimize the power profile exchanged with the main grid while preventing at the same time the battery life time against deep cycles of charging and discharging. As well as in previous work, the fuzzy logic controller is designed to minimize a set of quality indices. The benefits of the new approach are highlighted through numerical simulations using real generation and consumption measured data.**

***Keywords*— Mirogrids, Fuzzy logic controller, Energy management, Distributed power generation, Power profile**

I. INTRODUCTION

Distributed generation systems (DGS) (i.e. gas turbines, internal combustion engines, photovoltaic cells, wind generators, biomass combustions, etc..); and microgrids have taken a significant evolution in the last years due to its intelligence, flexibility and environmental protection. Besides an environmental pollution reduction when renewable generation is used, the main benefits of DGS derive from the fact that they can be installed close to the loads consumption, thus reducing transmission line losses and main grid investments [1], [2], [3], [4].

In this context, microgrids are power systems composed by DGS and consumption loads deployed across a limited geographical area [5], which require an energy management strategy in order to optimize the energy flow through the microgrid [6], [7], [8]. Due to the high variability of the renewable resources and the consumption loads, the inclusion of energy storage elements into the microgrid is necessary to regulate the power fluctuations introduced by the renewable sources [9], [10]. In addition, energy management strategies to regulate the energy flow through the microgrid depends on the goals to be achieved [11], [12],[13] and can be performed by the introduction of additional information into the controller (i.e. forecasting).

In this framework, this paper starts from a previous work [14] that proposed a battery energy management strategy for a grid-tied domestic microgrid based on a two inputs one output Fuzzy Logic Controller (FLC). This FLC was designed to minimize the fluctuations of the power profile exchanged with the mains by controlling the battery State of Charge (SOC). Since the main difficulties of this strategy have arisen due the unpredictability of the generated and consumed power, this paper proposes an improvement of the previous FLC design by introducing the microgrid power flux trend as additional input to the controller. This new input allows the controller rules to take into account the microgrid trend behavior in a near future (consumption or generation trend) in order to improve the features of the energy management system.

The study will focus on the design of a FLC for a domestic microgrid taking into account the information obtained through the microgrid power flux trend, with the aim of further minimizing the power profile exchanged with the grid. For the sake of completeness of this work, sections II and III recall the microgrid architecture under study, available power generation and consumption data, the definition of evaluation criteria as well as the control policy of the microgrid. For comparison purposes with the proposed approach, section IV resumes the previous two-input FLC design which is deeper analyzed in [14]. Section V presents the detailed design of the improved three inputs FLC taking into account the microgrid power flux trend. Section VI shows the simulations results of the improved FLC and the comparison with the previous work based on the quality indices. Finally, Section VII presents the conclusions of the work.

II. SYSTEM DESCRIPTION AND INPUT DATA

The grid connected domestic microgrid under study is shown in Fig. 1 [14], and includes a 4 kW_p (kilowatt-peak) photovoltaic generator, a 6 kW wind generator, a 72 kWh battery bank and a local load with a rated power of 7 kW.

In Fig.1 P_{PV}, P_{EO} and P_{gen} are the photovoltaic, wind and the renewable power generated respectively; P_{bat} is the power injected/absorbed by the battery bank; P_{load} is the electrical power consumed by the load; $P_{\mu grid}$ is the power available in the electric microgrid; and P_{grid} is the power injected/absorbed to/from the main grid.

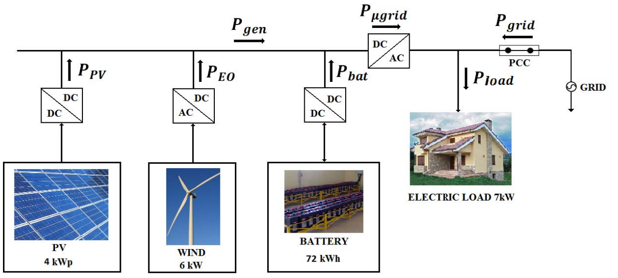


Fig. 1. Electric microgrid scheme

As was deduced in the previous work, the expressions associated with the microgrid behavior can be deduced from Fig. 1 as follows:

$$P_{gen} = P_{PV} + P_{EO} \tag{1}$$

$$P_{\mu grid} = P_{gen} + P_{bat} \tag{2}$$

$$P_{grid} = P_{load} - P_{\mu elec} \tag{3}$$

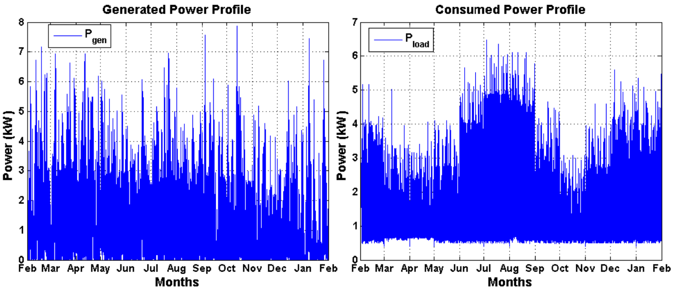
Considering the microgrid power balance P_{lg}, the power exchanged with the main grid can be obtained from (1) to (3):

$$P_{lg} = P_{load} - P_{gen} \tag{4}$$

$$P_{grid} = P_{lg} - P_{bat} \tag{5}$$

The power variables shown above were obtained considering: the power produced by both renewable generators P_{PV}, P_{EO} and power consumed by domestic load are always positive; the battery power P_{bat} is positive when the battery injects power to the main grid or microgrid (discharging process) and negative when the battery absorbs power from the main grid or microgrid (charging process); the power profile exchanged with the grid P_{grid} is positive when the main grid injects power to the microgrid and negative when the main grid absorbs power form the microgrid.

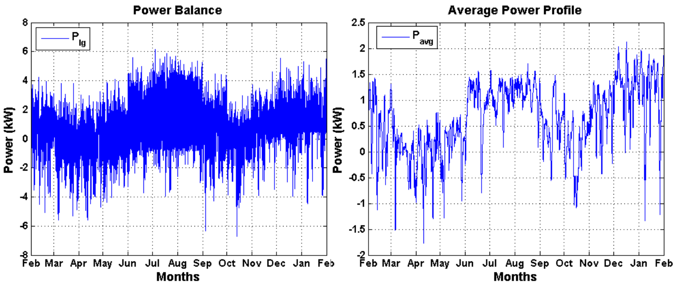
The power profiles generated by renewable sources P_{gen} and the consumed by the local load P_{load} obtained near to the Spanish city of Pamplona (42.29N, 1.38O) with a sample time of 15 minutes along a year, are presented in Figs. 2a and 2b respectively.



(a) (b)

Fig. 2. (a) Generated power profile P_{gen}. (b) Consumed power profile P_{load}

Fig. 3a shows the microgrid power balance P_{lg} and Fig. 3b shows the microgrid power flux trend P_{avg} (average power profile) which was obtained as the average power of the microgrid power balance.



(a) (b)

Fig. 3. (a) Power balance P_{lg}. (b) Power flux trend profile P_{avg}

III. BATTERY ENERGY MANAGEMENT STRATEGY

A. *Evaluation Criteria*

The main evaluation criteria proposed in [14] are referred for a complete understanding of the paper, these quality indices evaluate the features and behavior of an energy management strategy and are function of the power and energy variables involved in the system (6), (7) and (8).

$$\Delta E_i(t) = \int_t^{t+\Delta T} P_i(\tau)d\tau \tag{6}$$

$$\Delta E_i(nT_s) = \int_{(n-1)T_s}^{nT_s} P_i(\tau)d\tau \cong P_i[(n-1)T_s]T_s \tag{7}$$

$$E_{i,a} = \sum_{n=1}^{N} \Delta E_i(nT_s) \tag{8}$$

Where $\Delta E_i(t)$ is the energy evolution of a power variable $P_i(\tau)$ along a period ΔT, assuming equal integration and sampling periods ($\Delta T = T_s = 15\,mn$); $E_{i,a}$ is the annual energy; and N is the number of samples of one year ($N = 365 \cdot 24 \cdot 4 = 35040\,samples$)

Energy Dependence with the Grid (EDG): This criterion quantifies the need of energy coming from the main grid. Note that if $EDG = 1$ the microgrid does not depend on the energy supplied by the main grid; if $EDG > 1$ the microgrid generates more energy than the load consumption; and if $EDG = 0$ the microgrid is totally dependent on the main grid. In this context, the EDG values range should be $0 < EDG \leq 1$.

$$EDG = \frac{E_{load,a} - E_{sup\,grid,a}}{E_{load,a}} \tag{9}$$

$$E_{sup\,grid,a} = \sum_{n=1}^{N} \Delta E_{grid}(nT_s),\ \text{for } \Delta E_{grid}(nT_s) > 0 \tag{10}$$

Where $E_{load,a}$ is the annual energy consumed by the local load; $E_{sup\,grid,a}$ is the annual energy supplied by the grid

Power Quality (PQ): Is used to show the smoothness of the power profile exchanged with the main gird and it is defined as:

$$PQ = \frac{\sqrt{\sum_{n=2}^{\infty} P^2_{grid\_n}}}{P_{DC}} \tag{11}$$

Where P_{grid_n} is the n component of the FFT decomposition and P_{DC} is the average value of the grid power