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Energy based Battery Management System for Microgrids using Fuzzy Logic Controller

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Abstract — This paper presents an energy management system to effectively mitigate grid power profile fluctuations. The system assumes that neither renewable generation nor the load demand is controllable. This energy management system consists of a low complexity Fuzzy Logic Controller embedded with 25 rules in it. The approach is, monitoring rate of change in energy and State of Charge (SOC) of battery thus controlling the power delivered/absorbed by the grid.

Keywords— *Distributed power generation, energy management, fuzzy control, micro grid, Renewable energy sources and smart grid****.***

I. INTRODUCTION

This paper presents the modeling, analysis and design of fuzzy logic controller in a Battery management system for a Wind/ Solar hybrid system. With the variation of wind speed, solar isolation and the load demand, the fuzzy logic controller works effectively by turning on and off the batteries. The entire designed system is modeled and simulated using MATLAB/Simulink Environment. The control process of the battery charging and discharging is non-linear, time varying with time delays. It is a multiple variable control problem with unexpected external disturbances. Many parameters such as the charging rate, the permitted maximum charging current, the internal resistor, the port voltage, the temperature and moisture, etc. keep changing during the charging and discharging process can’t be directly obtained, so it is difficult to achieve the optimal operation performance by using traditional control methods. Hence a fuzzy control unit for battery charging and discharging used in a renewable energy generation system is developed.

The environmental and economic benefits related to the reduction of both carbon dioxide emission and transmission losses have made distributed renewable generation systems became a competitive solution for future smart grids. In this context micro grids are considered as the key building blocks of smart grids and have aroused great attention in the last decade for their potential and the impact they may have in the coming future.

The Microgrid (MG) concept has been discussed by several authors. Additionally ,in a MG scenario due to the stochastic nature of both the renewable sources and the power consumed by the load, the inclusion of Energy Storage System(ESS) (e.g. batteries, flywheels, ultra-capacitors) and Energy Management Systems(EMS) are highly recommended in order to improve the system stability and its performance. In general, MGs are capable to work in both grid-connected and stand-alone mode. They are defined a slow voltage systems comprised of loads, Distributed Generation(DG) units and storage devices ,that are connected to the mains at a single Point of Common Coupling(PCC).

In short, for the case under study, the EMS should be designed with the objective of smoothing the power exchanged with the grid, concurrently satisfying at any time the load demand (i.e. there is no demand side management) and the ESS constraints. This heuristic knowledge suggest the use of Fuzzy Logic Control to the design of the EMS for the case under study, since this approach easily integrates the experience of the user rather than using a mathematical model of the system. Taking the same input variables as in[1], the authors presented in [2] the design of a FLC with only 25-rules which slightly improved the battery SOC and the grid power profile obtained in[1].This work presented a detailed description of the rule-base and the Membership Functions (MF) design, which parameters (i.e. number and mapping) were adjusted to optimize a set of quality criteria of the MG behavior through an off – line learning – process simulation.

Furthermore, using the same design methodology, an improved EMS design based on FLC was presented in [3]. This new design was considering the MG Net Power Trend (NPT) as an additional input of the FLC, resulting in a 50-rules FLC. Even though the results evidence a low-frequency grid power profile with minimum fluctuations, the controller complexity was increased.

Additionally, a common drawback of all these previous designs [1], [2], [3] is that they do not operate properly when the RES generation exhibits strong differences from one day to the next one. In these cases, the battery SOC can eventually reach the undesired thresholds, thus compromising the battery lifetime. With the aim of improving the aforementioned designs as well as simplifying the FLC complexity (i.e. to reduce the controller inputs number and its rule-base), this work presents a new FLC-based EMS of only two-inputs, one-output and 25-rules. As it will be seen, the key factor of the new design is to consider the MG Energy Rate - of - Change (ERoC) as an input in order to anticipate the system behavior.

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The design methodology will follow the procedure and the optimization process developed in [2] (i.e. off-line controller parameter setting process).

The paper is organized as follows. Section II describes the architecture and variables of the Energy Management System. Section III describes the Microgrid. Section IV is about the proposed FLC Design and Section V presents the design of the proposed fuzzy Implementation. The experimental validation of the proposed EMS design is presented in Section VI. Finally, Section VII presents the main conclusions of this paper.

II. ENERGY MANAGEMENT SYSTEM

The system consists of Wind Turbine (WT), Photovoltaic conversion modules and a battery charger sharing the same DC bus. The system also includes a bidirectional inverter-rectifier module controlling the power exchanged with the load.

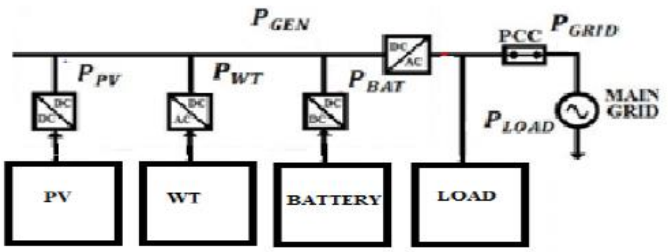

Fig. 1. Energy Management System for Residential Grid

Referring to Fig.1, the power fluxes are considered positive according to the direction of the corresponding arrows. The net power ,*PLG,*and the grid power ,*PGRID*,can be expressed as follows:

$$P_{LG}=P_{LOAD} – P_{GEN}, \quad (1)$$

$$P_{GEN} = P_{PV}+P_{WT}, \quad (2)$$

$$P_{GRID} = P_{LG} - P_{BAT}, \quad (3)$$

Where PLOAD is the load power, PGEN is the renewable source generated power, PPV is the photovoltaic power, PWT is the wind turbine power and PBAT is the battery power. PBAT depends directly to the battery SOC, which should be kept at any time between a minimum and maximum limits, SOCMIN and SOCMAX, respectively, to preserve the battery lifetime namely:

$$SOC_{MIN} \leq SOC\ (n) \leq SOC_{MAX}\ , \quad (4)$$

where:

$$SOC_{MIN} = (1\text{-}DOD).SOC_{MAX}, \quad (5)$$

DOD being the battery Depth of Discharge. This study considers a maximum DOD of 50%, since the lifetime of this type of battery is significantly reduced when operates at high DOD levels[36].In order to avoid discharging/ overcharging the battery out of the secure limits, the EMS strategy should cut – off the power delivered / absorbed by the battery.

In these cases $P_{BAT} = 0$, or equivalently according to (3) P_{GRID} = PLG meaning that all the power fluctuations are handled by the grid. A battery SOC estimator, shown in Fig. 2 is used to estimate the current battery SOC, which is expressed as:

$$SOC\ (n) = SOC\ (n\text{-}1) - SOC\ (n), \quad (6)$$

Where ΔSOC(n) represents the battery energy variation during the sampling period Ts and can be estimated using the general definition of the energy evolution Δei of a power variable Pi during a period time ΔT. Therefore, for sampled variables and assuming equal integration and sampling periods (i.e .$\Delta T = Ts$). The case under study assumes that the wind and PV modules are in charge of extracting the maximum renewable power and that the AC load power consumption is not controllable. In other words, P_{LOAD} and P_{GEN} (hence P_{LG}) cannot be controlled. In contrast, the power exchanged with the grid P_{GRID} will be controlled by means of the bidirectional inverter - rectifier, where as the battery charger will handle, if able to, the resulting battery power P_{BAT} according to (3).

Finally the main aim of the EMS design is to control the power inverter-rectifier in order to smooth the power profile exchanged between the grid(i.e. minimizing the grid power fluctuations and power peaks) while concurrently keeping the battery SOC within secure limits.

III.MICROGRID DESCRIPTION

The study developed in this paper is carried out for a microgrid with renewable energy sources and domestic load. The MG includes a domestic AC load with a rated power of 4kW, a Photovoltaic (PV) array of 1 kW, a small Wind Turbine (WT) of 2.5kW, and an ESS formed by a lead-acid battery bank with a rated capacity of 40kWh. The grid

power quality criteria is defined so that the lower the criteria values are, the EMS performance is better.

A. Positive and Negative Grid Power Peaks

The positive and negative grid power peaks, PG,MAX and PG,MIN, are defined as the maximum value of power delivered by the grid.

B. Maximum and Average Power Derivative

The Maximum Power Derivative (MPD) is defined as the maximum absolute value of the slopes during one full sample time.

The Average Power Derivative (APD) is defined as the absolute value of the annual average value of the slopes of two consecutive samples.

IV. PROPOSED FLC DESIGN

An improved FLC- based EMS design is presented in this section with the aim of minimizing the power peaks and fluctuations in the grid power profile while keeping the battery SOC evolution within secure limits as well as to reduce the FLC complexity .
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The new fuzzy EMS design suggests computing the grid power as the sum of the average value of the MG net power, PAVG(n), and an additional component, PFLC(n) which is in charge of modifying the grid power profile to keep the battery SOC within the secure limits at any time.

Thus, the grid power profile is defined as follows:

$$P_{GRID}(n) = P_{AVG}(n) + P_{FLC}(n), \qquad (7)$$

The proposed design computes by means of a FLC the additional component PFLC (n) from the following two inputs:

i. The SOC of the battery SOC(n),

ii. The MG energy rate -of- change, PAVG(n)

The FLC uses the SOC of the battery, SOC (n), as an input to check its value at any time in order to fit the constraints imposed by the maximum DOD of the battery and to preserve its life. Furthermore, PAVG(n) gives to the FLC the information of the magnitude of the MG energy change of two consecutive samples as shown in Fig.2.

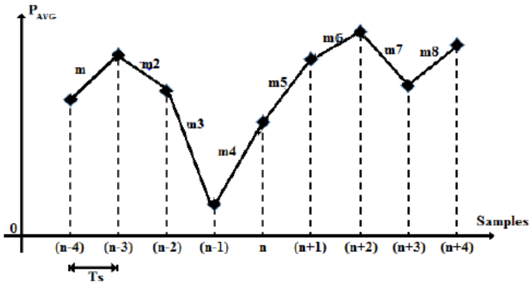


Fig.2.Slopes produced by two consecutive samples and average net power profile.

In this regard, a positive slope in Fig. 2 (e.g. m1, m4, m5, m6, m8) means a reduction of the renewable power generation or an increase of the load consumption in the MG. On the contrary, a negative slope (e.g. m2, m3, m7) corresponds to a MG renewable power generation increase or a load consumption decrease.

It is worth noting that PAVG (n) can be understood as the local prediction of the battery SOC future behavior if the grid power is not modified. For this reason, from the information of SOC(n) and PAVG(n) the FLC is in charge to modify PFLC(n) to increase, decrease or maintain the power delivered /absorbed by the mains to concurrently satisfy the load power demand and to keep the battery SOC within secure limits. Consequently, the controller output allows the interaction between the MG and the mains.

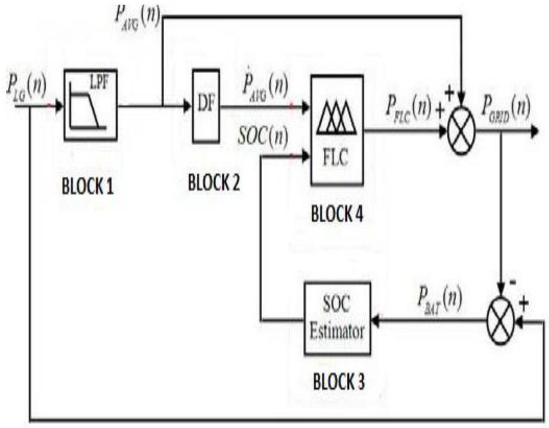


Fig.3. Fuzzy EMS designed on MG energy rate- of – change and SOC block diagram

The control block diagram of this strategy is shown in Fig.3, where PAVG (n) is obtained from PLG (n) by means of a LPF, PAVG (n) is obtained by a digital filter which implements and limiting the high-frequency gain and noise associated with the derivative term [41].Fig.3 also includes the battery SOC Estimator and the fuzzy controller.

V. FUZZY IMPLEMENTATION

The Fuzzy implemented here is a Mamdani -based inference and defuzzification of Center of Gravity with two - inputs, PAVG(n) and SOC(n), and one-output PFLC(n), which represents the second component of the grid power. Regarding the FLC design, the adjustment of all parameters involved in the fuzzy controller (e.g. number of MFs per Input / output, type, mapping, rule - base).

The procedure followed is described and summarized in the next steps:

*Step1:*Set the initial FLC design.
Set the MF of inputs and outputs variables: number ,type and mapping. Set the initial rule-base.

Step2: Adjust the inputs and outputs MFs. Using the real recorded data, adjust the inputs / outputs parameters of the MFs to minimize the quality criteria of Section III.

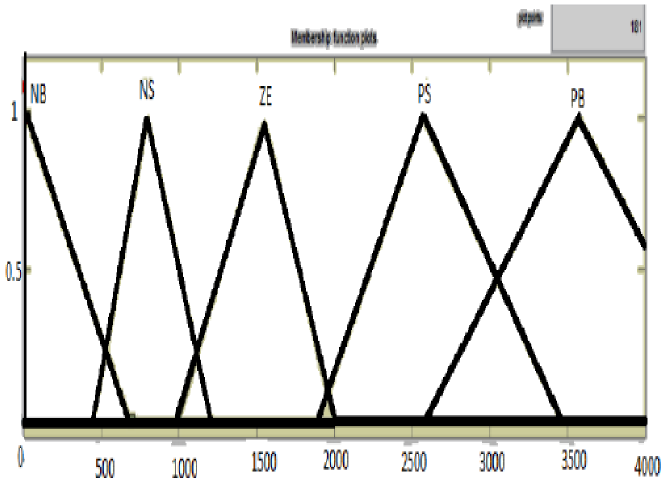
Step3: Optimize the initial rule -base. Using the real recorded data, adjust the initial rule –base to minimize the quality criteria.

By analysis of previous papers and previous experimental results, the optimization process leads to optimized FLC rule-base presented in Table I.

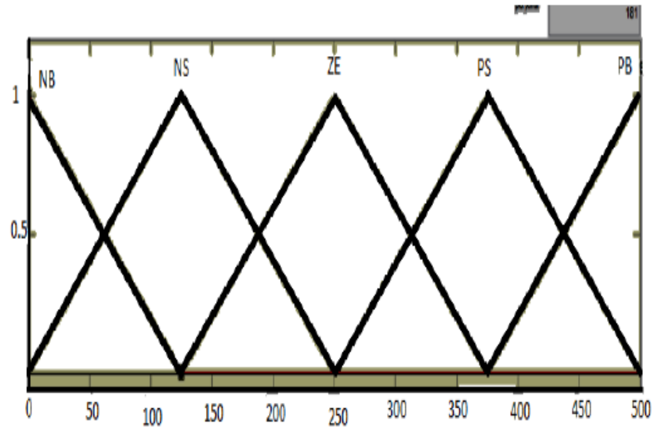
Table I :- Optimized Flc Rule-Base

SOC Err	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NS	NS
NS	NB	NB	NS	NS	NS
ZE	ZE	ZE	ZE	ZE	ZE
PS	PS	PS	PS	PB	PB
PB	PS	PS	PB	PB	PB

As a result of this rule - base five triangular MFs shown in Fig.4 and are defined for each input variable, and correspond to five fuzzy subsets noted as NB, NS, ZE, PS and PB where B represents “Big”, S “Small”, N “Negative”, P “Positive” and ZE “Zero”.



(a) Input variable “input 1”



(b) Input variable “input 2”

Fig.4. Input Variable membership functions.

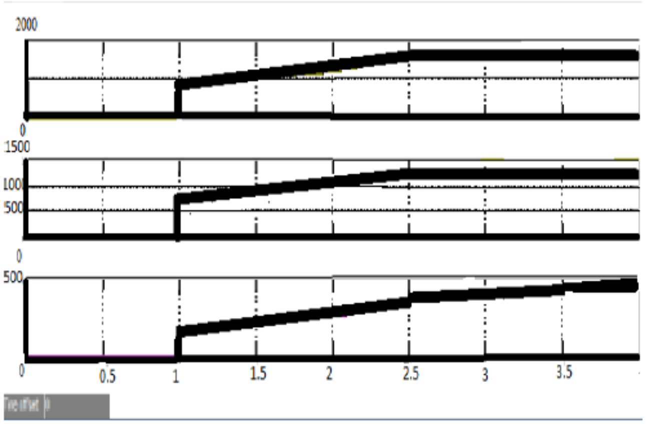


Fig. 5 a. P_{GEN} b. P_{LOAD} c. P_{BAT}

VI. EXPERIMENTAL VALIDATION

The proposed Fuzzy Logic design for Energy Management System is programmed in Matlab/Simulink platform. In order to experimentally validate the proposed EMS, the system has been tested in laboratory conditions. The experimental results are as shown in Fig. 5. The difference between generated power and load power is stored in the battery. If the difference is positive the battery charges and if negative battery discharges. This is experimentally validated under laboratory condition.

VII. CONCLUSION

In this proposed model a design of fuzzy logic control to achieve optimization of a Battery management system for a Wind/ Solar hybrid system is presented. According to the variation of the load, the fuzzy logic controller works effectively by charging and discharging the battery as per the grid status. Simulation results were obtained by developing a detailed dynamic hybrid system model. From the simulation results, the system achieves power equilibrium, and the battery SOC maintains the desired value for extension of battery life.

The control process of the battery charging and discharging is non-linear, time-varying with time delays. It is a multiple variable control problem with unexpected external disturbances. A fuzzy control unit for battery charging and discharging used in a renewable energy generation system is developed. Simulation results based on fuzzy strategies show that the control unit has satisfied performance in a laboratory environment.

Current work is focused on the extension of the proposed approach by implementing predictive method of control for better system efficiency.

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