

Intelligent control of battery energy storage for microgrid energy management using ANN

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ABSTRACT

In this paper, an intelligent control strategy for a microgrid system consisting of Photovoltaic panels, grid-connected, and li-ion battery energy storage systems proposed. The energy management based on the managing of battery charging and discharging by integration of a smart controller for DC/DC bidirectional converter. The main novelty of this solution are the integration of artificial neural network (ANN) for the estimation of the battery state of charge (SOC) and for the control of bidirectional converter. The simulation results obtained in the MATLAB/Simulink environment explain the performance and the robust of the proposed control technique.

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1. INTRODUCTION

The renewables sources represent the biggest interest for microgrids systems because are the primary sources of microgrids and due to their advantages compared with the others fossil sources [1]. These renewables sources, including micro turbines, wind generators, photovoltaic panels, and fuel cells are little emission and, low cost, and highly reliable [2]. The biggest challenge of these energy sources is the dependence of meteorology conditions. Which make the microgrid not stable and depend with meteorology conditions [3]. For this reason, the energy storage process plays an important role in the balance between the generation of power and the energy demanded. The main requirements of energy storage in a microgrid are balancing power demand between load and sources, and store the maximum energy during off-peak hours and supply all load with the stored energy [4]. The li-ion batteries are the best types of electrochemical batteries due to their advantages compared with the others batteries types. However, this type of batteries oblige the use of battery management system to protect the battery against the explosion [5]. As we already seen several accidents caused by li-ion battery packs like Japan Airlines 787 at Boston's due to battery overheating. Therefore, the battery management systems protect the battery and ensure the stability and the energy management of the microgrid. The li-ion battery connected to the microgrid throughout bidirectional DC/DC converter. Which is a DC-DC converter that levels up or down the input voltage to the load voltage. It is more similar or equivalent to fly back converter that has single inductor instead of transistor. The main objective of BMS strategy is to extend the battery life cycle by protection against all possible problem caused by the nonlinear change of renewable energy sources. The state of charge (SoC), depth of discharge (DOD)

and temperature represent the principal's element for the monitoring of battery. In this work, we will focus only on the use of SoC, which is represent the available charge that is stored in the battery compared with the rated capacity charge of the battery. Because of the non-linearity of li-ion battery voltage the SOC cannot be directly measured.

The SOC is an important parameter for battery control and for BMS strategies. Therefore, several methods to estimate SOC have been developed in the recent years. The coulomb counting or (ampere-hour counting) is the most common method for battery SOC estimation, by battery current integration [6]. This method is efficient if the initial state of charge known another method presented in [7] for state of charge calculation based on the relation between SoC and open circuit voltage, but this method is especially for battery lead acid.

Recently, several authors have use Kalman filter (KF) which is a robust algorithms to estimate SoC [8]. The major drawback of this approach is that a KF needs a suitable model for battery, however, using the feedbacks in this model will require a proper state initializing for the convergence of the model. In this paper, we used a feed-forward neural network to estimate SoC. In order to use this value for battery management system.

The generators of renewable sources and the li-ion battery must be coordinated in order to supply the energy required by the load and guarantee the balance of microgrid energy, which is the main objectif of the microgrids [9]. The microgrid is a low voltage distribution networks constitue by energetic resources, storage system, and control systems to supply the energy requirements of the selected application [10]. The microgrids concept can be applied to different application like smart homes [11] or smart village [12]. Furthermore, Microgrids classified as DC or AC Bus according to their voltage resources [13, 14]. The DC microgrids have recently obtained interest due to the important increase in the use of DC generators and loads, like electric vehicles [15].

The regulation of the DC-bus represent the main challenge of microgrids systems due to the instabilite of renewable energy sources, and the power cosumed by the load in order to ignore the difference between the power consumed and generated [16]. The li-ion battery is the direct responsible of blance in microgrids. If the renewable energy sources are absent, the micro-grid will be stabilized via the energy storage system, and store the energy surplus. The battery connected to the microgrid throughout bidirectional DC/DC converter [17]. Hence, the bidirectional DC/DC converter is managing the charging/discharging of the battery in ordre to blance the power at the DC_Bus [18]. Many papers focused on the control of the DC_Bus voltage by the control of bidirectional converter [19-30]. Traditional controls of bidirectionnel converter such as PID controllers are widely used in literature [19, 20]. However, this controls strategy are performant juste for linear systems. On the other side non-linear methods as sliding mode controls [21, 22] which are more performant than linear methods as mentioned in [23]. Nevertheless, these kinds of methods needs an accurat mathematical modeling and detailed knowledge on the controlled system. However, the intermittent of the renewable energy resources and their dependance of meteorological conditon, the random loads demand, and the presence of grid faults can make the system complicated to modeling and lead to unsatisfactory control performance, [24]. These limitations have motivated researchers to search and employ more advanced and adaptive control strategies for highly nonlinear microgrids systems [25]. The main advantage of intelligent control techniques for a given microgrid is to get better the dynamic performance and to increase the robustness against interruption that results in effective energy supply to client's loads. Previous studies indicate that several research works have been done concerning the intelligent control of the microgrids system. Adaptive neuro-fuzzy inference system (ANFIS) and fuzzy-sliding-mode control method used for microgrid systems presented in [26]. Another ANFIS based used as energy management system for a grid-connected hybrid system integrating renewable energies, hydrogen and batteries as presented in [27]. A voltage-frequency (V/F) control scheme based on fuzzy logic controllers is proposed in [28], for the control of a grid-connected inverter supplied from a microgrid system. As conclusion of this control overview are to apply the AI techniques for optimum sizing, parameters optimization, tuning methods improvement or for substitution of traditional controllers.

In this paper, an investigation and study on the control strategy of a grid connected MG consisting of PV panels, electrical grid, and BESS is carried out. An intelligent control structure is applied to supervise and drive the local controllers of bidirectionnel DC-DC converters. The main improvements suggested in this paper can be summarized as follows: i) the uses of Artificial neural network controllers NARMA-L2 which a robust controller for the bidirectional DC/DC converter; ii) The use of intelligent methods based on feed forward neural network to estimate state of charge; iii) The integration of state of charge in the energy management block. The rest of this paper organized as follows. Section 2 describes the method used to estimate SoC. Section 3 present the description of microgrid system. Section 4 details the energy management algorithm used in this paper. The section 4 presents the simulation scenario and the results of simulations, and section 5 draws some conclusions and gives directions for the future work.

2. STATE OF CHARGE ESTIMATION

ANN used to model complex systems due to their strong nonlinearity and their efficiency to model the dynamic systems. To design the ANN model of the battery, we use MATLAB/Simulink software and we respect the following steps:

- Chose a database (Learning and validation)
- Learning ANN and architecture optimization
- Validation mode

The Figure 1 present the proposed model to estimate SoC. This model based on FFNN (feed-forward neural network). The structure of FFNN, where the inputs are the measurement of the battery voltage, current, and temperature.

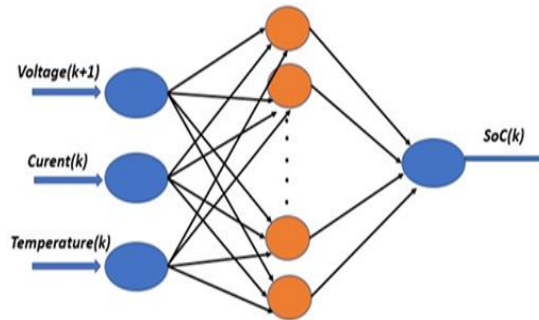


Figure 1. FFNN for SoC estimation

From the model of Figure 2 we can obtained the relationship of the output $Y(k)$ as a function of Input $U(k)$.

$$Y(k) = F(U(k), U(k - 1), \dots, U(k - d)) \tag{1}$$

The function F is the hyperbolic tangent, often used in the hidden layer as an activation function and linear transfer function in the output layer.

$$F(u) = \frac{2}{1 + \exp(-2 \cdot u)} - 1 \tag{2}$$

All parameters of neural network obtained after the step of neural network training using backpropagation algorithms.

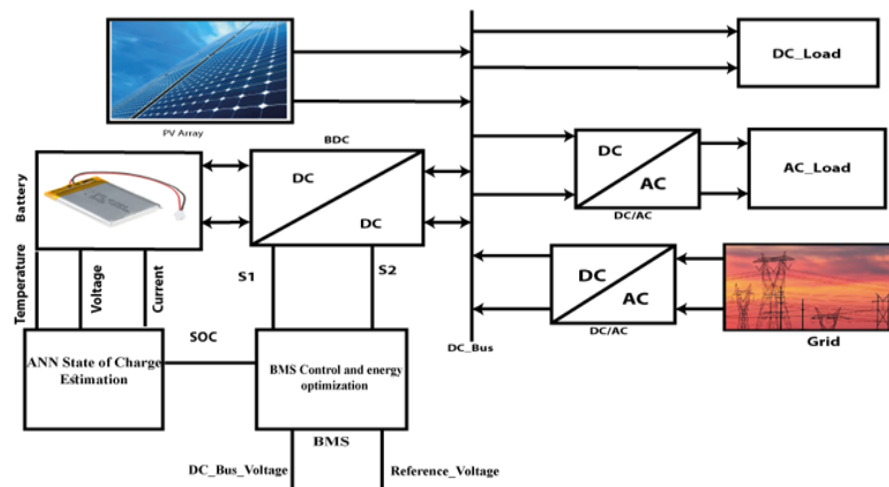


Figure 2. Studied microgrid system

3. MICROGRID SYSTEM

The proposed system as shown in Figure 3 composed of renewable energy source such as photovoltaic panels as a primary source and energy storage system (li-ion battery), and electrical grid used just in urgent case when the PV power not enough to cover all power needed, and the State of charge less than SOC_min. All energy sources dimensioned in order that each source will cover the power needs of the system loads. The sum of AC and DC loads equal to 15 KW. Therefore, we will dimensioned each sources in order to equal 15 KW. The characteristic of li-ion battery used in this system are with 48 V, and 315 Ah. In addition, using BDC the voltage up to 220 V. Then for the photovoltaic we have choose a cell American Solar wholesale ASW-280 M cell with 280 W maximum power and 37 V as maximum voltage. Therefore, to cover the needed power we have to use 54 cell. Six connected in series to up the voltage to 220 for this reason there we did not use a boost between PV and DC_BUS, and nine connected in parallel. For the electrical grid dimensioned also to cover the needed power and connected using an AC/DC converter.

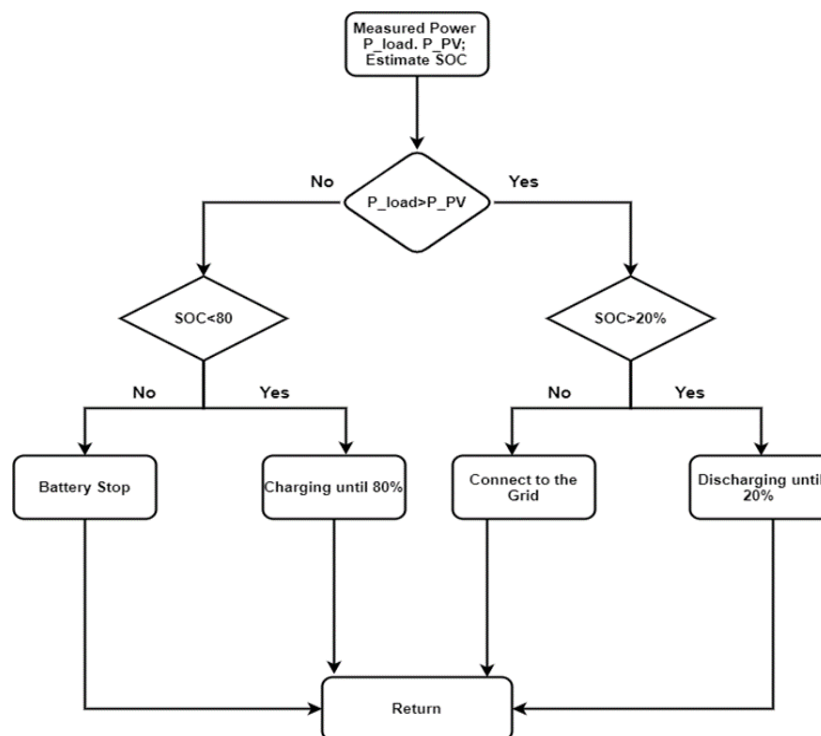


Figure 3. Battery energy management strategy

4. BATTERY MANAGEMENT SYSTEM STRATEGY

The li-ion batteries are sensible in energy management. Due to their dependency on how the battery works in each charging and discharging cycle. The over-charging/discharging was the main reason for most of the accident of li-ion batteries explosion. Therefore, the battery life and security needs to control the battery state of charge. For this reason, we have used in this study an effective technic to estimate the battery state of charge. The next flowchart represent the energy management strategy used in this paper.

As we can see from the flowchart, the system energy management based on the state of battery. We have three mode for the battery: Charging mode, discharging mode, and mode stop. The battery mode selection will made by the BMS bloc, based on the information of SoC and the DC_Bus voltage value. As we described before the battery connected the microgrid bus using bidirectional DC/DC converter. Therefore, the main function of the BMS is to control the bidirectional converter and the breakers between sources and DC_BUS. The ANNC used in this paper known by two names: feedback linearization control when the plant model has a particular form and NARMA-L2 control when the plant model estimated by the same form. The main object of this type of control is to linearize the nonlinear dynamics. The NARMA L2 controllers composed by two neural networks: The first neural network is NARMA model, which is the standard model, used to represent general discrete-time nonlinear systems in the system identification to identify the system to be controlled and the second network for the control design as shown in the Figure 4.

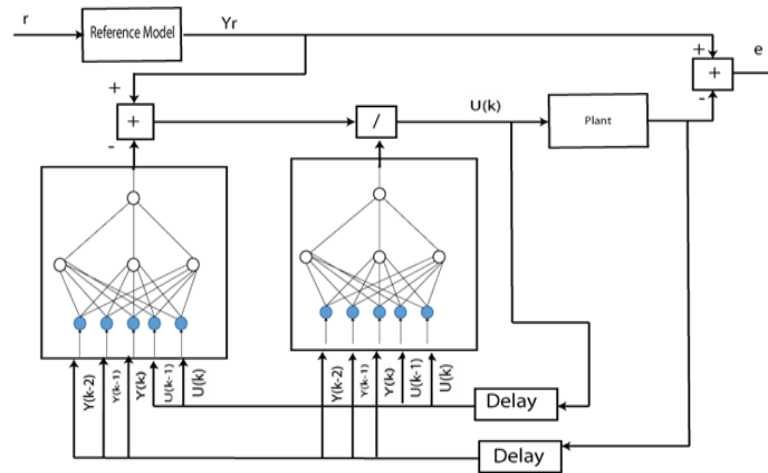


Figure 4. NARMA-L2 model plant

5. SIMULATION SCENARIOS

The scenario proposed for simulation in this paper based on the change of irradiation, which mean a different photovoltaic power production. The scenario contains several changes of irradiation as shown in Figure 5. The photovoltaic power production correspond to this irradiation is shown at the Figure 6. As shown in Figure 6 the PV power is not stable, some parts less than 15 KW and more than in others part, which mean another sources needed to cover the load power needed (15 KW). As we described in “microgrid system” the li-ion are the responsible of system stabilization by charging and discharging. The Figure 7 shows the variation of state of charge during simulation scenario.

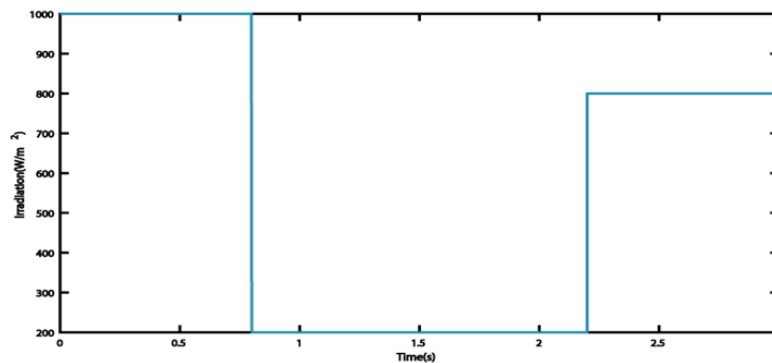


Figure 5. Solar irradiation (W/m²)

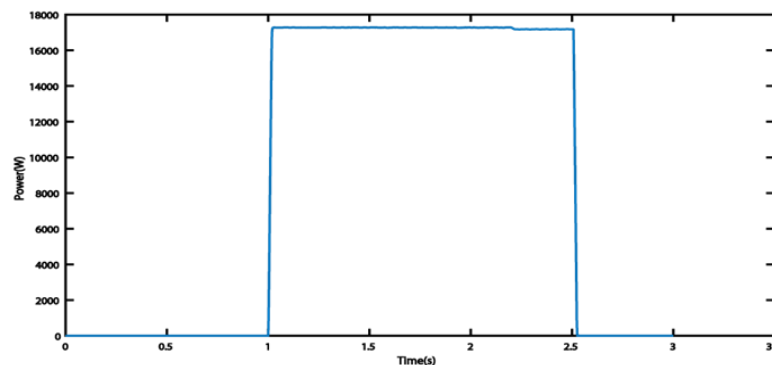


Figure 6. Photovoltaic power

At the beginning of simulation the PV power more than 15 KW, which mean the surplus of power will stored in the battery and at 0.6 s a brutal change of irradiation to 200 W/m², which decrease the PV power to. For this, reason the battery state of charge decrease at this time to cover the needed power of microgrid. At the time, 1 s as shown in the Figure 7 the SOC arrived to 20% the minimum value fixed to the BMS. Therefore, other sources are needed to keep the stability because the priority for the security of the battery. The electrical grid network connected at this time as shown in the Figure 8.

The grid power cover the load power demanded and charging the battery. With the protection and management of battery energy. The BMS stabilize the voltage of DC_Bus at the reference value. In this paper, we fixed the reference voltage at 220 V as show in the Figure 9. We can see from the Figure 9 the effectiveness of the proposed technique in term of convergence speed and the error between the voltage variation and the reference.

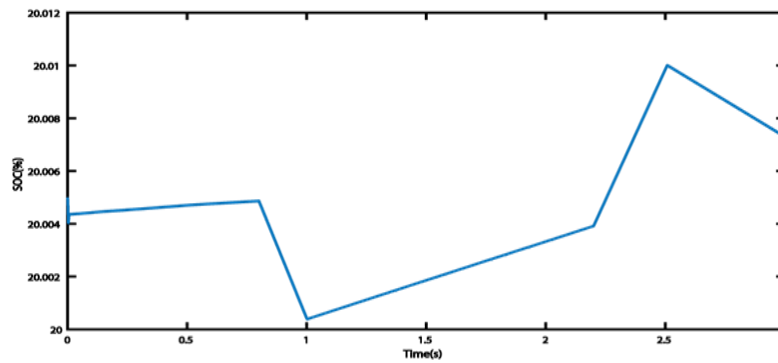


Figure 7. Battery state of charge variation

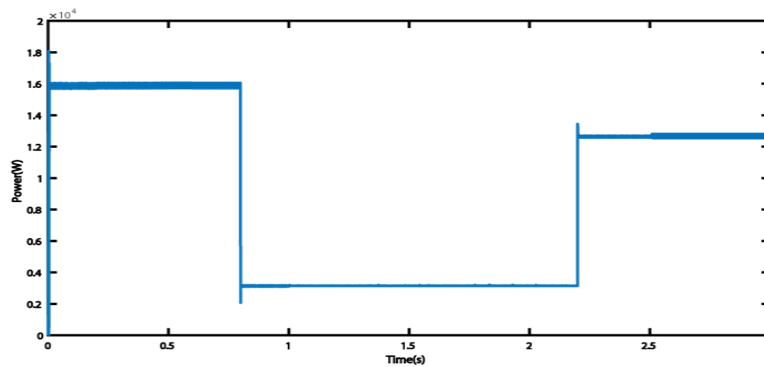


Figure 8. Electrical grid power

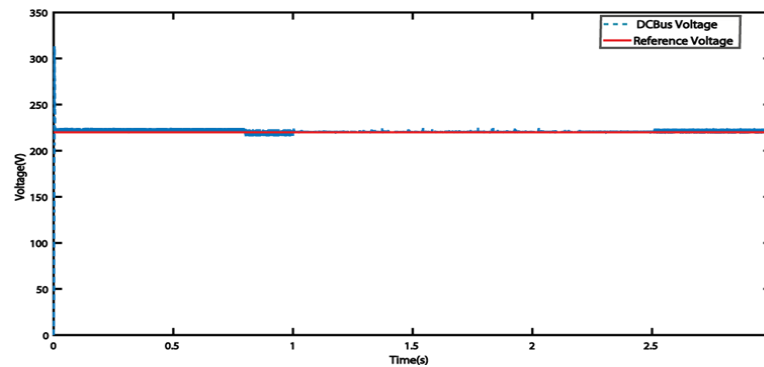


Figure 9. Comparison of reference and measured DC_BUS voltage

6. CONCLUSION

In this paper, energy management strategy for microgrid system has been proposed. Where the Photovoltaic is the main source for electricity, the battery, and the grid backup system to stabilize the system. Furthermore, for the BDC in a microgrid, simulations were carried out under a complicated scenario indicating satisfactory performance with the proposed control method. In the results of simulation, we figure out the effectiveness of the proposed technique in term of convergence speed and the error between the voltage variation and the reference. Another management strategy based on multi-agent system will be discussed in the future work.

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