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Energy Management System Using a Fuzzy Logic Controller for Grid-Connected Hybrid Renewable Energy Sources

Fatima Menzri*, Tarek Boutabba**, Rachid CHENNI **

* Electric engineering department, University of oum El Bouaghi, Algeria
**MoDERNa Laboratory Mentouri, University of Constantine1, Constantine 25000, Algeria
**university of Abbès Laghrour Khenchela, LSPIE Batna laboratory Algeria
E-mail: fatima93menzri@gmail.com, Rachid.chenni@umc.edu.dz, boutabba_tarek@yahoo.fr.

Abstract

This paper presents a comparison study between a conventional energy management systems (EMS) based on a PI controller and an intelligent technique. A Fuzzy Logic Controller (FLC) was studied to solve the EMS energy management system of an isolated system. This hybrid system including the photovoltaic system (PV), wind turbine system, an energy storage system (ESS) and a dump load. All energy sources are connected to a DC bus via a DC-DC power converter. The proposed strategy for the energy management system in this design is to determine the power to be generated by the ESS using a conventional EMS and a new EMS (FLC), taking into account the power generated by the main resources (PV, wind), the power demanded by the grid and the state of charge (SOC).

Keywords: PV, wind, Renewable sources, Power management, PI controller, fuzzy logic.

1. Introduction

Renewable energy (RE) sources will become an increasingly important part of power generation, as the reserves of fossil fuels get closer to depletion. Among available RE technologies, wind and solar energy sources are the most promising choice, as they are omnipresent, freely available, and environmentally friendly [1].

Hybrid energy sources HES including at least two or more different energy types together with storage system [2]. In this, work a typical HRES configuration from photovoltaic (PV) panels and wind turbine (WT) with ESS. The renewable sources are used as primary energy sources. However, because the sun irradiance and the wind speed are incontrollable parameters a support energy source is needed to increase the degree of controllability and operability of the HRE [3].traditionally, this function is performed by an ESS such as battery [4].

This paper presents a comparative study between a classical energy management system CEMS based on PI controller and an intelligent control techniques called a fuzzy logic controller FLC. The main objective of this comparison is to determine the power that must be generated from energy storage system ESS.

In some literature such as [3-5-6] the HES problem many optimization methods have been proposed for solving the problems of energy management system EMS in our case, we have chosen to work with the FLC technique.

1. Modeling of hybrid system

The architecture of HRES is presented in figure 1. Where the all parts of the hybrid system were presented. Each main source is connected DC bus through DC-DC power converters. While that the ESS system is connected to DC bus using DC-DC bidirectional converter and the dump load is attached to the DC bus by a DC-DC buck converter. DC bus converted into DC-AC inverter. The LC filter is used to reduce the harmonics presented in inverter voltage [7] then linking with load.

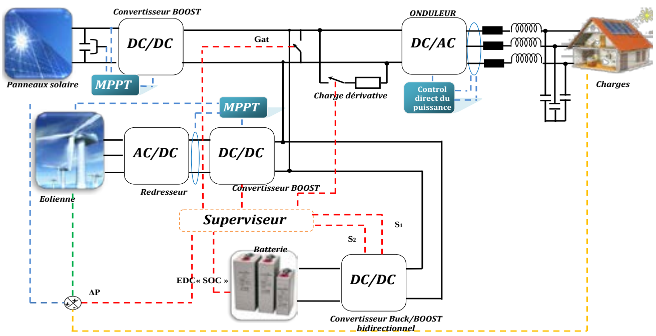


Fig.1. HRES for the proposed controller implementation

2. Control of hybrid energy source

This work present the different strategies are used in energy management system, considering that the energy storage systems ESS play an important role in the development of energy in the years to come. The battery is connected to the DC bus through a DC-DC bidirectional converter. The control of this converter can maintain the DC bus voltage constant at its reference value (V*dc=1680 V).

2.1. Battery management using PI controller

The PI control is one of the most commonly used approaches for controls that seek to reduce the error of the output value by using its feedback. In fact, it takes into consideration the time delay to adjust the system output. The design of the linear controller is based on mathematical calculations and a model of buck converter. To obtain an accurate measure for performance, an exact model should be considered. Many equivalent modeling techniques have been proposed in literature. The state space averaging modeling was very often proposed for DC-DC converter (Guo et al., 2009). For our application, the main transfer function for small signal control, which applies the averaging technique, is given by reference [8].

$$\frac{V_0(s)}{d(s)}=\frac{V_0}{D}\left(\frac{1+SR_cC}{1+as+bs^2}\right) \tag{1}$$

Where

$$a=R_cC+\left(R\backslash\backslash R_l\right)C+\frac{1}{R+R_l} \tag{2}$$

$$b=\frac{R+R_c}{R+R_l}LC \tag{3}$$

In this transfer function, V_o is the output voltage, D is the duty cycle, C is the output capacitance, L is the inductance and R is the load resistance. Parameters R_c and R_l are the ESR of C and L, respectively.

The transfer function for a continuous PI controller $C(s)$ is given by:

$$C(s)=\frac{K_pS+K_I}{S} \tag{4}$$

Where K_P and K_I are the gains of the PI controller [9].

The battery is connected to the DC bus through a DC-DC bidirectional converter. The control of this converter can maintain the DC bus voltage constant at its reference value (V^*_{dc}=1680 V). The battery voltage it is very lower as compared to reference DC bus voltage value. The output battery voltage about 200 V. In order to reduce fluctuations in the DC bus voltage, appropriate supervision is necessary to maintain a DC-DC bidirectional converter is implementing the DC bus voltage constant at its reference value. This regulation across a classic controller PI (Proportional - Integral).

The control of the DC-DC bidirectional converter. In this control technique, the DC bus voltage (V_{dc}) is detected and compared with the reference DC bus voltage (V_{*dc}). The error between these two values is applied to PI regulator.

2.2 Battery management using fuzzy logic

Fuzzy logic control (FLC) is a technique very often used in control systems based on microprocessors, since it does not require an exact model of system and is insensitive to variations of the parameters and operating points. It is based on rule basis and membership functions (MF), which are usually obtained by a trial-and-error method and thus is a very time-consuming and error-prone process [10-11].

In our case, a FL controller (FLC) is proposed to control the voltage of DC bus taking into state of charge.

The universe of discourse for the inputs variables using the error (e) and the derivative of the error (Δe) and of the output controller (ΔI) is assigned in terms of their linguistics variables by using seven fuzzy subsets. The membership functions for the variable are shown in figure 2 and figure 3 depicts the universe of discourse for the output variable, ΔI.

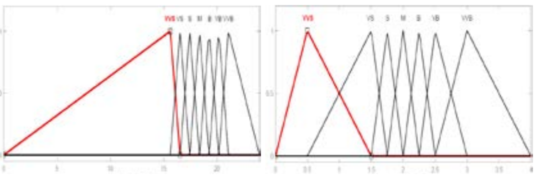


Fig .2. Membership Functions of the inputs the error (e) and the derivative of the error (Δe)

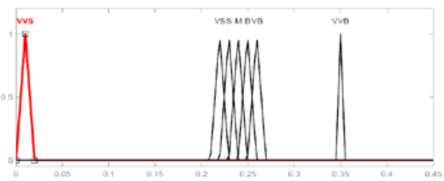


Fig .3. .Membership Functions of the output controller (ΔI)

The fuzzy system rule base is created as shown in Table 1 with (e) and (Δe) as inputs while ΔI is the output. The fuzzy inference of the FLC is based on the Mamdani's method which is associated with the max-min composition. The defuzzification technique is based on the centroid method which is used to compute the crisp output, ΔI.

TABLE 1: Fuzzy rule table

Δe / e	*VVS*	*VS*	*S*	*M*	*B*	*VB*	*VVB*
VVS	*VVS*	*VVS*	*VVS*	*VS*	*VVS*	*VVS*	*VS*
VS	*VVS*	*VVS*	*VVS*	*VS*	*S*	*M*	*B*
S	*VVS*	*VVS*	*VS*	*S*	*M*	*B*	*VB*
M	*VVS*	*VS*	*S*	*M*	*B*	*VB*	*VVB*
B	*VS*	*VVB*	*VVB*	*B*	*VB*	*VVB*	*VVB*
VB	*S*	*M*	*B*	*VB*	*VVB*	*VVB*	*VVB*
VVB	*M*	*B*	*VB*	*VVB*	*VVB*	*VVB*	*VVB*

3. Simulation Results

The dynamic simulation model for the system is described. The system consists of various units, PV power and wind power units as primary sources of energy, battery bank unit as auxiliary source of energy, dc-dc and dc-ac converters, load unit and control unit. The function of controller unit is to ensure the management of the power, which is delivered by the hybrid system to satisfy the load and to charge the battery. The inverter unit is used to convert the DC generated power from renewable energy sources to feed the load with the required AC power. The excessive charge from the battery will be dumped to the dump load unit. The dump load in this case is the battery storage.

figure 4 shown the results of management system using the proposed methods (**PI** controller and **FLC** controller).The different of power existing in the HRES are (power load, power hybrid "Ppv+Pwind", power battery), we observe that when $\mathbf{P_{load}>P_{gen}}$ (Ppv+Pwind) at time t=[0.8 1.54] (s) that the **ESS** system intervene to deliver the needed energy to recover the load energy demand, and from t=[0.5 0.8] (s) where the $\mathbf{P_{load}=P_{gen}}$ (Ppv+Pwind) the battery power don't interfere and equal to 0, also from t=[0 0.5] and t=[1.54 3] where $\mathbf{P_{load}<P_{gen}}$ (Ppv+Pwind) follows the progression of the renewable energy. As we can see the logic controller results **are** better than a classic controller of the battery power by deleting the peaks .

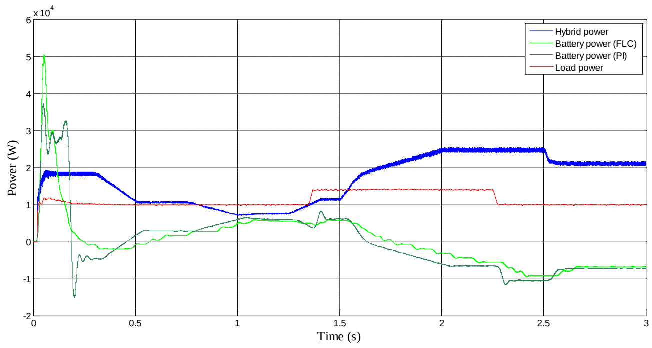


Fig. 4. Battery management system using FLC and PI controller

In figure 5 shows the voltage of DC bus . The voltage quality is always respected (f = 50Hz, V = 1680V) in all climatic and operating conditions.

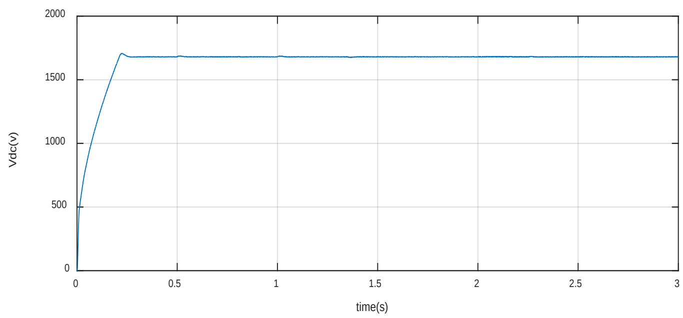


Fig.5.DC bus voltage

In figure 6 shows the variations in weather conditions (wind speed and solar irradiance) applied wind and solar generator respectively.

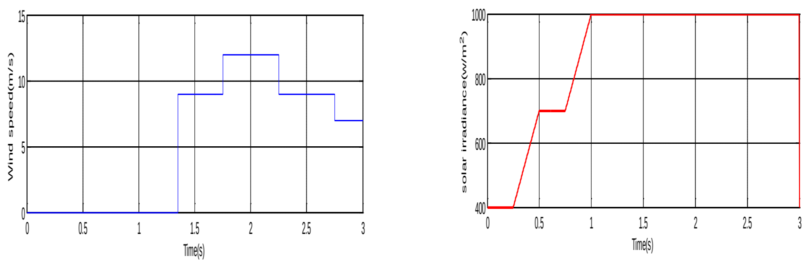
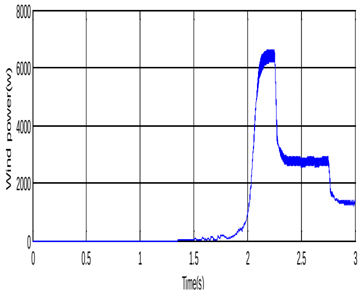


Fig.6. Wind speed and solar irradiance variation

In figure 7 show the wind and solar power are changed according to the variation in weather conditions.



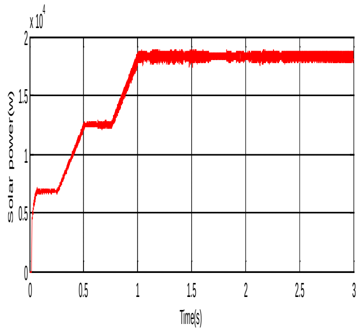


Fig.7. Wind and solar power variation

4. Conclusion

This paper presents the performance analysis of a novel PV-wind hybrid energy power system with battery storage under various atmospheric and loading conditions. A detailed modeling of both PV and wind subsystem components are discussed and simulated in the Matlab/Simulink environment. The performances of the Fuzzy logic controller FLC for the energy management system have been included. The results confirm that the FLC is better than the classical controller for the energy management hybrid renewable energy system HRES.

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