The Study of the Energy Management System Based-On Fuzzy Control for Distributed Hybrid Wind-Solar Power System

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Abstract: An energy management system based on Hierarchical fuzzy controller for the distributed hybrid wind-solar power system is designed. Based on hierarchical fuzzy control, the energy management system switches the mode of power supply and controls the load share according to the condition of wind power, solar radiation and load requirement. Through the suitable allotter of the generation ratio from wind power and photovoltaic cells, the distribution generation system, combined with battery bank, can provide user with reliable electric power. The energy management system is implemented from microprocessor and Data Acquisition System. This energy management system is applied in an experimental equipment. The hybrid generation system controlled by the fuzzy energy management system, at the appearance of random variation of wind speed and solar radiation, supplies with stable electric power.

Key words：hybrid generation system, hierarchical fuzzy control, energy management system

1. Introduction

Electric power supply in the areas isolated from the main grid can be provided by means of stand-alone systems based on renewable energy sources. Wind power generation is a complementarily electric power supplier. In recent years, wind power has been gaining renewed interest due to an increased emphasis on environmental sustainable resources as well as progress in wind related technologies. However, the variable and largely random nature of wind, makes the wind electric power unreliable. So the supplementary generation equipment is required to ensure continuous load supply. There exist many different topologies of the electric generation hybrid system. The relationship between wind power and solar power is complementary naturally. The hybrid generation system (HGS), combining the wind power generation and photovoltaic subsystems, is an ideal topology of complementary generation [1-2]. However, the performance of this kind of HGS is imposed largely by the meteorological conditions and the load demand. The reliability of the power supply is ensured only through the reasonable arrangement of various components and the collocation of the storage device [3]. These groups have different characteristics in delivering energy. Its application shows strongly irregular load diagram during the time of day and the week too [4]. In addition, the duration of storage device is usually narrow (it 's 2-3 years for the lead- acid batteries). The dimension of the storage device has an important weight in the final cost of the system [5]. The application of this HGS depends on the reliable performance and the lower cost. In order to achieve reliable power supply, as well as it is very important to optimize the architecture and components of the HGS, but as important is the energy management strategy (EMS) that is used to control the complete system.

The main objective of EMS is to supply the load with its full demand while monitoring the output power of HGS and the charging status of the storage batteries. EMS realizes the well-balanced operation by optimizing the ratio of wind power generation and photovoltaic power generation [6], and equipping the suitable capacity of storage device. Such aim is achieved through the following steps:

1. Monitoring the charging status of the storage batteries, as well as the supply power of the wind and solar power generated and comparing them with the load demand.

2. Each wind power generator can be disconnected to the HGS when the supply power exceeds the demand. The PV array is divided into 5 groups and can also be disconnected to the HGS respectively if necessary for accurate management.

3. The storage batteries compensate the load supply when the output power from the wind power generator and PV array is deficient. And its charging status is monitored by the EMS on-time.

In view of the complexity of the HGS composition, as well as unknown properties of the meteorological conditions and load power demand, EMS based on the accurate model is not easily implemented. The fuzzy logic controller does not require a detailed mathematical model of the system and its operation is governed by a set of rules. Thus, it is easy to implement and the same performance is ensured over the years[7]. So it is applied in HGS to evaluate the problems arising from imprecision and improve the robust[8]. However, one of the main impediments to developing the fuzzy controllers is the complexity involved with implementing the rule-based when there are a relatively large number of system variables. Since the conventional monolithic Fuzzy Logic Controller processes rules in a sequential manner, the size of the rule-base has a direct influence on the real-time performance of the Fuzzy Logic Controller. The size of the rule-base increases exponentially with the number of inputs. Hierarchical Fuzzy Control (HFC) has the capacity to significantly simplify the development process and reduce the size of the required rule-base for a number of general purpose tracking and control situations. This is

achieved without compromising the robustness and capability of the completed system.

In this paper, a hierarchical fuzzy control EMS is designed for a HGS comprising wind, PV and storage batteries. EMS operates depending on the Data Acquisition System (DAS) and manages the power flow between the system components in order to satisfy the load requirements throughout the whole day. By selecting the output power of wind and PV array, as well as the load demand and the charging level of storage batteries as fuzzy variables, we construct a supervisory fuzzy rule set. This EMS is applied to a 100KW experimental HGS and the simulink result is satisfactory.

2. System Configuration

The HGS, studied in this article, consists of 75KW wind power generation (5×15KW) and 15KW PV array as and is shown in Fig.1. The fixed-pitch wind turbine is directly coupled to a multi-pole permanent magnet synchronous generator, Which is connected, through an AC-DC power electronic interface with diode bridge rectifier and a DC/DC buck-boost converter, to a DC bus. The photovoltaic array, which consists of 300 polycrystallipe silicon solar cells modules each of them deliver 50W peak, is also linked to the DC bus after rectified. The bus voltage is imposed by the battery bank. Finally, a variable alternate load is fed using a static inverter. Load includes lamps, air-conditions, computers, and inductance motors.

In order to manage the energy flow accurately, the photovoltaic array is divided into 5 groups. Each group is isolated and can be controlled independently. The coherent information about the system moving is collected and sent to EMS by DAS. EMS cut the part system of photovoltaic array and wind energy when the electric load is low, and, contrariwise, the electric power is a supplement
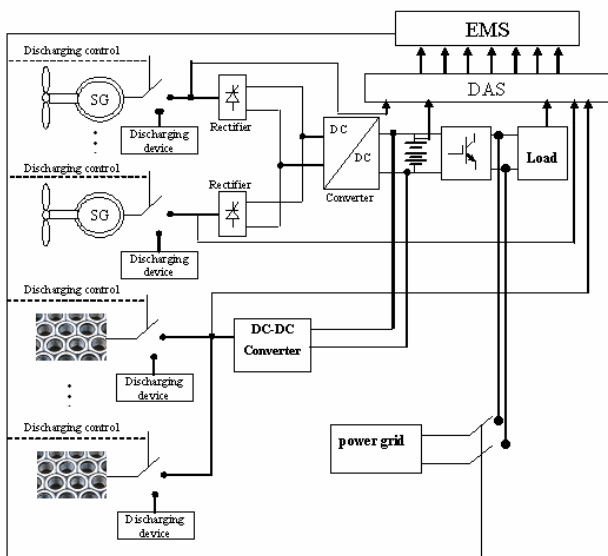

Fig.1 Electric generation hybrid system based on EMS

3. Fuzzy Logic and Hierarchical Fuzzy Controller for EMS

In this EMS, wind turbine (15kW*5), photovoltaic array (15kW) and electric load are needed to monitor. The control of wind turbine and photovoltaic array can maintain the feed and need in balance, can make sure the whole system stable.

A) Inputs and Outputs of the system

Inputs of the system are selected 5 group power datum of wind turbine, photovoltaic array and electric load. In order to reduce input number of the controller, measured power 5 groups datum of wind turbine are united to an input Pwind of fuzzy controller. The input Ppv and Pel are gotten as Pwind.

Outputs the system are the datum of loading or cutting of the wind turbine, photovoltaic array, and the offering power datum of electric power.

B) Fuzzification of system inputs and outputs

According to the actual conditions of the system, the base scope and language value are given. Given [0kW, 75kW] is the base scope of output power PW of WT which language value P'W is X={1，2，3，4，5}. The value in the look up table is Small, Smaller, Middle, Bigger, and Big. The fuzzification method of other system is similar to this one. In the actual system, each fuzzy subset is selected in a certain control precision, few number and low complexity. In the fixed EL conditions, every switch shouldn't switch frequently if the whole status didn't vary in a large scope. In this time reasonable fuzzy subset is plotted according to the characteristic of each variable.

For its simpleness, the triangle function is adopted as the membership grade function of input/outpt parameter.

C) Modeling the reasoning of hierarchical fuzzy controller

The Structure of hierarchical fuzzy controller is shown in Fig. 2. The variables which affect the system mostly are selected to be the first class look up table, and then the variables taken the second place are the second class look up table. In the end, the whole output power of the system is close to the needed power through the hierarchical fuzzy controller and the power meet the need. Here, PEL and PW are selected to be the input of the first class.
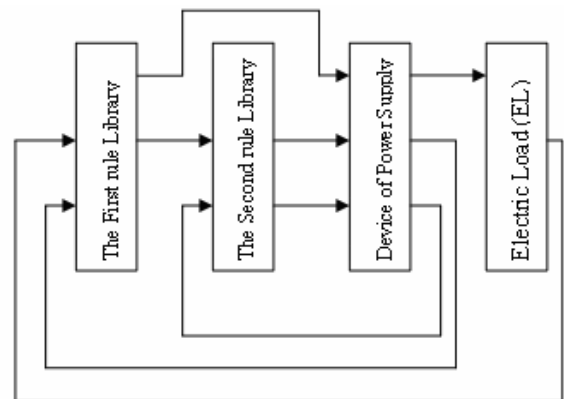

Fig. 2 The Structure of Hierarchical fuzzy controller

The first rule is given as follows:

if (x_1 is $a_{1,1}$, and x_2 is $a_{1,2}$) then (output y_1 is b_1)

(1)

Where, x_1 is the EL power; x_2 is the output power of WT in heavy load; y_1 is the ratio of expecting using number of WT and whole number (5). The membership grade function of three value are given as follows:
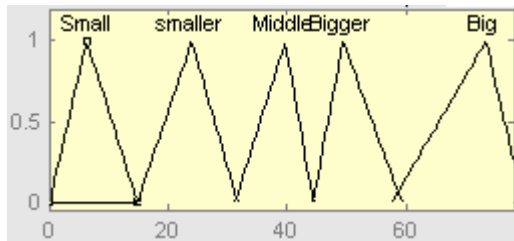

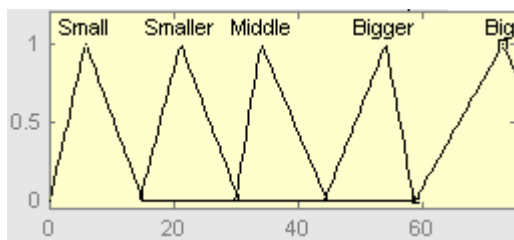Fig. 3 (a) membership grade Function of EL
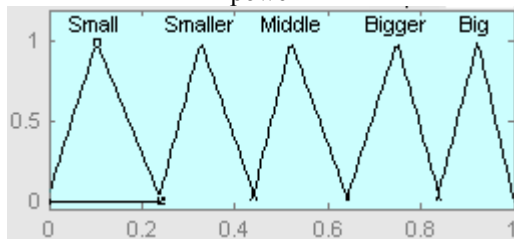

Fig. 3 (b) membership grade Function of WT output power

Fig. 3 (c) membership grade Function of y_1

The first class look up table is given in Table 1. After the first class reasoning, y_1 is gotten and the using number 5* y_1 of WT and output power $y_1 x_2$ are gotten, too.

The using number of WT is determined by y_1 which is looked as the power supply device module. $x_1 - y_1 x_2$ is sent to the second class look up table.

Table 1 The First Class Look up Tabl

x_1 \ x_2	Small	Smaller	Middle	Bigger	Big
Small	Big	Smaller	Small	Small	Small
Smaller	Big	Big	Middle	Smaller	Smaller
Middle	Big	Big	Big	Bigger	Middle
Bigger	Big	Big	Big	Big	Bigger
Big	Big	Big	Big	Big	Big

The second rule is given as follows:

If (x_3 is $a_{2,1}$, and $x_1 - y_1 x_2$ is $a_{2,2}$)

then (output y_2 is b_2)

(2)

Where, x_3 is the output power of PV array in the heavy load; $x_1 - y_1 x_2$ is the polynomial of the first class input/output, and this means the absent parts after absorbing the power of WT. y_2 is the ratio of using number of PV and its whole number (5). The **membership grade** function of these three values is the same as the first class fuzzy control. But the sections are different. In addition, the scope of output $x_1 - y_1 x_2$ is large because of the EL power and WT power. The **membership grade** function is given as follows:
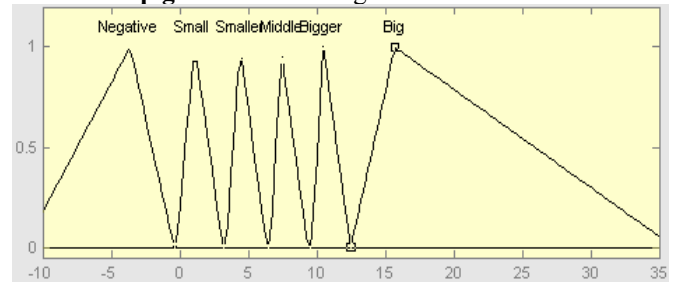

Fig.5 The **membership grade** function of $x_1 - y_1 x_2$

The second class look up table can see as Table 2

Table 2 The Second Class Look Up Table

x_3 \ $x_1 - y_1 x_2$	Negative	Small	Smaller	Middle	Bigger	Big
Zero	Zero	Big	Big	Big	Big	Big
Small	Zero	Big	Big	Big	Big	Big
Smaller	Zero	Smaller	Big	Big	Big	Big
Middle	Zero	Small	Middle	Big	Big	Big
Bigger	Zero	Small	Smaller	Middle	Big	Big
Big	Zero	Small	Smaller	Middle	Bigger	Big

After two hierarchical fuzzy control, the summation power of WT and PV and EL power export in some proportion when the summation power is more than the EL power. In this time the whole power is in balance. When the summation power is less than the EL power, the absent parts $x_1 - y_1 x_2 - y_2 x_3$ ($y_1 = y_2 = 1$) of the power are given by power system which is controlled by the second class fuzzy control.

D) Fuzzy Ruling of output

In the second class fuzzy reasoning, fuzzy ruling of output adopted the maximal membership grade, due to the only and discrete of WT and PV in the state of loading or cutting. For example, in the first class fuzzy rule, $y_1^{'}$ is adopted which membership grade $\mu_{Y_1^{'}}(y_1^{'})$ is maximal in the output fuzzy volume $Y_1^{'}$ as transition output, and then judge $y_1^{'}$ belonged to which fuzzy subset. The value of y_1 is given at last. When y_1 is "Small, Smaller, Middle, Bigger, Big", the value of y_1 is "0.2, 0.4, 0.6, 0.8, 1"

respectively. y_1x_1 is the needed output power of WT. The fuzzy ruling of y_2 is the same as y_1.

4. Simulation and Analysis

In order to validate the feasibility of the designed project, an energy management simulation system based on Hierarchical Fuzzy Controller which is according as supply and demand of power of some day (Time: 7:00-20:00) is designed.

There are some large-scale fluctuating in the power of wind turbines (WTs), PV array and Electrical Loads (EL), showing as Fig. 7 and Fig. 8. The power system is unstable, if the power is not controlled. In the following figures, the unit of abscissa is hour (h), and the vertical is kilowatt (kW).
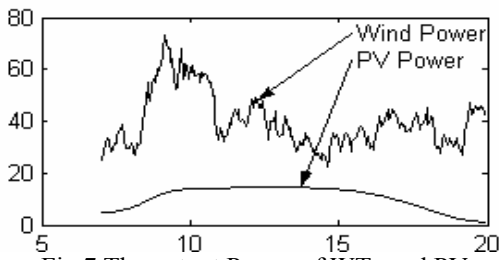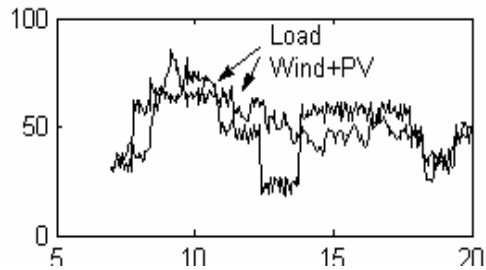
Fig.7 The output Power of WTs and PV

Fig. 8 The Output Power of EL and whole Power system

Fig. 9 gives the actual curves of output power of EL and controlled WT in the class fuzzy control. In the second class fuzzy control, the no-compensated power of WTs and the output power of PV are given in Fig. 10. The two figures show that the whole output powers of WT and PV are closed to the EL after the two class fuzzy control, and Fig. 11 shows in evidence at this point.
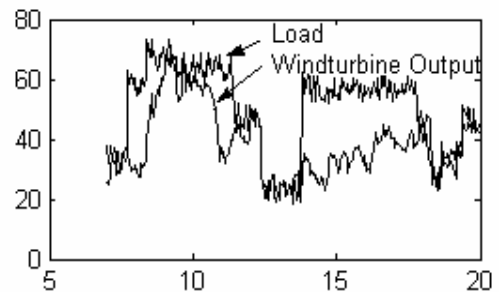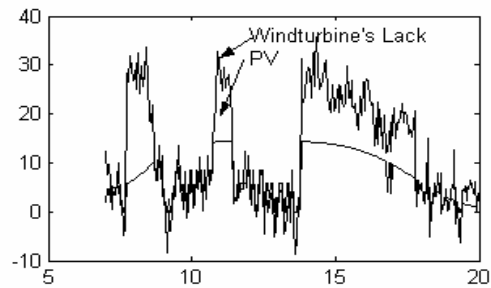
Fig. 9 Output Power of EL and Controlled WT

Fig. 10 No-compensated parts of WT and output Power of PV

In Fig. 11, the whole output power of WT and PV are matching the EL power and this result is better than Fig. 8. Meanwhile, there is some large spacing (showing as the shadow parts) between two curves in Fig. 11. The reasons are that the whole power of WT and PV isn't matching the EL power when the wind speed, light radiating and other weather conditions are nonideal. In this time, the outer power supply is needed in order to meet the requirement of EL.

So, according to the information of the second class fuzzy controller gives low power, a part of the EL power is supplied by power system. After the adjusting power, the whole curve is showed in Fig. 12.
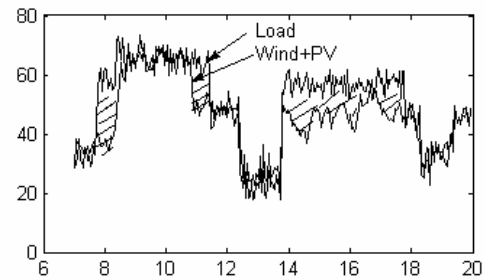
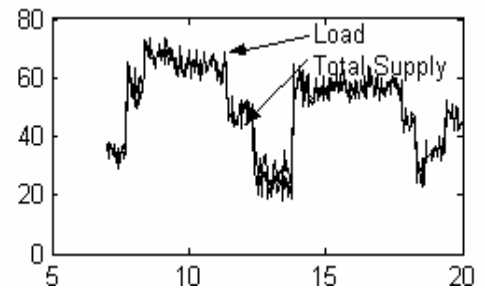Fig. 11 Power of EL, WT and PV Array

Fig. 12 Power of EL and Whole Supplying Power

5. Conclusion

In allusion to the MIMO distributed hybrid wind-solar power system, an Energy Management System (EMS) based on Hierarchical fuzzy controller is designed. The simulation results showed that the EMS can switch the mode of power supply and control the load share according to the condition of wind power, solar radiation and load requirement. In addition, the algorithm has no complex operation, little rule library and fast implement speed. All these reduced the complexity of the EMS and met the need of the whole system

Acknowledgement

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