Modeling and Control of Wind/PV/Battery Micro-grid Based on Matlab/Simulink[1]

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Abstract. Isolated micro-grid makes a great sense of supplying power in the area without large power grid covers. In this paper, an isolated operating micro-grid model is built based on the Matlab/Simulink environment, which contains miniature wind power system, PV system and energy storage system. In order to improve the quality of electrical energy, a composite control method with PI controller and neural network is designed. Simulation result shows the presented control method is effective.

Introduction

In recent years, with the increasing depletion of fossil fuels such as oil and coal, how to develop and utilize new energy has become a hot research topic[1],[2]. According to the statistics, there are more than ten millions non electric people mainly distributed in the remote mountainous areas of the West and the frontier islands in China.These regions usually have good wind energy resources and solar energy resources. Therefore, the construction of isolated micro-grid composed of photovoltaic power generation, wind power with energy storage unit, is an effective way to solve this problem. In this paper, a model of isolated micro-grid with wind power system, PV system, and energy storage system is built using Matlab/Simulink. A compound control method is presented for the sake of rasing the power quality, and its efficacy is verified through the simulation.

Wind Power System

Permanent magnet direct drive wind power system adopts low speed PMSG, which has the advantages of simple structure, high reliability and small mechanical losses [3]. Therefore, permanent magnet direct drive wind power system is a adopted as one part of the micro grid in this paper, and its structure is shown in Fig.1.

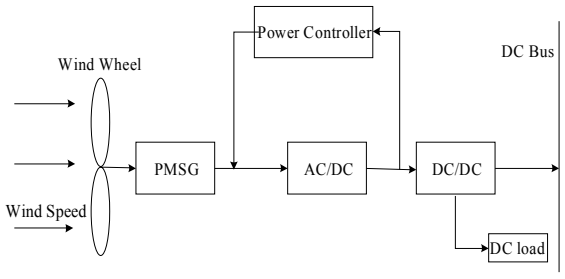


Fig.1 the wind power generation system

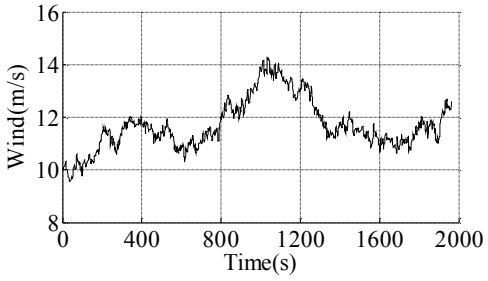


Fig.2 simulation of wind speed

Model of **W**ind **S**peed**.** The real-time dynamic wind speed model of the Risoe National Laboratory is adopted, which is improved with white noise and Kaimal spectral analysis. The parameters of this wind speed model include average wind speed V, diameter of the rotor R and turbulence intensity TI. In this paper, we set V=10m/s, R=1.56m,TI=12%, the wind speed simulation diagram is shown in Fig.2.

Model of Wind Power Generator. Wind energy utilization power is the wind energy that can be used by the unit time. In order to reflect the wind energy utilization ratio, C_p is defined as the wind energy utilization coefficient which equals the power absorbed by fans divides the kinetic energy of the airflow getting through the fan. C_p is also concerned with the wind speed, the fan rotational speed and blade pitch angle[3]. According to the Betz's law, the useful power P_s that the wind wheel actually gets is:

$$P_s = 0.5 r p R^2 V_w{}^3 C_p(b, l)$$

Where ρ is air density, β is the blade pitch angle, R is the radius of the wind wheel, l is the tip speed ratio.

The aerodynamic torque of the wind wheel is:

$$Tr = 0.5 r p R^3 V_w{}^2 C_T(b\ ,\ l)$$

C_T is the aerodynamic torque coefficient, and the relationship between the wind energy utilization coefficient C_P is as follows:

$$C_p(b\ ,\ l) = l C_T(b\ ,\ l)$$

The permanent magnet synchronous generator model is obtained by send the negative value of the torque signal of the wind wheel into the permanent magnet synchronous motor module in MATLAB/Simscape.

Module of Power Control and Rectifier-Boost Circuit. Module of power control is the maximum power point tracking module which is built based on variable step perturbation and observation method. The wind generator produces the alternating current, the output of the wind power generation system is connected to the DC bus, so the output voltage of the wind generator needs to be carried out AC/DC conversion and DC/DC conversion. The MATLAB/Simscape/Power Electronics/Universal Bridge is adopted for rectifier.

The boost converter controlled by the switch is brief and the driver is simple, therefore, it is chosen in boost segment, the driver signal is generated by the Matlab/SimElectronics/BLocks/ Actuators&Drivers /Controlled PWM Voltage module.

Photovoltaic Power Generation System

The photovoltaic power generation system in this paper is composed of photovoltaic cell module, power control module, PWM control module and the Boost module. The topology structure of the whole model is as shown in Fig.3.

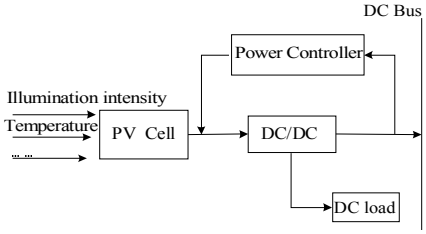


Fig.3 the photovoltaic power generation system

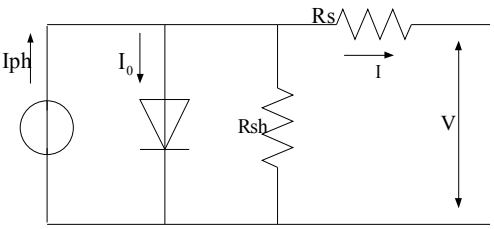


Fig.4 the equivalent circuit of PV cell

Model of Photovoltaic Cells. Basic characteristics of the photovoltaic cells are similar to the diode, and the equivalent model is shown in Fig.4. In the model, the effects of environmental temperature, illumination intensity, current temperature coefficient and voltage temperature coefficient on the characteristics of photovoltaic cells are considered, and the maximum power point voltage U_{mpp}, I_{mpp}, I_{sc}, U_{oc} and other necessary parameters are included in [4].

Module of Rectifier-Boost Circuit. Like wind power system, variable step perturbation and observation method is used for tracking the maximum power point of the PV generator system, and Boost circuit is also taken for stepping the voltage.

Energy Storage Model

Energy storage model is established by the super capacitor, and the super capacitor is paralleled to DC bus, which is the output of PV generation system and wind power system. The super capacitor of DC side can eliminate the ripple by using its energy storage characteristics, and it can make the DC voltage has little pulse and to be stable. The super capacitor model can be simplified as a serial structure of an ideal capacitor and an equivalent resistance, which can also accurately reflect the external electric characteristics in the process of charging and discharging, as shown in Fig.5 [5].

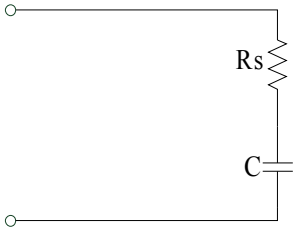


Fig.5 model of the super capacitor

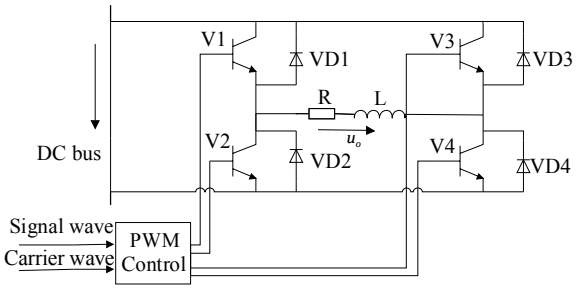


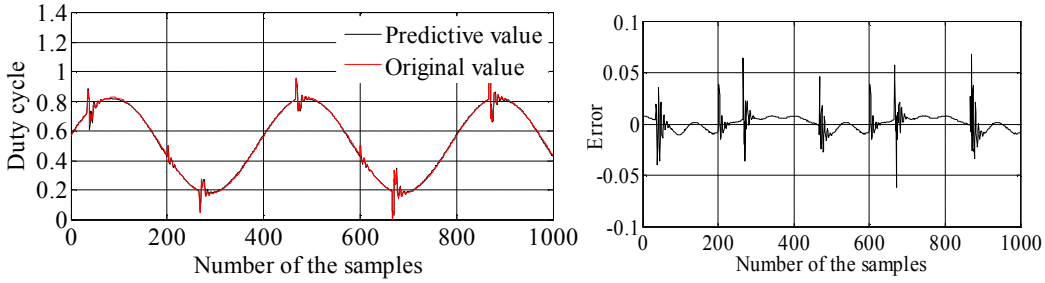
Fig.6 circuit of the inverter

Model of the Inverter

Circuit of the inverter. The single phase bridge PWM inverter circuit is selected in this paper, and IGBT is taken as the switching device. The Circuit of the inverter is shown in Fig.6.

PWM Control Method. The control aim of inverter is to ensure the stability of the micro-grid voltage. PI controller has the virtues of simpleness and easy to be adjusted, so it is widely used in the application. Due to the small capacity of the isolated micro-grid, the load fluctuation and carrying capacity change in energy storage unit could cause the distortion of the voltage. In order to improve the quality of electric energy, a compose method of PI and BP neural network is adopted in this paper.

The prediction model of BP neural network is built firstly. The inputs are the DC voltage U_{dc}, filter capacitor voltage U_c, inverter voltage U_o, inverter current I, duty cycle D at the K moment, the estimated inverter voltage U_o and inverter current I at the K+1 moment. Three-layer structure is adopted, so the input layer contains 7 neurons, the hidden layer contains 9 neurons, and the output layer contains 1 neuron. Tansig function is taken as the transfer function of hidden layer, and the purelin function is taken as the transfer function of output layer. After training the BP neural network, the predicted duty cycle and its error are shown in Figure 7(a), (b) respectively. Take the output of the model as feed forward and add it to the output of the single closed-loop PI controller, a compound control method is constructed.



(a)duty cycle (b)error

Fig.7 prediction result of the BP neural network

Finally the PWM control module built by matlab is shown in Fig.8.

Simulation Result

The rectifier load is typical nonlinear load, which is easy to cause the distortion of the grid voltage. In order to verify the effectiveness of the presented control method, simulation is performed with

nonlinear load, the inverter voltage and inverter current are shown in Fig.9(a), (b) respectively, and the Total Harmonic Distortion (THD) of the inverter voltage is 0.057.

Summary

In this paper, an isolated micro-grid model which contains miniature wind power system, PV system and energy storage system is built based on the Matlab/Simulink environment. In order to improve the quality of electrical energy, a composite control method with PI controller and neural network is designed. Simulation result shows the presented control method is effective.

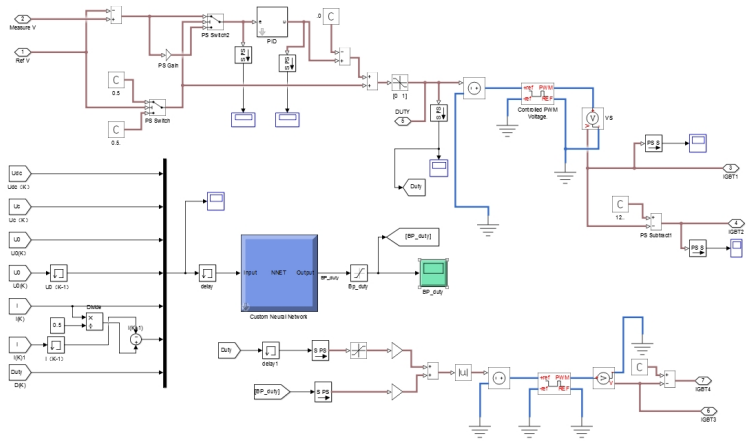
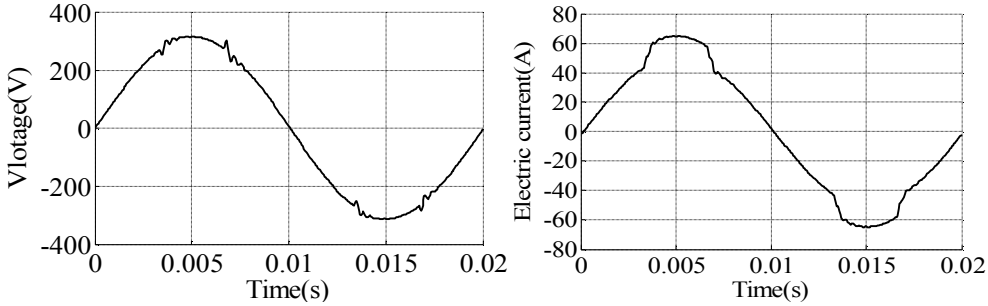


Fig.8 PWM control module



(a) inverter voltage (b) inverter current

Fig.9 simulation result of the presented control method

Acknowledgment

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