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Neural Network Pid Control of a Distributed Power Generation System Based on Renewable Energy

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Abstract: This study proposed a new energy control strategy for a distributed power generation system based on renewable. A mathematical model of the system was built based on a vector-controlled induction machine driving a flywheel. The BP Neural network control method was designed in the system in order to regulate DC Bus voltage, which is the object of the system. The experimental results on a wind simulator and flywheel based system verified that proposed energy complementary control can satisfactorily regulate the power of the storage unit to store and release energy and thus to maintain a steady DC voltage from the distributed power generation system.

Key words: Renewable energy, distributed power generation, neural network control, energy control

INTRODUCTION

Electric power generation using renewable energy presents tremendous social, economic and environmental benefits over fossil and nuclear power generation. Further more, renewable energy enables the development and applications of a new mode of power generation-distributed power generators as a complement to traditional central power generation stations. The area of west of China is far more that of east of China, but the terrain of west is very complicate. Electrical energy wasn't transported any isolated areas of west. However, numerous isolated areas have significant wind and solar energy potential. If these resources should be used effectively in isolated areas, the problem of absence of electrical energy will be resolved. Though there are so many advantages for renewable energy, there are uncertainty and non-line character for power of renewable energy. The unstable factors of these energy results in the power quality of a distributed power generation system that is bad. Wind and solar energy and storage energy equipments are combined to stabilize the distributed power generation system[1-6]. The storage energy equipments perform the storage and release process of energy and smooth the DC bus voltage in the system. The stability problem of a system with DC bus voltage 650 V is introduced[7]. In this study DC bus voltage of system is less than 200 V. The system is based on a vector-controlled induction machine driving a flywheel and addresses the problem of regulating the DC bus voltage with neural network PID controller.

STRUCTURE AND PROMCIPLES OF THE DISTRIBUTED POWER GENERATION SYSTEM

The present study primarily focused the studies of the energy control of the wind energy system (Fig. 1). The wind power generator is implemented by a simulator unit composed of an induction motor and a permanent magnet synchronous generator. The induction motor simulates the characteristics of a wind turbine under variable wind speeds and drives the permanent magnet synchronous generator to generate electric power. As one of storage units, the flywheel storage equipment is composed of an induction motor and steel flywheel.

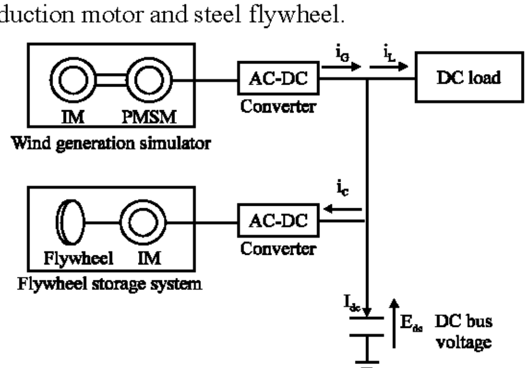

Fig. 1: Structure of the distributed power generation system based on renewable

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Due to the power of wind generation system is changed with the wind speed and load is changed with the time, DC bus voltage fluctuates, that is the system is unstable. When the DC bus voltage E_{dc} decreases, the induction machine is controlled to operate as a generator, transforming the inertial energy stored in the flywheel into electrical energy supplied to the DC Bus. When the DC bus voltage E_{dc} increases, the induction machine motors, transferring energy from the DC Bus to the flywheel.

SYSTEM MODELLING AND NEURAL NETWORK CONTROLLER CONSTRUCTING

In the system, it is based on a standard indirect-rotor-flux-orientated (IRFO)[8] control of the induction machine driving the flywheel. The dq current and voltage values are referred to the reference frame aligned to the rotor flux and take DC values in steady state (Fig. 2).

The torque current reference I^*_q is derived from the E_{dc} fuzzy controller.

Mathematical model of energy control system: The mathematical model of the system is built according to the principles of the energy control. In Fig. 2, the power balance between the DC bus side and the induction machine side is expressed as:

$$E_{dc}\left((i_G - i_L) - C\frac{dE_{dc}}{dt}\right) = P_{loss} + k(V_d i_d + V_q i_q) \quad (1)$$

Where, E_{dc} is the DC bus voltage, i_G is the output current of wind generation simulator, i_L is the current of DC load, P_{loss} is the inverter and iron power losses, k is the coefficient of the 2-3 axes scaling, V_d and V_q are the dq voltage of the stator respectively and i_d are the i_q current of the stator, respectively, C is the total capacitance of the DC bus.

According to the mathematical model of rotor-flux orientation of induction machine[2] , V_d, i_d, V_q and i_q are given by:

$$V_d = (R_s + \sigma L_s p)i_d - \omega_s \sigma L_s i_q \quad (2)$$

$$V_d = \omega_s \sigma L_s i_d + (R_s + \sigma L_s p)i_q + \omega_s \frac{L_m}{L_r}\varphi_r \quad (3)$$

Where, R_s and R_r are the stator and rotor resistance, respectively, L_s and L_r are the stator and rotor inductance, respectively L_m is the magnetizing inductance, φ_r is the rotor flux, ω_s is the rotational speed of stator, p is the differential operator,

$$\sigma = 1 - \frac{L^2_m}{L_s L_r}$$

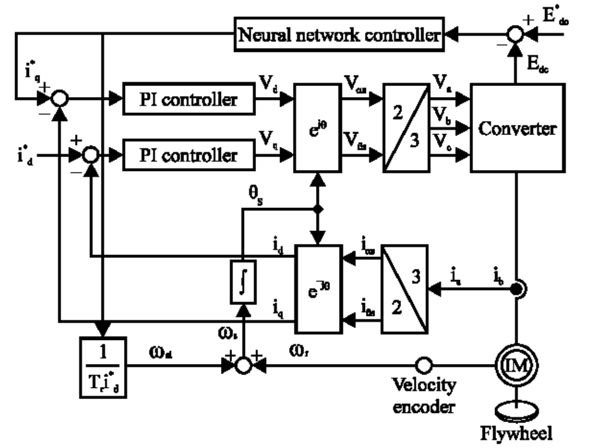

Fig. 2: Energy control system based on induction machine

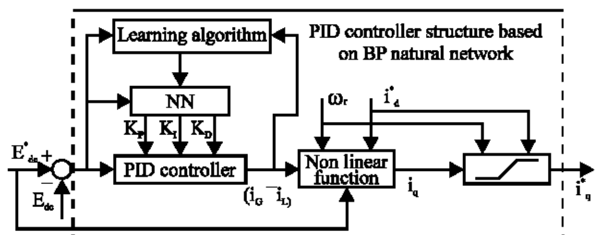

Fig. 3: PID controller structure based on BP neural nerwork

Using (1)-(3), it can be shown that the power balance can be de rived as:

$$E_{ds}(i_G - i_L) - \frac{1}{2}C\frac{dE^2_{dc}}{dt} = P_{losss} + k\left[R_s(i^2_d + i^2_q) + \left(\frac{L_m}{L_r}\right)^2 - R_r i^2_q\right] + \omega_r \frac{L^2_m i_d}{L_r} i_q + \frac{1}{2}\sigma L_s\left(\frac{di^2_q}{dt} + \frac{di^2_d}{dt}\right) \quad (4)$$

Since the flywheel inertia will be large (the speed dynamics will be slow) and neglecting the variation in the energy stored in σL_s, C and P_{loss} then the steady-state system equations may be used effectively. Using Eq. 4, the steady-state power balance is obtained as:

$$E_{ds}(i_G - i_L) = k\left[R_s(i^2_d + i^2_q) + \left(\frac{L_m}{L_r}\right)^2 .R_r i^2_q + \omega_r \frac{L^2_m i_d}{L_r} i_q\right] \quad (5)$$

Using Eq. 5, the steady-state torque current i_q is expressed as:

$$i_q = \frac{-\omega_r\left[\frac{L^2_m i_d}{L_r}\right] + \sqrt{\left(\frac{\omega_r L^2_m i_d}{L_r}\right)^2 - 4\left(R_s + R_r\left(\frac{L_m}{L_r}\right)^2\right)\left(R_s i^2_d - \frac{1}{k}\left(E_{dc}(i_G - i_L)\right)\right)}}{2\left(R_s + R_r\left(\frac{L_m}{L_r}\right)^2\right)} \quad (6)$$

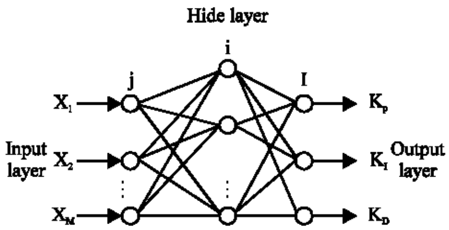

Fig. 4: Structure of BP neural network

Neural network PID controller constructing: According to Eq. 6, the structure of neural network PID controller for the DC bus voltage E_{dc} is shown in Fig. 3. The input current i_G-i_L of the flywheel storage energy system is obtained by the fuzzy control rule of DC bus voltage E_{dc}.

According to state change of the system, the parameters of PID controller (K_P, K_I and K_D) are regulated by the BP neural network (Fig. 3). There are three layers in the BP neural network (Fig. 4). It is composed of input layer, hide layer and output layer. The activated functions (f(x) and g(x)) of hide layer and output layer are expressed as:

$$f(x) = \tanh(x) = \frac{e^x - e^{-x}}{e^x + e^{-x}} \tag{7}$$

$$g(x) = \frac{1}{2}(1 + \tanh(x)) = \frac{e^x}{e^x + e^{-x}} \tag{8}$$

The operation process of neural network PID controller is composed of working and learning. Every weight of nerve cell is not change in the working process. According to input signals, the outputs (K_P, K_I and K_D) are computed by the neural network and then they are delivered to the PID controller in order to obtain the value of i_G-i_L. Every state of nerve cell is not change in the learning process. In order to obtain the desired output character of the neural network, the weight values between nerve cells are regulated according to learning sample. So the neural network PID controller can regulate parameters online with the change of object. It takes on the adaptive ability.

EXPERIMENTAL RESULTS

In the present study, induction machine of rating power 550 W is used for the actuator of the flywheel storage energy system. PMSM of rating power 2 kW and induction motor of rating power 2.2 kW are combined for the actuator of the wind generator simulator. The parameters of 550 W induction machine are shown in Table 1. The parameters of 2 KW PMSM are shown in Table 2. Figure 5 shows the Experimental system, which is composed of the control structure of Fig. 3 embedded in the system structure of Fig. 2 and wind generation

Table 1: Parameters of the induction motor

Parameter names	Units	Parameter values
Stator resistance (R_s)	(Ω)	10.0105
Rotor resistance (R_r)	(Ω)	11.9358
Stator inductance (L_s)	(H)	0.0767
Rotor inductance (L_r)	(H)	0.0767
Magnetizing inductance (L_m)	(H)	1.6041
Shaft and load inertia (J)	(kg m^2)	0.0165
Rating line voltage (U)	(V)	380
Rating power (P)	(W)	550
No. of pole pairs, (n_p)		1

Table 2: Parameters of the PMSM

Parameter names	Units	Parameter values
Stator resistance (R_s)	(Ω)	0.04
Stator inductance (L_s)	(H)	0.002
Rating power (P)	(kW)	2
Rating line voltage (U)	(V)	220.0
Rating line current (I)	(A)	9
Shaft and load inertia (J)	(kg m^2)	0.0082
Rating rotational speed	(rpm)	200
Maximum rotational speed	(rpm)	450
No. of pole pairs,(n_p)		4

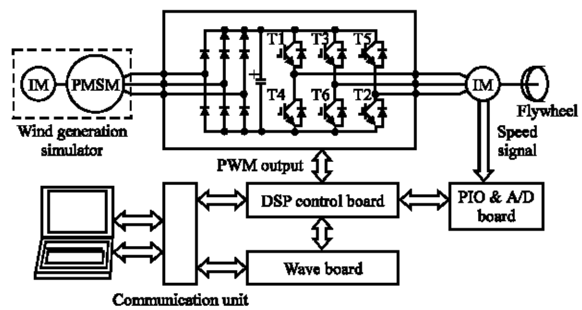

Fig. 5: Schematic diagram of experimental system

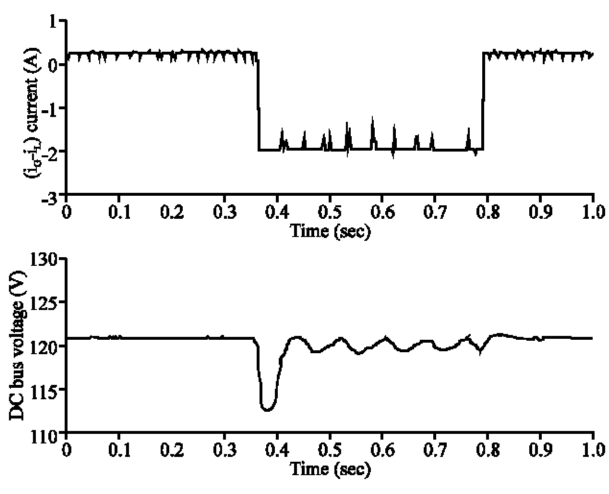

Fig. 6: The response of current i_G-i_L and DC bus voltage E_{dc}, connected at t=0.36 sec and disconnected at t=0.79 sec

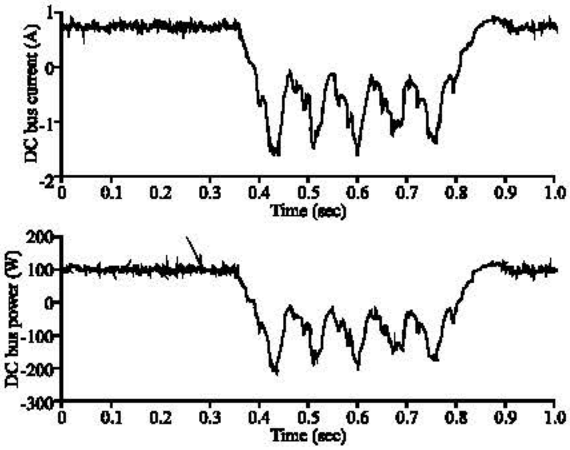

Fig. 7: The response of DC bus current I_{dc} and DC bus power P, connected at t=0.36 sec and disconnected at t=0.79 sec

Fig. 8: Experimental system. (In the picture: 1-wind generation simulator unit including an induction motor and a permanent magnet synchronous generator; 2-DC load; 3-flywheel energy storage unit; 4-converters and control system; 5-control computer)

simulator. The picture of experimental system is shown in Fig. 8. A incremental encoder provides the flywheel speed. The demanded DC bus voltage is 120 V. The demanded load is 1500 W.

Figure 6 shows the response of current i_G-i_L and DC bus voltage E_{dc}. Figure 7 shows the response of DC bus current I_{dc} and DC bus power P. The load is applied at t=0.36 sec and disconnected at t=0.79 sec. When the load is connected, the DC bus voltage E_{dc} moves towards down of the demanded voltage. The output current of the neural network PID controller also moves towards down, that is the load current is more than the generation current. At the same time, the DC bus Current values are negative; the stored energy is delivered from the flywheel to the DC load. Finally, the DC bus voltage E_{dc} moves towards the demanded voltage. When the load is disconnected, the DC bus voltage E_{dc} moves towards up of the demanded voltage. The output current of the neural network PID controller also moves towards up, that is the load current is less than the generation current. At the same time, the DC bus Current values are positive; the flywheel stores the redundant energy generated from wind. Finally, the DC bus voltage E_{dc} moves towards the demanded voltage.

CONCLUSION

This study has proposed a new energy control strategy of a distributed power generation system. The control strategy for regulating the DC bus voltage is performed in an experimental wind flywheel hybrid energy system. The system uses a metal flywheel for power smoothing employing an inverter-fed vector-controlled induction machine. The neural network PID controller embedded in the system is used for the object of energy control. The experimental results confirmed the satisfactory operation of the proposed system.

REFERENCES

1. Boutot, T., L. Chang and D. Luke, 2002. A low speed flywheel system for wind energy conversion. Proceeding of IEEE Candian Confereence on Electric Computer Engineering, pp: 251-256.
2. Iqbal, M.T., 2003. Modeling and control of a wind fuel cell hybrid energy system. Renewable Energy, 28: 223-237.
3. Leclercq, L., B. Robyns and J.M. Grave, 2003. Control based on fuzzy logic of a flywheel energy storage system associated with and diesel generators. Math. Computers, Simulation, 63: 271-280.
4. Iqbal, M.T., 2003. Simulation of a wind fuel cell hybrid energy system. Renewable Energy, 28: 511-522.

5. Cárdenas, R., R. Peña, G. Asher and J. Clare, 2004. Power smoothing in wind generation systems using a sensorless vector controlled induction machine driving a flywheel, IEEE Trans. Energy Conversion, 19: 206-216.
6. Szabados, B. and U. Schaible, 1998. Peak power bi-directional transfer from high speed flywheel to electrical regulated bus voltage system: A practical proposal for vehicular technology, IEEE Trans. Energy Conversion. 13: 34-41.
7. Cárdenas, R., R. Peña, G. Asher and J. Clare, 2001. Control strategies for enhanced power smoothing in wind energy systems using a flywheel driven by a vector-controlled induction machine. IEEE Trans. Industrial Electronics, 48: 625-635.
8. Leonhard, W., 1985. Control of Electrical Drives. Berlin, Germany: Springer-Verlag, pp: 70-90.