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Multiple models decentralized coordinated control of doubly fed induction generator

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ABSTRACT

In this paper, a multiple model optimal tracking control (MOTC) design method for the double fed induction generator (DFIG) using correlative measured technique is proposed. The DFIG is represented by a third-order model, where electro-magnetic transients of stator are neglected. By using the correlative measured technique, the correlative measured matrix (CMM) of wind power system is obtained firstly. Then, a nonstandard state space equation of DFIG is obtained with the correlative measured vectors (CMVs), which reflect interactions between the DFIGs and grid. In order to cope with nonlinearities and continuous variation in the operating points, a multiple model design method is proposed in the discrete domain. The obtained control law, synthesized by using Bayesian probability, only depends on the local measured parameters. Hence, the MOTC can be regarded as a decentralized coordinated control, which can simplify the control structure and improve the transient stability of DFIG. To illustrate the effectiveness of the proposed MOTC strategy, simulations on a hybrid wind thermal power (HWTP) system are performed. The results show that the proposed MOTC strategy can provide acceptable performance throughout the whole operating region. Comparing to the conventional PID control, transient stability, damping, and fault ride-through capability of DFIG with the proposed MOTC design method have been improved effectively.

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Introduction

Over the past few years, renewable energy such as wind power energy has been the world's fastest growing energy source [1] and many wind power generators have been integrated into power systems, which cause the share of wind power to reach a considerable level. With the continuing integration of wind power generators into grids, the impact of wind power on power system stability, such as transient stability, system damping and fault ride-through capability, are of increasing concern.

Because of low investment and flexible control, DFIG is becoming the dominant type that used in the wind farms (WFs) [2]. A decoupling control strategy using conventional PID control for the active power and reactive power proposed in [3] has been widely used in control of DFIG [4–6]. For their reliability and simplicity, the conventional PID control methods are well accepted in the engineering field. With these features, the conventional PID control methods have been widely used in power systems. However, the parameters of the conventional PID controller are usually tuned with the approximated linearized model. In this situation, the dynamic control performance may not be guaranteed during the whole operating region, especially under large disturbances in power systems. Hence, novel methods should be investigated in order to achieve better control performance of DFIG.

Decentralized coordinated control (DCC) is based on local variable compensation. Compared with the centralized control, controller design method by using DCC can simplify the structure of controller and avoid the curse of dimensionality [7]. In the DCC design method, the correlative measured matrix is used to represent coupling relationship between the subsystems. Each controller is coordinated by the correlative measured matrix, thus the dynamic control performance of DCC method to the disturbance may be improved. In the past, DCC design methods have been used in power system stability control problems. A DCC method using an efficient decentralized modal control algorithm has been applied successfully in tuning of power system stabilizer parameters in multi machine power systems [8], where the damping and transient stability of the power systems were improved. A DCC robust adaptive control method based on nonlinear robust adaptive control theory has been presented in [9] for AC/DC interconnected power systems. The robustness of the controller to deal

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Nomenclature

Indices
- R, S subscript for rotor and stator variables, respectively
- D, Q subscript for component of d and q axis, respectively
- X, Y subscript for component of x and y axis, respectively
- e, m subscript for electric and mechanical variable, respectively
- 0 subscript for steady-state value

Parameters
- H inertia time constant of the rotor
- F the damping factor;

Variables
- E' transient electromotive force
- R, X resistance and reactance, respectively
- X_M the mutual reactance
- V, I voltage and current, respectively
- T torque
- S slip of DFIG
- ω rotor speed
- δ the angle between q and X axis
- X' transient reactance
- Z_{ij} is mutual impedance between nodes i and j
- P and Q output active and reactive power

with the uncertainties of parameters and disturbances was improved, and the design process of controller was simplified. A decentralized excitation and governor coordinated controller design for hydraulic power plants have been proposed in [10], and the power system transient stability under larger disturbance was enhanced.

A decentralized nonlinear control design method using differential geometry theory has been used in the rotor excitation control of rotor side converters, where the DC voltage was regulated effectively and the transient stability of power system was improved [11], whereas neither the performance under various wind speed (WS) was investigated nor the coupling interactions between the DFIG and grid were considered. A small signal linear (SSL) model for an asynchronous machine has been presented in [12]. The proposed model has low complexity and permits direct solution of differential equations. Simulations in [12] demonstrated that the SSL model presented good accuracy compared to the dynamic model and the transient DFIG model could be substituted by the SSL model for the dynamic analysis of the wind power system. With the growing integration of wind power generations into power systems, it will be important to develop effective control methods in improving the robustness and transient stability of the wind power systems.

As far as we know, control of DFIG using DCC with correlative measured technology has not been investigated yet, and the correlative measured matrixes of wind power systems equipped with DFIGs have not been obtained yet. In this paper, a multiple model DCC method with SSL model for a WF equipped with DFIGs via correlative measured technology will be investigated in the transient stability control of wind power systems, where the correlative measured matrixes of the wind power systems are obtained. Control performance of the multiple model DCC method will be examined in terms of large disturbance both from grid side and WS.

The paper is arranged as follows. In section 'Models of wind power system,', a third-order model of DFIG and a model of network are recalled at first. Based on the correlative measured method, a nonstandard state space equations of DFIG for DCC design is derived in section 'MOTC design method', where the SSL model of DFIG and network are obtained. Then, a MOTC design method is presented based on the nonstandard state space equations of DFIG. The minimum principle and linear quadratic regulator design method are applied to obtain the control law. In section 'Dynamic simulations', the MOTC method is applied to control a grid connected WF. By using MATLAB, simulations are performed on a HWTP system to verify the effectiveness of the proposed MOTC for DFIG, while conclusions are drawn in section 'Conclusion'.

Models of wind power system

The equivalent circuit of DFIG is shown in Fig. 1, where the drive train is represented with a one-mass model [13] and the electromagnetic transients of the stator are neglected [14,15]. Then, the model of DFIG used in this paper is a third-order model as follows:

Dynamic equations:

$$\begin{cases} \dot{E}'_D = -\frac{R_R}{X_{RR}}\left(E'_D + \frac{X_M^2}{X_{RR}} I_{QS} + \frac{X_M}{R_R} V_{QR}\right) + SE'_Q \\ \dot{E}'_Q = -\frac{R_R}{X_{RR}}\left(E'_Q - \frac{X_M^2}{X_{RR}} I_{DS} - \frac{X_M}{R_R} V_{DR}\right) - SE'_D \\ \dot{\omega} = \frac{1}{2H}(Te - Tm - F\omega) \end{cases} \tag{1}$$

Electrical equations:

$$\begin{cases} E'_D = V_{DS} - R_S I_{DS} + X' I_{QS} \\ E'_Q = V_{QS} - R_S I_{QS} - X' I_{DS} \end{cases} \tag{2}$$

$$\begin{cases} P_S = V_{DS} I_{DS} + V_{QS} I_{QS} \\ Q_S = V_{DS} I_{QS} - V_{QS} I_{DS} \end{cases} \tag{3}$$

$$Te = E'_D I_{DS} + E'_Q I_{QS} \tag{4}$$

where $X_{RR} = X_R + X_M$, $X' = X_S + X_M \cdot X_R/X_{RR}$. The equations of the DFIG which are presented by (1)–(4) are all based on the motor convention. In the case of transient stability studies, it is common to reduce the fifth-order model to such a third-order model [16,17]. From (1)–(4), the model of the DFIG is a system of two inputs and two outputs in the d–q reference frame. The inputs are V_{DR} and V_{QR}, respectively, and the outputs are P_S and Q_S, respectively.

The network model in the terms of the node impedance matrix can be written as follows:

$$\begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_N \\ \vdots \\ V_m \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1N} & \cdots & Z_{1m} \\ Z_{21} & Z_{22} & \cdots & Z_{2N} & \cdots & Z_{2m} \\ \vdots & \vdots & & \vdots & & \vdots \\ Z_{N1} & Z_{N2} & \cdots & Z_{NN} & \cdots & Z_{Nm} \\ \vdots & \vdots & & \vdots & & \vdots \\ Z_{m1} & Z_{m2} & \cdots & Z_{mN} & \cdots & Z_{mm} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_N \\ 0 \\ 0 \end{bmatrix} \tag{5}$$

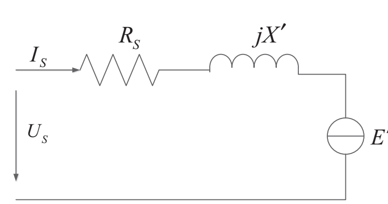

Fig. 1. Equivalent circuit of DFIG.

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