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Model predictive based load frequency control_design concerning wind turbines

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ABSTRACT

This paper presents a load frequency control (LFC) design using the model predictive control (MPC) technique in a multi-area power system in the presence of wind turbines. In the studied system, each local area controller is designed independently such that stability of the overall closed loop system is guaranteed. A frequency response model of multi-area power system including wind turbines is introduced. A physical constraints of the governors and turbines are considered in the model. The model was employed in the MPC structures. Digital simulations for a two area power system are provided to validate the effectiveness of the proposed scheme. The results show that, with the proposed MPC technique, the overall closed loop system performance demonstrated robustness in the face of uncertainties due to governors and turbines parameters variation and load disturbances. Also, it was denoted that wind turbine has a positive effect on the total response of the system. A performance comparison between the proposed controller with and without the participation of the wind turbines and a classical integral control scheme is carried out for confirming the superiority of the proposed MPC technique in the presence of the participation of the wind turbines.

1. Introduction

In fact, the LFC becomes an important function of power system operation where the main objective is to regulate the output power of each generator at prescribed levels while keeping the frequency fluctuations within pre-specified limits. Different types of controllers have been proposed in literature for the load frequency control design. The proportional integral PI controller, is widely employed in the LFC application [1]. But this type is considered as a fixed parameters controller which designed at nominal operating points and may no longer be suitable in all operating conditions. For this reason, adaptive gain scheduling approaches have been proposed for LFC synthesis [2–4].

Robust adaptive control schemes have been developed to deal with changes in system parameters. Fuzzy logic controllers have been used in many reports for LFC design in a two area power system [5], with and without nonlinearities. The applications of artificial neural network, genetic algorithms, and optimal control to LFC have been reported in [6,7]. In their findings it is observed that the transient response is oscillatory and it seems some other elegant techniques are needed to achieve a desirable performance. On the other hand, the MPC appears to be an efficient strategy to control many applications in industry, it has many advantages such as fast response, robustness against load disturbance and parameters uncertainty.

Its straightforward design procedure is considered as a major advantage of the MPC. Given a model of the system, only an objective function incorporating the control objectives needs to be set up. Additional physical constraints can be easily dealt with by adding them as inequality constraints, whereas soft constraints can be accounted for in the objective function using large penalties. Moreover, the MPC is well adapted to different physical setups and it allows for a unified approach [8–10].

Recently, a few attempts studied the idea of wind turbines in the issue of LFC. Variable speed wind turbines (VSWTs), the most utilize type of modern WTs, is partially or totally decoupled from the power network due to the power electronic converters limiting their capacity to provide primary frequency support to the network in case of disturbances. The inertial response of WTs is discussed in detail in [11,12].

A detailed background of frequency responses, including primary and secondary responses, are given in [11]. A detailed comparison is made about fixed-speed wind turbines (FSWTs) and doubly fed induction generator (DFIG) type wind turbines (WTs) through detailed simulations, the potential of FSWTs to contribute to the frequency response. On the other hand, these simulations also show that the DFIG-based WTs have negligible contribution

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to frequency responses and, hence it sounds that an additional control loop is necessary.

In [12], it is reported that full converter (FC) type WTs are completely decoupled from the power grid and no contribution is given to the frequency regulation. In addition, it is pointed out that the DFIG-type WTs have some small contribution to the power network.

In [13], and [15], fast response and robustness against parameter uncertainties and load changes can be obtained using MPC controller for both single and multi-area load frequency control application respectively, but without the participation of WTs.

While in [16], an attempt of study the effect of merging the wind turbines in the power system controlled by model predictive load frequency control method, a positive effect on the system response could be noted, but that only for a single area.

This paper studies the effect of merging the wind turbines on the system frequency response of multi area power system. In this paper, each local area includes an aggregated wind turbine model (which consists of 200 wind turbine units) beside the main generation unit. The MPC technique law produces its optimal output derived from a quadratic cost function minimization based on the dynamic model of the single area power system.The technique calculates the optimal control signal while respecting the given constrains over the output frequency deviation and the load change. The effects of the physical constraints such as generation rate constraint (GRC) and speed governor dead band [1] are considered. The power system with the proposed MPC technique has been tested through the effect of uncertainties due to governor and turbine parameters variation and load disturbance using computer simulation. A comparison has been made between the MPC (with and without wind turbine participation) and the traditional integral controller confirming the superiority of the proposed MPC technique and showing the positive effect of the WT participation on the total system performance. Also, the simulation results proved that the proposed controller can be successfully applied to the application of power system load frequency control.

The rest of the paper is organized as follows: A simplified wind turbine model is presented in Section 2. The description of the dynamics of the power system is given in Section 3. General consideration about MPC and its cost function are presented in Section 4. The implementation scheme of a multi area power system together with the MPC technique is described in Section 5. Simulation results and general remarks are presented in Section 6. Finally, the paper is concluded in Section 7.

2. Simplified wind turbine model for frequency studies

Fig. 1 shows a simplified model of DFIG based wind turbine for frequency response [14]. This simplified model can be described by the following equations:

$$\dot{i}_{qr} = -\left(\frac{1}{T_1}\right)i_{qr} + \left(\frac{X_2}{T_1}\right)V_{qr} \tag{1}$$

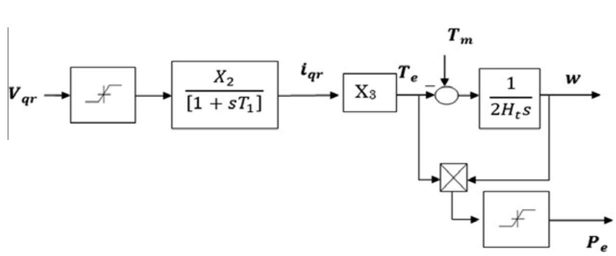

Fig. 1. Simplified model of DFIG based wind turbine.

Table 1
Parameters for Fig. 1 [14].

X_2	X_3	T_1
$\frac{1}{R_r}$	$\frac{L_m}{L_{ss}}$	$\frac{L_0}{w_s R_s}$

$$\dot{w} = -\left(\frac{X_3}{2H_t}\right)i_{qr} + \left(\frac{1}{2H_t}\right)T_m \tag{2}$$

$$P_e = wX_3 i_{qr} \tag{3}$$

and for linearization, Eq. (3) can be rewritten as:

$$P_e = w_{opt}X_3 i_{qr} \tag{4}$$

and

$$T_e = i_{qs} = -\frac{L_m}{L_{SS}}i_{qr} \tag{5}$$

where the parameters are defined as follows: w_{opt} is the operating point of the rotational speed, T_e the electromagnetic torque, T_m the mechanical power change, w the rotational speed, P_e the active power of wind turbine, i_{qr} the q-axis component of the rotor current, V_{qr} the q-axis component of the rotor voltage, H_t the equivalent inertia constant of wind turbine.

Table 1 shows the detailed expressions of the main parameters utilized for the simplified model of Fig. 1.where

$$L_0 = \left[L_{rr} + \frac{L_m^2}{L_{ss}}\right], \; L_{ss} = L_s + L_m, \; L_{rr} = L_{rs} + L_m$$

and, L_m is the magnetizing inductance, R_r and R_s the rotor and stator resistances, respectively, L_r and L_s the rotor and stator leakage inductances, respectively, L_{rr} and L_{ss} the rotor and stator self-inductances, respectively, w_s is the synchronous speed.

3. System dynamics

A multi-area power system comprises areas that are interconnected by tie-lines. The trend of frequency measured in each control area is an indicator of the trend of the mismatch power in the interconnection and not in the control area alone. The LFC system in each control area of an interconnected (multi-area) power system should control the interchange power with the other control areas as well as its local frequency. Therefore, the dynamic LFC system model must take into account the tie-line power signal. For this purpose, consider Fig. 2, which shows a power system with N-control areas [1].

In this section, a frequency response model for any area-i of N power system control areas with an aggregated generator unit in each area is described [1].

The overall generator–load dynamic relationship between the incremental mismatch power $(\Delta P_{mi} - \Delta P_{Li})$ and the frequency deviation (Δf_i) can be express

$$\Delta\dot{f}_i = \left(\frac{1}{2H_i}\right)\Delta P_{mi} - \left(\frac{1}{2H_i}\right)\Delta P_{Li} - \left(\frac{D_i}{2H_i}\right)\Delta f_i - \left(\frac{1}{2H_i}\right)\Delta P_{tie,i} \tag{6}$$

the dynamic of the governor can be expressed as:

$$\Delta\dot{P}_{mi} = \left(\frac{1}{T_{ti}}\right)\Delta P_{gi} - \left(\frac{1}{T_{ti}}\right)\Delta P_{mi} \tag{7}$$

the dynamic of the turbine can be expressed as:

$$\Delta\dot{P}_{gi} = \left(\frac{1}{T_{gi}}\right)\Delta P_{ci} - \left(\frac{1}{R_i T_{gi}}\right)\Delta f_i - \left(\frac{1}{T_{gi}}\right)\Delta P_{gi} \tag{8}$$