The 3rd International CUA Graduate Students Symposium

سومین سمپوزیوم بین‌المللی دانشجویان تحصیلات تکمیلی دانشگاه‌های عضو اتحادیهٔ قفقاز

University of Mohaghegh Ardabili

دانشگاه محقق اردبیلی

June 5-6, 2016

16–17 خردادماه

Optimal Design of PI Controller for Load Frequency Control in a Two-Area Power System with DFIG Based Wind Turbine

Samira Fallahi
Hossein Shayeghi
Abdolah Younesi

Technical Engineering Department, University of Mohaghegh Ardabili, Ardabil, Iran
Technical Engineering Department, University of Mohaghegh Ardabili, Ardabil, Iran
Technical Engineering Department, University of Mohaghegh Ardabili, Ardabil, Iran

Abstract

Stability of power system is one of the most important aspects in electric system action in the presence of wind power. The technological advancements have made it possible for wind generators to participate in frequency control. This paper shows the optimal design of the PI controller for an interconnected power system with dynamic participation of doubly fed induction generator based wind turbines (DFIG) in two case. The Power system model 1 is a two area interconnected power system without DFIG and the Power system model 2 is a two area interconnected power system with DFIG. DA algorithm is used for optimal PI controller of two area system and speed controller of DFIG parameters with considering 2% load disturbance in area 1.

Keywords: Doubly fed induction generator (DFIG), Load frequency control, Inertial control, Wind energy conversion system.

1. Introduction

Among the various sources of renewable energy, the wind is one of the most promising sources [1]. Frequency regulation in a generation mix having large wind power penetration is a critical issue. The aim of the LFC in a power system is to provide an acceptable high level of power quality while maintaining both voltage and frequency within tolerance limits [2]. Wind turbine generation does not participation in frequency regulation services in power systems. Doubly fed induction generator (DFIG)-based wind turbines to demonstrate their possibility to provide separate active and reactive power control [3]. Few methods are reported in the literature on how variable speed wind turbine (VSWT) can participate in system frequency regulation [4, 5]. The first method is based on inertial control and other is power reserve (pitch and speed control) and third is control by communication method. Inertial control is provided by the DFIG through a supplementary inertia control loop with a suitable gain [6]. That it is sensitive to system frequency and releases kinetic energy from DFIG. DFIG injected active power during frequency exclusion. That it is proportional to the derivative of system frequency [7]. Different method is used to maintain the power system in the stability state. In [8] a nonlinear artificial neural network controller based on µ-synthesis deal with the LFC issue of inter-connected power system was proposed. Çam & Kocaarslan in [9] are used a fuzzy game scheduling proportional and integral controller for improving load frequency dynamic performance of a two area power system. The objective of this paper is designing optimal PI controller for load frequency control of a two area interconnected system with DFIG-based wind turbines in both areas.

2.Simulation Model

Fig 1 shows the linearized model of two area interconnected power system. The model includes system parameters such as damping factor (D), the drop (R), the inertia H, governor time constant (T_h) and turbine time constant (T_t) , power system time constant (T_p) and power system gain (K_p). The parameter values are presented in [10]. The ΔP_g is the output from which the incremental power demand ΔP_D is sub ducted. The incremental hydraulic valve position change is shown with ΔP_h. ΔP_{NC} is added to the system according to Eq 1.

$$\Delta P_g + \Delta P_{NC} - \Delta P_{12} - \Delta P_D = \Delta P_f \qquad (1)$$

$$K_P = \frac{1}{D}\,, \quad T_P = \frac{2H}{fD} \qquad (2)$$

Fig 2 shows the model DFIG-based wind turbine control based on frequency change. The base of emulation control given in Ref [11, 12]. In emulation control of the DFIG, an additional control signal tries to conform the power set point ΔP_f^* as a function of deviation and rate of change of frequency. The controllers have a duty to keep the turbine at optimal speed in order to generate the maximum power. The controller provides a power set point ΔP_W^* that is based on measured speed and measured electrical power. ΔP_{NC} is consisting of two parts; ΔP_f^* and ΔP_W^* that are based on frequency change and optimum turbine speed respectively, as is given by:

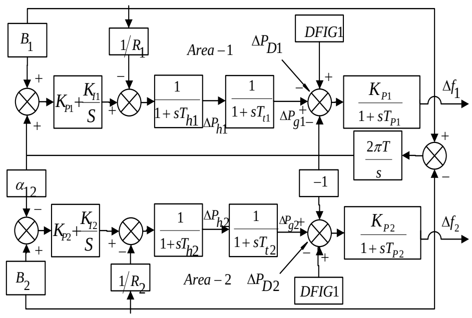
$$\Delta P_f^* = -K_{df}\frac{df}{dt} - K_{Pf}\Delta f \quad (3) \qquad \Delta P_W^* = -K_{WP}\left(W^* - W\right) + K_{Wi}\int\left(W^* - W\right)dt \quad (4)$$

$$\Delta P_{NC} = \Delta P_f^* + \Delta P_W^* \quad (5)$$

Where K_{WP} and K_{Wi} are constants of the PI controller. The contribution of the DFIG in system inertia is given by:

$$\frac{2H}{f}\frac{d\Delta f}{dt} = \Delta P_f - D\Delta_f = \Delta P_g + \Delta P_{NC} - \Delta P_{12} - \Delta PD - D\Delta f \quad (6)$$

$$\underbrace{\left(\frac{2H}{f} + K_{df}\right)}_{2H^*}\frac{d\Delta f}{dt} = \Delta P_f - D\Delta f = \Delta P_g + \Delta P_{NC} - \Delta P_{12} - \Delta PD - \underbrace{\left(K_{pf} + D\right)}_{D^*}\Delta f \quad (7)$$



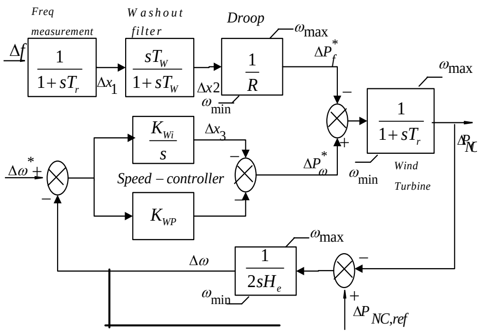


Fig 1. The model of two area interconnected power system based frequency change

Fig 2. DFIG-based wind turbin

Reference point ΔP_f^* *is obtained as follows:*

$$\Delta P_f^* = \frac{1}{R}(\Delta X_2) \quad (8)$$

Where ΔX_2 is the frequency change measured where the wind turbine is connected to the network.

3. Dragonfly Algorithm

The main inspiration of the DA emanates from the static and dynamic swarming behaviors of dragonflies. Two basic phases of optimization exploration and exploitation, are designed by modeling the social in traction of dragonflies in navigating, searching for foods and avoiding enemies when searching dynamically or statistically. There are five main factors in position updating of individuals in swarms as follows:

$$s_i = -\sum_{j=1}^{N} x - x_j \quad (9) \qquad A_i = \frac{\sum_{j=1}^{N} v_j}{N} \quad (10) \qquad C_i = \frac{\sum_{j=1}^{N} x_j}{N} - x \quad (11)$$

$$F_i = x^+ - x \quad (12) \qquad E_i = x^- - x \quad (13)$$

Where x is the position of the current individual, x_j is the j-th neighbouring individual and N is the number of tham, v_j is the velocity of *j-th* tham, x^+ and x^- show the position of the food source and enemy respectively. The position of artificial dragonflies update as follow:

$$\Delta x_{i+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + w\,\Delta x_t \quad (14) \qquad x_{t+1} = x_t + \Delta x_{t+1} \quad (15)$$

Where s, a, c, w show the weight factor, f is the food factor, e is the enemy factor and t is the iteration counter. To improve the randomness, position of dragonflies is updated as following:

$$x_{t+1} = x_t + levy(\mathrm{d}) \times \mathrm{x}_t \quad (16) \qquad levy(\mathrm{x}) = 0.01 \times \frac{r_1 \times \delta}{|r_2|^{1/\beta}} \quad (17)$$

Where d is the dimension of the position vectors, r_1 and r_2 are two random numbers in [0,1], β is a constant equal to 1.5 in this work. Finally, the algorithm work is completed [13].

$$\Gamma(x) = (x-1)! \quad (18)$$

$$\delta = \left(\frac{\Gamma(1+\beta) \times \sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left(\frac{1+\beta}{2}\right) \times \beta \times 2^{\left(\frac{\beta-1}{2}\right)}} \right)^{1/\beta} \quad (19)$$

3. PI Controller Design

In this paper, the PI controller based on DA algorithm has been investigated for LFC in the two area interconnected power system with the dynamic participation of DFIG based wind turbine. To raise the participation of the DFIG in frequency control parameters of speed controller from DFIG have been obtained. The result has been shown for 10% wind penetration level in table 1. The ITAE technique is used for obtaining the optimum value of controller as following:

$$J = ITAE = \int_{0}^{t_{sim}} \left(|\Delta F_1| + |\Delta F_2| + |\Delta P_{tie}|\right).tdt \qquad (20)$$

4.Simulation ResultS

Simulations have been done in a two area system check the influence of the DFIG in system frequency control. The results have been extracted for a load perturbation of 2% in area 1 with 10% level of wind penetration. DA algorithm to obtain the optimal values of the controller is used. Fig 3-5 show the response of the power system with considering DFIG in both areas and without DFIG. Tables 2 shows analyze result for power system with and without DFIG based wind turbine. The result shows effectively presence in frequency control.

Table 1. Optimal parameters of the controller for 10% wind penetration

Controller parameter	Area 1				Area2			
values	K_{p1}^*	K_{i1}^*	K_{wi1}	K_{wp1}	K_{p2}^*	K_{i2}^*	K_{wi2}	K_{wp2}
	2	0.8434	-1.2918	1.9813	2	0.9574	1.0278	2

Table 2. Analyze result for power system with and without DFIG based wind turbine

	Power system without DFIG				Power system with DFIG			
	OS	US	T_S	ITAE	OS	US	T_S	ITAE
DF1	0.0194	0.0635	40.0513	1.5939	0.0209	0.0468	16.4837	0.4394
DF2	0.0071	0.0240	48.54	1.6679	1.7822e-05	0.0104	17.890	0.2207
DP12	1.4019e-04	0.0053	47.9018	0.2439	8.5980e-06	0.0033	18.054	0.2207

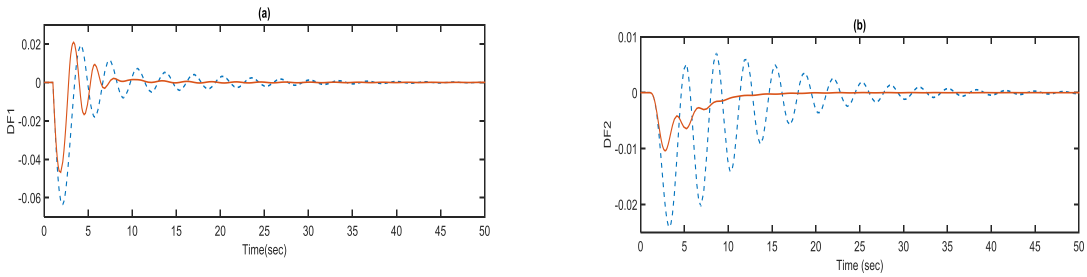


Fig 3. Frequency response with 10% of DFIG; (a): area 1, (b): area 2. Solid (with DFIG), Dashed (without DFIG)

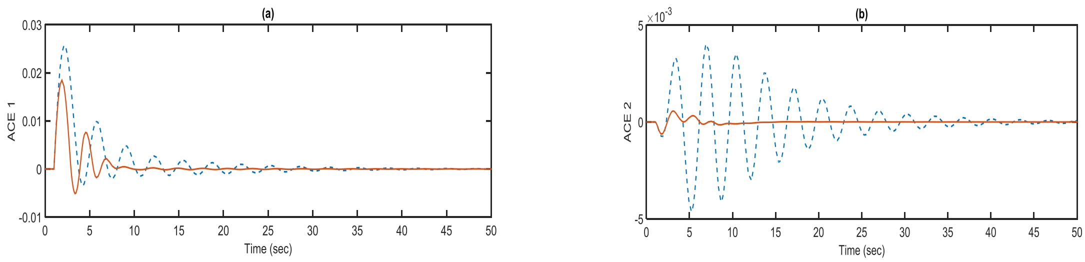


Fig 4. Response of ACE with 10% of DFIG; (a): area 1, (b): area 2. Solid (with DFIG), Dashed (without DFIG)

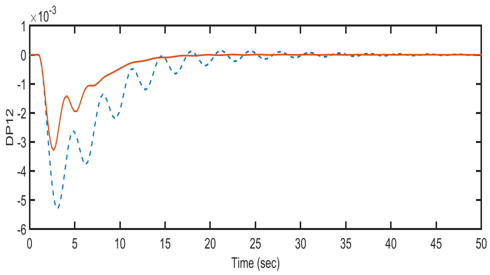


Fig 5. Response of tie line power with 10% of DFIG; Solid (with DFIG), Dashed (without DFIG)

Conclusion

This paper shows the optimal design of the PI controller for an interconnected power system with the dynamic participation of DFIG-based wind turbines.The peak frequency and settling time are reduced when the DFIG-based wind turbines participate in frequency regulation along with the conventional generators. Thus, the presence of DFIG can be effective in frequency control.

References

1. Ibraheem, Niazi, K. R., & Sharma, G. (2015). Study on dynamic participation of wind turbines in automatic generation control of power systems. *Electric Power Components and Systems*, *43*(1), 44-55.

2. Pandey, S. K., Mohanty, S. R., & Kishor, N. (2013). A literature survey on load–frequency control for conventional and distribution generation power systems. *Renewable and Sustainable Energy Reviews*, 318-334.

3. Jalali, M., & Bhattacharya, K. (2013, July). Frequency regulation and AGC in isolated systems with DFIG-based wind turbines. In *Power and Energy Society General Meeting (PES), 2013 IEEE* (pp. 1-5). IEEE.

4. Lalor, G., Mullane, A., & O'Malley, M. (2005). Frequency control and wind turbine technologies. *Power Systems, IEEE Transactions on*, *20*(4), 1905-1913.

5. Mullane, A., & O'Malley, M. (2005). The inertial response of induction-machine-based wind turbines. *Power Systems, IEEE Transactions on*, *20*(3), 1496-1503.

6.Yingcheng, X., & Nengling, T. (2011). Review of contribution to frequency control through variable speed wind turbine. *Renewable Energy*, *36*(6), 1671-1677.

7. De Almeida, R. G., & Lopes, J. (2007). Participation of doubly fed induction wind generators in system frequency regulation. *Power Systems, IEEE Transactions on*, *22*(3), 944-950.

8. Shayeghi, H., & Shayanfar, H. A. (2006). Application of ANN technique based on μ-synthesis to load frequency control of interconnected power system. *International Journal of Electrical Power & Energy Systems*, *28*(7), 503-511.

9. Çam, E., & Kocaarslan, I. (2005). Load frequency control in two area power systems using fuzzy logic controller. *Energy Conversion and Management*, *46*(2), 233-243.

10. Verma, Y. P., & Kumar, A. (2012). Dynamic contribution of variable-speed wind energy conversion system in system frequency regulation. *Frontiers in Energy*, *6*(2), 184-192.

11. Morren, J., De Haan, S. W., Kling, W. L., & Ferreira, J. A. (2006). Wind turbines emulating inertia and supporting primary frequency control. *Power Systems, IEEE Transactions on*, *21*(1), 433-434.

12. Mauricio, J. M., Marano, A., Gómez-Expósito, A., & Ramos, J. L. M. (2009). Frequency regulation contribution through variable-speed wind energy conversion systems. *Power Systems, IEEE Transactions on*, *24*(1), 173-180.

13. Mirjalili, S. (2015). Dragonfly algorithm: a new meta-heuristic optimization technique for solving single-objective, discrete, and multi-objective problems. *Neural Computing and Applications*, 1-21