Frequency Regulation in Multi Area Power System Optimized By Firefly Swarm Hybridization Algorithm

P.Venkatesh, S.Upender Rao, T.Suneel

Abstract: Automatic Generation Control of two area multi unit interconnected thermal power system with dynamic participation of Doubly Fed Induction Generator based on the wind turbines. In this work two areas consisting of three unequal turbines both areas are connected to the DFIG based wind turbine. Area 1 consisting of three reheat turbines with Doubly Fed Induction Generator based on wind turbine and area2 consisting of three non reheat turbines with Doubly Fed Induction Generator based on wind turbine and two areas interconnected by tie line. Two different controllers are used, namely PID and cascaded PD-PI controllers. The controllers effectively tuned by hybridization algorithm. 1% step load disturbance is applied in area 1 for analyzing the dynamic performance. The performance of two area multi-unit power system is done in MATLAB/SIMULINK software. The dynamic response of the considered system is compared in terms of undershoots, overshoot and settling times.

Keywords: Automatic Generation Control (AGC); Proportional Integral Derivative (PID) and cascaded PD-PI controllers; Doubly Fed Induction Generator based wind turbine (DFIG).

I. INTRODUCTION

Two areas 1 and 2 interconnected by a tie line. The main objectives of AGC are to maintain zero steady state error in frequency deviation and tie line power deviation. There are many control techniques are used to maintain constant frequency. Area 1 and area 2 are connected by the DFIG with turbine. In this paper wind energy is also considered. Now a day’s most of the electrical power is generated using DFIG wind turbines. DFIG is to control the active and reactive power required system operation.

In the literature survey several optimization techniques and control strategies have been proposed in the field of LFC. In LFC of single area thermal power system controlled by the PID and integral controller and optimized by PSO optimization technique [2]. Liner Quadratic Regulator using load frequency control [3]. Two area two units interconnected power system controlled by PID controller and optimized by DEPSO [4]. AGC interconnected power system controlled by cascaded PD-PID controller optimization technique is GWO [5]. Optimized by DE algorithm [6].

Five areas interconnected power system using Firefly algorithm [7]. Interconnected power system and each area attached to PEV using TLBO optimization technique [8].

Automatic generation control of both areas are fixed to DFIG wind turbine controlled by integral controller [9]. Interconnected thermal power system controlled by PID controller by TLBO optimization[10]. Active frequency control by PD-PI controller using TLBO algorithm [11]. Single area controlled by PD-PI controller by using GWO [12].

To Minimize the ITAE function in area1, applied 1% step load distribution. Both areas are connected to the DFIG wind turbine. Speed controller of different penetration levels are 5%, 20% and 50% and it is observed that lower wind penetration improves steady state performance. The performance of the PID controller and PD-PI controller is studied for different penetration levels. Lower penetrations are best performance as compared to higher penetration levels.

Area1 consists of three reheat turbine units and area2 consists of three non reheat turbine units. Hybridization algorithm is implemented for PID and cascaded PD-PI controllers and to know the optimum values of the controllers. Area participation factors are area1 are a11+a12+a13=1 and area2 are a14+a15+a16=1. Each unit participation factor taken as 0.33.

\[
ACE1 = \Delta P_{12} + B_1 \Delta f_1 \tag{1}
\]

\[
ACE2 = \Delta P_{21} + B_2 \Delta f_2 \tag{2}
\]

Where \(\Delta P_{12}\) and \(\Delta P_{21}\) are represents deviation of tie line powers. Two areas connected to wind DFIG. DFIG generate the electrical power in large wind turbine. Wind energy do not participate frequency control because added to doubly fed induction generator is constant output voltage and constant frequency. Two controllers are implemented to thermal power system.

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II POWER SYSTEM INVESTIGATED

A. Power system network used in this work

![Fig.1 Two area three unit thermal power system](image1)

B. Structure of controllers

PID controllers are used in many control applications. PID controllers are used to reduce the overshoot time, undershoot time and settling time are taken less time but PID controllers not satisfactory input signal contains noise and unwanted harmonics. Cascaded PD-PI controller gives better transient response with less settling time. It is combination of two controllers which takes single input and produces single output value. Cascaded PD-PI controller reduces the over shoot, undershoot time and settling time. Cascaded PD-PI controller structure shown in figure 2.

![Fig.2 Cascaded controller of PD-PI](image2)

III MODELLING OF DFIG WIND TURBINE

In general wind energy does not participate in frequency control. So as to maintain the constant frequency DFIG is added to the AGC. DFIG is used to active power to be controlled required by the system operations. DFIG wind turbine active frequency control shown in figure [3]. Additional control signals are considered ΔP'f is a wind power set point based on the frequency, it produces maximum power.

![DFIG wind turbine](image3)

IV. HYBRIDIZATION OF PSO AND FA (HPSOFA)

Firefly to another firefly is calculated as shown in Eq.3.

\[ r_{ab} = \sqrt{\sum_{k=1}^{n} (x_{a,k} - x_{b,k})^2} \]  

When ever light intensity Firefly a is less than the firefly b then a is moved towards b, then update the particle position using Eq.4.

\[ x_a = x_a + \left[ \beta \left( r \right) \right] (x_b - x_a) + \alpha (\text{rand}) \]  

Problems in the firefly algorithm overcome with the hybridization of FA with PSO. The velocity equation in PSO is modified by replacing acceleration constants with FA parameters.

\[ V_{i+1} = wV_{i} + \beta_0 e^{-\gamma r} \left( P_{best} - Z_i \right) + \alpha \left( \text{rand} - \frac{1}{2} \right) \left( G_{best} - Z_i \right) \]  

V ANALYSIS OF RESULTS

Hybridization algorithm used to tune the gains of PID and cascaded PD-PI controllers by considering the ITAE as objective function. The performance of the considered system is analyzed using PID and PD-PI controllers. Frequency deflection in area 1 without DFIG wind turbine are fig. 4 and frequency deflection in area 2 without DFIG wind turbine are shown in fig. 5. Tie line deviation without DFIG wind turbine shown in fig. 6.

\[ \text{ITAE} = \int_0^t \left( |\Delta f_1| + |\Delta f_2| + |\Delta P_{tie}| \right) dt \]  

Two area three units interconnected thermal power system with DFIG wind turbine, both areas connected to the DFIG wind turbine. Three levels of wind penetration i.e. 5%, 20% and 50% are taken into the consideration. It is observed that the lower wind penetration levels shows less settling time and improves the performance. Three levels of wind penetrations applied for both controllers i.e. PID and cascaded PD-PI controllers. Deviation in area 1 with DFIG wind turbine shown in fig. 7 and area 2 fig. 8 and tie line fig. 9 for PID controllers. Cascaded PD-PI controller frequency deviation in area 1 with wind turbine shown in fig. 10, and area 2 shown in fig. 11, and tie line power shown in fig. 13. The wind penetration values are shown in table4 [9].
A. Frequency deviation with DFIG wind turbine with PID controller.

Fig. 4. Frequency deviation in area 1 without DFIG

Fig. 5. Frequency deviation in area 2 without DFIG

Fig. 6. Tie line power deviation without DFIG

Table 1. Peak overshoots ($O_{1b}$), Peak undershoots ($U_{1b}$), and Settling time ($T_s$) of different controllers

| Percentage | $U_{1b}$ | $O_{1b}$ | $T_s$ |
|------------|---------|---------|------|
| 5%         | -0.01444| 0.0005  | 8.68 |
| 20%        | -0.0017 | 0.0145  | 8.39 |
| 50%        | -0.0146 | -0.0078 | 8.95 |

Fig. 7. Frequency in area 1 with DFIG wind turbine

Fig. 8. Frequency deviation in area 2 with DFIG wind turbine

Fig. 9. Tie line power deviation with DFIG wind turbine

Table 2. Peak undershoots ($U_{ab}$), Peak overshoots ($O_{ab}$), and Settling time ($T_s$).

| Percentage | $U_{ab}$ | $O_{ab}$ | $T_s$ |
|------------|---------|---------|------|
| 5%         | -0.01444| -0.00078| -0.011|
| 20%        | -0.0017 | -0.00719| -0.0110|
| 50%        | -0.0146 | -0.0072 | -0.0112|
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B. Frequency deviation with DFIG wind turbine with cascaded PD-PI controller.

Table 3. Under shoot ($U_{sh}$), Peak over shoot ($O_{sh}$), and Settling time ($T_s$). For cascaded PD-PI controller.

| Percentage | $U_{sh}$ | $O_{sh}$ | $T_s$ |
|------------|----------|----------|-------|
| 5%         | -0.0070  | 0.00012  | 9.7   |
| 20%        | -0.0074  | 0.00012  | 9.8   |
| 50%        | -0.0073  | 0.00012  | 9.8   |

Table 4. Optimum values of speed controller for different DFIG wind turbine penetrations levels.

| Wind penetration | $K_{opt}$ | $K_{opt1}$ | $K_{opt2}$ | $K_{opt3}$ |
|------------------|-----------|------------|------------|------------|
| 5%               | 1.2       | 0.1        | 1          | 0.1        |
| 20%              | 2         | 0.3        | 1.98       | 0.1        |
| 50%              | 1.7       | 0.2        | 0.1        | 1.0        |

Table 5. Optimum gain values of PID controller tuned by Hybridization algorithm.

| PID controller | Area1 | Area2 |
|----------------|-------|-------|
| $K_p$          | 3.7689| 3.8548|
| $K_i$          | 2.3458| 3.8628|
| $K_d$          | 1.8773| 2.9586|

Table 6. Optimum gain values of cascaded PD-PI tuned by hybridization algorithm.

| PI-PD controller | Area1  | Area2  |
|------------------|--------|--------|
| $K_p$            | 1.7156 | 0.5565 |
| $K_i$            | 1.9989 | 1.9998 |
| $K_d$            | 1.7656 | 1.9669 |

VI CONCLUSION

The dynamic performance of AGC has been carried out for two-area multi-unit interconnected power system with DFIG. Area1 consists of three reheat turbines and area2 consists of three non-reheat turbine units and both areas interconnected to DFIG wind turbine. 1% step load disturbance is applied in area 1 to study the dynamic performance. Hybridization optimization technique is used for tuning of both controllers. It is observed that Cascaded PD-PI controller is better than PID controller in all aspects. The frequency response is improved by using DFIG wind turbine. The performance of the PID controller and PD-PI controller is also studied for different penetration levels. It is also observed that Lower penetration gives the best performance as compared to higher penetration levels.

APPENDIX I

For thermal power system

| Parameter              | Symbol | Value |
|------------------------|--------|-------|
| Frequency bias factor  | $B$    | 0.4249|
| Governor time constant | $T_G$  | 0.08  |
| Turbine time constant  | $T_F$  | 0.3   |
| Re heat time constant  | $T_R$  | 10    |
| Control area gain      | $K_p$  | 120   |
| Regulation             | $R$    | 2.4   |
| Synchronization time constant | $T$ | 0.0866|
| Re heat gain           | $K_R$  | 0.5   |

APPENDIX I
Area participation factors APF 0.33
Control area time constant \( T_p \) 20

**DFIG wind turbine parameters**

| Parameter                        | Area1 | Area2 | Value |
|----------------------------------|-------|-------|-------|
| Wind turbine inertia             | \( H_{e1} \) | \( H_{e2} \) | 3.5 |
| DFIG proportional controller gain| \( K_{wp1} \) | \( K_{wp2} \) | 1 |
| DFIG turbine                     | \( T_{a1} \) | \( T_{a2} \) | 0.2 |
| Transducer time constant         | \( T_{r1} \) | \( T_{r2} \) | 15 |
| Wash out filter time constant    | \( T_{w1} \) | \( T_{w2} \) | 6 |
| Regulation                       | \( R_1 \) | \( R_2 \) | 2.4 |

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