Electrical Power and Energy Systems 84 (2017) 135–142

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Pattern search algorithm based automatic online parameter estimation for AGC with effects of wind power

L.V. Suresh Kumar [a,*], G.V. Nagesh Kumar [b], Sreedhar Madichetty [c]

[a] GMRIT, Rajam, India
[b] GITAM University, India
[c] BITS Pilani, India

ARTICLE INFO

Article history:
Received 30 March 2016
Received in revised form 12 May 2016
Accepted 16 May 2016

Keywords:
Automatic Generation Control
IEEE 39 Bus System
Impact of wind energy
Parameter estimation
Power System

ABSTRACT

The increasing portion of wind energy in the power system puts forward stability challenges to the power grid. With introduction of wind generating systems, maintaining constant frequency became one of the important problems taking stability into account. The system could be maintained with constant frequency with the help of controllers. The controller gains are usually designed with fixed values for various scenarios of power system which considerably vague due to existing system complexity. Also, the usage of conventional techniques consumes a lot of computational time and does not possesses accurate control gain parameters. To address the aforementioned challenges, an automatic online gain estimation algorithm by using pattern search optimization technique has been proposed in this article. This method computes the parameters on its own based on variable wind power output and controller gains will adjust automatically to achieve the best desired performance. The proposed method was tested in a modified IEEE 39 bus system for scenarios like system with 3% and 10% GRC (Generator Rate Constraint) with 10% and 20% SLP (Step Load Perturbation). Following that the system with proposed method was investigated with variable wind power and results demonstrate significant better results which comply with IEEE standards.

Introduction

ENERGY has become the basic necessity. Generation in large interconnected power system comprises thermal, hydro, nuclear gas, wind, Photo Voltaic (PV) and biomass power generation. Generally, thermal power generating stations, for instance nuclear power stations are kept at base load due to their maximum output and high efficiency. However, these plants will not participate usually in Automatic Generation Control (AGC) of the system. Whereas other generating units can participate in AGC. Now-a-days, wind and solar energy plays a significant role in large interconnected power system. The energy derived from wind turbine and PV system are uncertain and comparatively low as well. The continuously increased penetration of Renewable Energy Sources (RES) increases the risk of tie line power damping oscillations, frequency changes and harmonic currents. This ultimately leads to abnormal behavior in power systems. It can affect the technical performance especially during abnormal condition which is a threat to power system. Hence there is a need to develop robust power system frequency and damping controllers with the penetration of wind power into the power system.

AGC is very significant control processes that can operate continually between generated power and load consumption in a power system at mitigated cost. Hence it is responsible for power interchange through the tie lines, frequency control for individual control areas and economic dispatch as usual. In literature there were many techniques have been applied to solve AGC problem. But, with the increased penetration of wind energy into the grid poses new technical challenges in maintaining of system stability. Basically these stability problems has been formulated to reduce the power frequency deviation and steady state error. Many control strategies are applied to AGC for instance, such as classic/conventional proportional integral (PI) and proportional integral and differential (PID) controllers have been applied. These controller gains can be tuned by using various conventional and intelligent approaches. However application of these approaches may consume time or may applicable to specific load disturbances. A distributed AGC problem with high wind energy penetration has been investigated in [1]. It has applied through flatness based approach, where *n*-linear control systems can be decoupled. Various test cases has been performed and results were promising. However, the steady state frequency deviation reached at long

* Corresponding author at: EEE Department GMRIT, Rajam, Srikakulam, Andhra Pradesh 532127, India. Tel.: +91 9000799361.

E-mail address: lvenkatasureshkumar@gmail.com (L.V. Suresh Kumar).

http://dx.doi.org/10.1016/j.ijepes.2016.05.009
0142-0615/

Nomenclature

f	system frequency	T	sampling time period
P_{ri}	rated power in area i	ACE	area control error
H_i	inertia constant for generator i	$V_m(t)$	wind speed
ΔP_{Di}	change in load in area i	$V_e(t)$	wind speed error at time t
ΔP_{gi}	change in generation in area i	N	normal distribution
R_i	governor speed regulation parameter	P_t	mechanical output power of wind turbine
T_{gi}	steam turbine governor time constant of area i	ρ	air density
k_r	steam turbine reheat constant	λ	tip speed ratio
T_{ri}	steam turbine reheat time constant of area i	ΔP_{tiei}	change in tie line power flow for area i
T_{ti}	steam turbine time constant of area i	$\Delta\omega_i$	change in angular frequency deviation for area i (i = 1,2,3...n)
B_i	frequency bias constant	s	differential operator
K_{ii}	integral gain constant for area i	T_e	electromagnetic torque
K_{pii}	proportional gain constant for area i	T_m	mechanical power change
β_i	area frequency response characteristics	L_m, L_s, L_r	magnetizing, self and rotor inductance
J	cost index		

interval of time. Which may not be practically acceptable. The wind turbine system with Maximum Power Point Tracking (MPPT) algorithm has been modeled in [2]. A new model predictive control technique has been applied to AGC in [3] and found many fascinating results comparable with conventional controllers. A complete review of load frequency controlling mechanisms has been given [4]. It provides a comprehensive review about AGC mechanism with various optimization techniques. A double fed induction generator (DFIG) with MPPT technique has been applied in [5,6]. Various optimization techniques has been applied in literature which includes Particle Swarm Optimization, Bacteria Foraging Optimization Techniques for multi area power generating systems can be found in [7–13]. For faster and accurate the response, a new algorithm has been applied and named as Automatic Gain Tuning Algorithm (AGTA). This AGTA works with higher safety control loops based on pattern search optimization technique. The proposed algorithm is tested on an IEEE-39 bus system and results has been explored.

The significant contribution of proposed work is as follows

- A new pattern search algorithm has been applied for online control parameters estimation in IEEE-39 bus system with 10 reheat steam turbine system generators in three control areas and three wind generators in respective control areas.
- This algorithm is automatically computes the control parameters for various loading conditions and various wind effects of wind energy system.
- Small signal model of wind energy system has been modeled in conjunction with the standard bus system.
- Different case studies and test cases has been performed; which includes various Step Load Perturbance (SLP-10% and 20%), Generator Rate Constraints (GRC-3% and 10%).
- All the obtained gains has been listed in the form of a figure and prospective results has been explored and compared with conventional techniques.

This article is comprised with the five sections. In section 'Introduction', introduction and past literature work has been reviewed. Modeling of thermal reheat turbine systems and wind energy systems has been discussed in section 'Modeling of proposed systems'. Application of proposed algorithm has been kept forward in section 'Application of pattern search algorithm'. Two case studies on IEEE-39 bus system has been investigated and its results have been explored in section 'Simulation results' and finally section 'Conclusion' is comprised with the conclusion.

Modeling of proposed systems

In this section, interconnected thermal reheat turbine systems and wind turbine system has been modeled. The term control area is used for the analysis of the AGC system. The control area is defined as, the area consisting of group of generators and loads, where all units responds unison for changes in the load. All these control areas are interconnected by the tie lines. The scheme of interconnection for the case study has been shown in Fig. 1 and its standard bus system is shown in Fig. 4a. Each generating system consists of a GRC's, governor dead band, and time delays. Due to presence of these items, system became highly nonlinear. One of the important parameters, that is used in the system areas are speed regulation parameter (R). It is defined as the ration of speed change to the output generated i.e. $R = \frac{\Delta f}{\Delta P_g}$. The generator load relationship between the incremental power mismatch and change in frequency can be written as

$$\Delta P_g(t) - \Delta P_L(t) = 2H \cdot \frac{d\Delta f(t)}{dt} + D \cdot \Delta f(t) \tag{1}$$

If we write the above equation in Laplace transform, then we can yield the following equation

$$\Delta P_g(s) - \Delta P_L(s) = 2H \cdot s \cdot \Delta f(s) + D \cdot \Delta f(s) \tag{2}$$

And the tie line power could be written as

$$\Delta P_{tie,i} = \sum_{\substack{j=1 \\ j\neq i}}^{N} \Delta P_{tie,ij} = \frac{2\pi}{s}\left[\sum_{\substack{j=1 \\ j\neq i}}^{N} T_{ij}\Delta f_i - \sum_{\substack{j=1 \\ j\neq i}}^{N} T_{ij}\Delta f_j\right] \tag{3}$$

where T_{ij} is the synchronizing torque between i and j. The area control error can be calculated as

$$\text{ACE}_i = \Delta P_{tie,i} + \beta_i \Delta f_i \tag{4}$$

where β_i is the bias factor

$$\beta_i = \frac{1}{R_i} + D_i \tag{5}$$

The resulted signal from ACE is given to the proposed dynamic controller. Where the α_{ki} is the participation factor.

$$\sum_{k=1}^{n} \alpha_{ki} = 1; 0 \leqslant k_i \leqslant 1 \tag{6}$$

Also, it considers the important physical parameter constraints i.e. rate of change of power generation due to its limitation of