Available online at www.sciencedirect.com
ScienceDirect
Journal of the Franklin Institute 00 (2017) 1–21
www.elsevier.com/locate/jfranklin

An optimization methodology of susceptance variation using lead-lag controller for grid connected FSIG based wind generator system

Ashik Ahmed, Md. Mehedi Hassan Galib*, Shafi Md. Kawsar Zaman, Golam Sarowar

Department of Electrical and Electronic Engineering, Islamic University of Technology, A Subsidiary Organ of Organization of Islamic Cooperation, Board Bazar, Gazipur 1704, Bangladesh

Received 5 May 2017; received in revised form 25 September 2017; accepted 17 November 2017
Available online 5 December 2017

Abstract

In wind power system, low frequency oscillations are observed due to imbalance between mechanical input and electrical output. Hence, variable susceptance controllers are being adopted to mitigate these oscillations. However, improper modulation of control parameters also leads to system instability. Therefore, we propose an optimization methodology for mitigating low frequency oscillations in wind power generation system. To visualize our methodology, we use a lead-lag type variable susceptance controller for *fixed speed induction generator* (FSIG) based wind generation system. Then, we optimize gain and time constants of lead-lag controller using three optimization algorithms: *particle swarm optimization* (PSO), *genetic algorithm* (GA), and *flower pollination algorithm* (FPA). Later, we perform non-linear time domain simulation and quantitative analysis to find average fitness, standard deviation, run time, and iteration number for these optimization algorithms. Moreover, non-parametric statistical analysis, such as Kolmogorov–Smirnov and Wilcoxon signed-rank tests are employed for identifying statistically significant differences among these algorithms.

* Corresponding author.
E-mail address: galib2091@iut-dhaka.edu (Md.M.H. Galib).

https://doi.org/10.1016/j.jfranklin.2017.11.013
0016-0032/

1. Introduction

Since efforts are being made to generate electricity from clean, green, and environment friendly energy sources; renewable sources such as wind, small hydro, solar, tidal, geothermal, and waste are gaining more popularity with time [1,2]. Among these clean energy sources, wind seems to be more prominent technology considering following facts: its development in last decade [3], available abundantly all the time (unlike solar, tidal, geothermal and waste) [1], zero carbon emission [4], and also zero fuel cost [5]. Now, this wind energy is first converted to mechanical energy by a wind turbine, and then to electrical energy by a suitable generator (such as synchronous, induction) [6]. However, wind power is unpredictable, means its speed varies with time, and hence, due to the imbalance between mechanical input and electrical output, low frequency oscillations may occur and hinder stability of the power grid [7] if not properly damped.

To mitigate these oscillations, several types of control mechanisms are adopted such as *proportional integral derivative* (PID), fuzzy based controller/neural network based controller, robust controller, predictive controller, and lead-lag based controller. PID controller, reported in [8], has only one optimization algorithm to tune its parameters without presenting any comparative study with other optimization algorithms. Also in reference [9], application of PSO technique for wide-area oscillation control using *proportional integral* (PI) controller is shown, however, results are not compared with any other standard optimization techniques. In case of fuzzy based [10] and neural network based [11] controllers, actual dynamic model is not considered. Rather, a data-driven model is generated, which may degrade controller performance due to lack of accurate training. Hence, even with the slightest variation in the data, controller does not show acceptable response. Advanced control techniques, such as robust control and predictive control are much more mathematically involved and their implementation in practical field are cumbersome [12]. On the other hand, lead-lag controller is comparatively simpler in structure and unlike neural network based controller, it can deal with actual dynamic model [13].

Although lead-lag controller is effectively employed in many control applications, its usage is hardly found in susceptance variation for mitigation of oscillations in wind power generation system. Variation of susceptance at machine terminal modulates the flow of power balance between electrical and mechanical subsystems [14]. Moreover, improper modulation resulting from inappropriate tuning of controller parameters also leads to unstable system dynamics [15,16]. Hence, a methodology is proposed to optimize controller parameters to ensure system stability through proper modulation of susceptance. The contribution of this paper can be summarized as follows:

- To start our methodology, we need to derive a *dynamic algebraic equation* (DAE) model of wind energy system. We build our system matrix using fourth order dynamic model of generator, lumped-mass drive train model, and algebraic model for mechanical input power to turbine, electrical output power of generator, and transmission system. Then, we analyze system stability without controller through eigenvalue and participation factor analyses.
- We use a lead-lag type controller for varying susceptance at generator terminal. Parameters of this lead-lag controller are tuned using three different optimization algorithms: namely, PSO, GA, and FPA. The optimization of controller is performed based on minimization of an eigenvalue based objective function. Later, quantitative comparison is conducted based on iteration number, fitness value, and elapsed time between these three optimization