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Real power and frequency control of a small isolated power system

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ABSTRACT

This paper describes the dynamic analysis of a small isolated power system comprising a wind turbine generator and a diesel generator. The analysis is carried out in time domain considering simplified models of the system components by taking into account the wind turbine pitch controller and the diesel engine speed governor. Wind disturbance model consisting components of gusting of wind, rapid ramp changes and random noise. The wind generator is always operated with its rated power and the additional power required by the load is supplied by the diesel generator. For better dynamic performances of wind–diesel system under wind and load disturbance conditions, two control schemes are used. In the first case, a proportional–integral (P–I) controller and in the second case a proportional–integral–derivative (P–I–D) controller are used. Gain parameters of these controllers are optimized using genetic algorithm (GA) and Particle swarm optimization (PSO) considering two different objective functions and the results are compared. The sensitivity analysis of the wind diesel system is carried out for parameter uncertainties and the stability of the system is analyzed using D-stability criterion. Analysis is also carried out to examine the effect of power injection to a 69 bus radial distribution network by wind–diesel isolated system.

Introduction

With the rapid depletion of fossile fuels the role of renewable energy resources is increasing in the current world energy scenario. Wind power generation is most economical compared to other nonconventional energy resources. Wind turbine generators (WTG's) are mainly suitable for isolated loads where the power transmission is a major problem. In remote areas generally electrical energy has been supplied by diesel generators. The wind–diesel isolated power system is most popular for remote areas. Diesel generator functions as a backup source to compensate the power supply variations due to wind speed fluctuations. High power fluctuations results at the output of wind turbines due to sudden changes in load and abnormal wind speed variations and they should be minimized. A number of conventional methods such as state space method, optimal control and robust control are found in the literature to control WTG output power. The objective is to achieve good dynamic performance of WTG output power under wind and load disturbance conditions. Scott et al. [1] have studied the dynamic behavior of an autonomous system comprising of diesel generator and wind turbine generators. Their analysis reveals that the change in control system settings can improve the damping. Kamwa [2] studied the dynamic modeling and performance of wind–diesel systems by applying a programmable smoothing-load and using a standard PID regulator installed on the diesel unit. Tripathy et al. [3] have used magnetic energy storage unit to minimize the power and frequency deviations under load disturbance conditions in the isolated wind–diesel power system. Kariniotakis and Stavrakakis [4,5] have studied the autonomous wind–diesel system under various scenarios. They have presented the mathematical model as well as implementation of their algorithm. Das et al. [6] have studied the dynamic performance of an isolated wind–diesel hybrid power system. Chedid et al. [7] have used fuzzy logic controller for an isolated wind–diesel hybrid power system. However fuzzy logic controller for such system depends extensively on heuristic knowledge. Papathanassiou and Papadopoulos [8] have integrated the analysis of main modes of the wind–diesel hybrid system and the parameters of the controllers. Above literature review shows that the dynamic behavior of wind–diesel power system has been the subject of many researchers [1–8] dealing with small autonomous installation but most of the literatures mentioned above did not consider the details of modeling of wind speed and power [2,3,6–8].

Previous researchers have also not made any attempt to optimize the gain parameters of the controller to improve the dynamic performances of the wind–diesel system to withstand wind disturbance. In addition to that they have not studied the

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Nomenclature

C_p	coefficient of wind turbine power
$MGWS$	maximum gust wind speed (m/s)
$MRWS$	maximum ramp wind speed (m/s)
ω_B	angular velocity of blade (mech rad/s)
γ	tip speed ratio (m/rad)
β	blade pitch angle (degrees)
P_{max}	wind turbine generator setpoint
P_{wtg}	wind turbine generator power (kW)
P_w	mechanical power of wind turbines (kW).
V_w	total wind velocity (m/s)
V_{WB}	constant wind component (m/s)
V_{WG}	wind component of gust disturbance(m/s)
V_{WR}	wind component ramp disturbance (m/s)
V_{WN}	wind component of random noise (m/s)
T_{gust_1}	gust starting time (s)
T_{gust}	gust period (s)
T_{ramp_1}	ramp start time (s)
T_{ramp_2}	ramp maximum time (s)
T_d	time delay
c_1, c_2	acceleration of the swarm
r_1, r_2	random numbers in between 0 and 1
x_i^k	position of ith particle at kth iteration
x_i^{k+1}	position of ith particle at $(k+1)$th iteration
v_i^k	velocity of ith particle at kth iteration
v_i^{k+1}	velocity of ith particle at $(k+1)$th iteration
$pbest_i^k$	best position of ith particle
$gbest^k$	best position of the swarm
w^k	inertia weight of kth iteration
w_{max}	maximum value of the inertia
w_{min}	minimum value of the inertia
$iter_k$	value of the kth iteration
$iter_{max}$	value of the maximum iteration
IT	generation number
ITMAX	maximum number of generations

effect of power injection by wind–diesel system into a distribution network.

In power systems P–I–D controller is generally used in the design of power system stabilizers and load frequency control applications to improve the dynamic responses of the system [9–12]. In this paper, two control schemes are used to control the blade pitch angle of the wind turbine generator for obtaining the better dynamic performances of wind–diesel hybrid system under wind disturbance conditions. The first controller is a proportional–integral (P–I) controller and second one is proportional–integral–derivative (P–I–D) controller. Gain parameters of these two controllers are optimized using genetic algorithm (GA) and Particle swarm optimization (PSO) considering the two different objective functions. The sensitivity analysis and stability analysis of wind diesel system are studied to test the robustness of the closed loop system for parameter variations. Finally, the power injection by the wind diesel system into 69 node distribution network is also examined.

Modeling of wind speed and power

Model of wind speed

A wind disturbance model is considered to study the dynamic performance of wind–diesel system. The wind disturbance is modeled considering the sum of base wind, gusting, ramp, and random noise. The generated power of the wind turbine generator depends on wind speed (V_W). The mathematical model for different wind speed components are discussed below in detail [13].

The four component wind model is described by using the following equation:

$$V_W = V_{WB} + V_{WG} + V_{WR} + V_{WN} \tag{1}$$

The base wind mathematical model is expressed by

$$V_{WB} = K_B \tag{2}$$

where K_B is a constant and this component of wind is constant component present in the model of wind speed.

The gust wind mathematical model is expressed by

$$V_{WG} = \begin{cases} 0 & \text{for } t < T_{gust_1} \\ V_{cos} & \text{for } T_{gust_1} < t < T_{gust_1} + T_{gust} \\ 0 & \text{for } t > T_{gust_1} + T_{gust} \end{cases} \tag{3}$$

where 't' is time in seconds and,

$$V_{COS} = (MGWS/2)(1 - cos(2\pi[(t/T_{gust}) - (T_{gust_1}/T_{gust})])) \tag{4}$$

The ramp wind mathematical model is expressed by

$$V_{WR} = \begin{cases} 0 & \text{for } t < T_{ramp_1} \\ V_{ramp} & \text{for } T_{ramp_1} < t < T_{ramp_2} \\ 0 & \text{for } t > T_{ramp_2} \end{cases} \tag{5}$$

where

$$V_{ramp} = MRWS(1 - (t - T_{ramp_2})/(T_{ramp_1} - T_{ramp_2})) \tag{6}$$

where $T_{ramp_2} > T_{ramp_1}$. This equation can be approximated to a step change by minimizing the difference between T_{ramp_2} and T_{ramp_1}.

The noise wind model is expressed by

$$V_{WN} = 2\sum_{i=1}^{N}[S_V(\Omega_i)\Delta\Omega]^{1/2} cos(\Omega_i t + \phi_i) \tag{7}$$

where

$$\Omega_i = (i - 1/2)\Delta\Omega \tag{8}$$

ϕ_i = a random variable with uniform probability density on the interval 0–2π and $S_V(\Omega_i)$ is the spectral density function defined as

$$S_V(\Omega_i) = \frac{2K_N F^2|\Omega_i|}{\pi^2[1 + (F\Omega_i/\mu\pi)^2]^{4/3}} \tag{9}$$

where

K_N = surface drag coefficient = 0.004
F = turbulence scale = 2000 m
Ω_i = ith frequency component of random noise
μ = mean speed of wind = 7.5 m/s

Here N is considered as 50.

The four components together are considered for analyzing the dynamics of the wind–diesel hybrid system.

Wind generator output power

The wind turbine generator characterized by the power coefficient C_p and wind velocity. The power coefficient C_p is again characterized by tip speed ratio and blade pitch angle. The wind blade dynamics are approximated by the following non linear functions.