International Journal of Research in Engineering, Science and Management
Volume-2, Issue-1, January-2019
www.ijresm.com | ISSN (Online): 2581-5792

Design of Robust Controller for Load Frequency Control in Isolated Microgrid Power System

R. Raghuraman
Assistant Professor, Department of EEE, C.K College of Engg. & Tech., Cuddalore, India

***Abstract*: The intermittent output power of renewable energy may cause series problem of frequency and voltage fluctuation of the grid. To overcome this problem, an energy storage such as battery, SMES can be employed. As energy storage is expensive for developing countries, they prefer cheaper technologies to suppress the frequency oscillation. In this paper robust PI controllable load is designed to stabilize the frequency fluctuation in a remote micro grid power system. To provide robustness of proposed PI controller genetic algorithm is employed to tune and optimize the PI controller parameters. The performance and robustness of the proposed robust PI controllable load on remote hybrid wind diesel power system for various disturbances are analyzed using simulation studies.**

***Keywords*: Integral square error (ISE), Genetic Algorithm (GA), PI Controller, hybrid power system**

1. Introduction

There has been a continuous enhancement of power generation from renewable energy sources in recent years in developing countries. The increasing demand of electricity due to development at a faster rate further widens the gap between supply and demand. Hence, it is becoming difficult to fulfill the increasing demand of electricity only with conventional sources. The main advantages of renewable energy sources of power generation are no fuel consumption in most cases, sustainable and eco-friendly, but suffer from the disadvantage of their fluctuating nature. The renewable energy sources such as wind, solar and micro/mini hydro etc. are generally integrated with diesel system to supply reliable power to isolated loads [1]. The diesel generator with synchronous generators and renewable sources are operated in parallel to meet load demand through a small distribution network. There are many remote and isolated places in the world, which are still without electrical power and low generation capacity of the grid connected systems, especially in developing countries. The mismatch between supply and demand can be minimized if some of the locations have standalone power systems to meet local load requirements [2]. Moreover, wind power is expected to be economically attractive when the wind speed of the proposed site is considerable for electrical generation and electric energy is not easily available from the grid [3]. This situation is usually found on islands and/or in remote localities. In most remote and isolated areas, electric power is often supplied to the local communities by diesel generators. Due to the environmental and economic impacts of a diesel generator, interest in alternative cost efficient and pollution free energy generation has grown enormously [4]. To reduce dependence of fuel for electric power generation, an appropriate power generation technology is required in conjunction with the diesel based system [5]. By virtue of geographical location, renewable energy sources like wind; small hydro streams etc. are available in abundance in most areas of the world. There has been a considerable advancement in the wind turbine and micro hydro technology for power generation. The alternate renewable energy in parallel operation with diesel based systems forms a suitable power generation system which may be economically viable. Such systems are called isolated or stand-alone hybrid power system.

2. Modelling of isolated hybrid power system

A. *Load frequency controller*

Load Frequency Control (LFC) is an important issue in power system operation and control. It is implemented to solve the problem which occurs due to sudden small perturbation which is continuously perusable for normal operation of power system. The following basic requirements are to be fulfilled for successful operation of the system.

- The generation must be adequate to meet all the load demands.
- System frequency must be maintained with narrow and rigid limits.

The control strategy evolved here may also result in overall high efficiency (fuel saving) and minimum additional equipment to avoid cost, maintenance etc. The supplementary controller of the diesel generating unit, called the load-frequency controller. The function of the controller is to generate, raise or lower command signals to the speed-gear changer of the diesel engine in the response to the frequency error signal by performing mathematical manipulations of amplification and integration of the signal. The speed-gear changer must not act too fast, as it will cause wear and tear of the engine and, also should not act too slow, as it will deteriorate the system performance. Therefore, an optimum load-frequency controller is required for satisfactory operation of the system. Here a detailed study has been performed for hybrid wind diesel isolated power systems by considering a small signal transfer function model. Optimum selection of the gains of the controllers is obtained using the ISE technique.

B. System modeling

The model considered in this study consists of the following sub-systems:

- Wind dynamics model
- Diesel dynamics model
- Blade pitch control of wind turbine
- Generator dynamics model

The wind model is one feature that is unique to the wind turbine generator and is not required for diesel generator system in the stability program. Anderson et al have presented one model that can properly simulate the effect of wind behavior, including gusting, rapid (ramp) changes and background noise the basic conditions for startup and synchronization are that the wind speed is to be within an acceptable range and there must be a phase match between the generator and system voltage. The diesel dynamics is associated with diesel power and the nature of the dynamic behavior in this model is dominated by diesel speed governor controller. A total power set point is selected in which it can manually adjusted from zero to maximum value. The purpose of the adjustable power set point is to allow system utility personnel to lower the power setting below the maximum setting of the wind generator to prevent controlling diesel from dropping to less than 50% of the rated power. Operation of a diesel engine for extended periods at two power levels could result in possible engine damage. Pitch control has the potential for producing the highest level of interaction because of the presence of diesel and wind turbine control loops. The pitch control system consists of a power measurement transducer, a manual power set point control, a proportional plus integral feedback function, and a hydraulic actuator which varies the pitch of blades Turbine blade pitch control has a significant impact on the dynamic behavior of the system. This type of control only exists in horizontal axis machines. Variable pitch turbines operate efficiently over a wider range of wind speeds than fixed pitch machines. However, cost and complexity are higher. The generator dynamics model consists of a synchronous generator driven by a diesel engine through a flywheel and connected in parallel with an induction generator driven by a wind turbine. The diesel generator will act as a dummy grid for the wind generator which is connected in parallel. Variations of electrical power due to changes in wind speed should be as small as possible; this is obtained by using induction generator as a wind turbine drive train. Unlike synchronous generator, induction generator are high compliance couplings between the machine and the electrical system. This is true for induction generators with the slip of at least 1-2% at rated power. The controlled variables are turbine speed and shaft torque. Control acts on the turbine blade pitch angle (pitch control). Since the torque speed characteristic of the induction generator is nearly linear in the operating region, torque changes are reflected as speed changes. Therefore, it is possible to provide a single speed controller to control speed as well as torque. Fig. 1 shows the conceptual model wind-diesel power system.

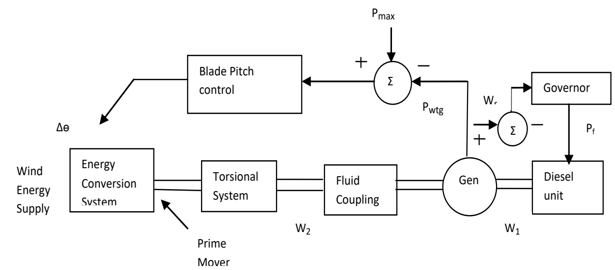

Fig. 1. Conceptual Model of Wind Diesel Power System

1) Transfer function model of governor controller, pitch controller and controllable water heater

The block diagram of governor controller is shown in Fig. 2 and Fig.3.represents the block diagram of pitch control. The governor controller and pitch controller are represented by a simple first order PI controller which uses system frequency deviation and output power of wind power as a feedback input signal, respectively .The water heater block diagram is depicted in Fig.4. The controllable water heater diagram consists of two transfer function i.e. the water heater model and PI based frequency controller. The water heater can be modeled by first-order transfer function. Here the battery controller is presented by 1st order PI controller with single feedback input signal, system frequency deviation and the proposed design approach is applied to design of robust-controllable load.

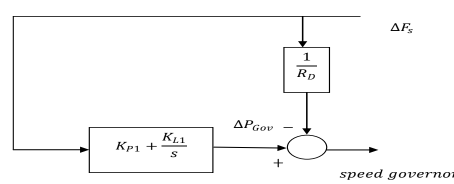

Fig. 2. Block diagram of governor controller

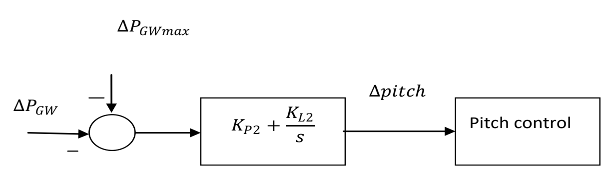

Fig. 3. Block diagram of pitch controller

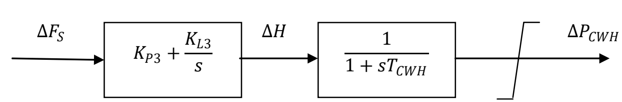

Fig. 4. Block diagram of controllable water heater

2) Transfer function model of isolated wind-diesel hybrid power system

The block diagram representation of isolated wind-diesel hybrid power system with controllable water heater is shown in Fig.5. This model consists of the following subsystem: wind dynamic model, diesel dynamic model. Governor control of diesel side, controllable water heater, pitch control of wind side and power network model.

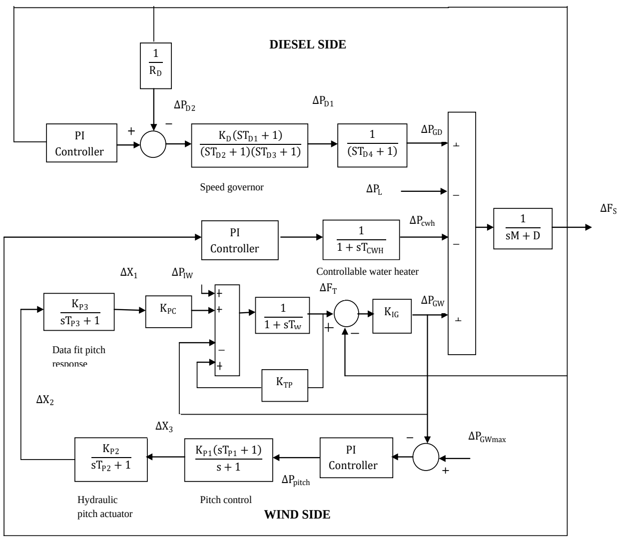

Fig. 5. Transfer function model of wind-diesel hybrid power system with controllable water heater

3. Design of PI controller

A. Design of proportional plus integral controller

In a controller design, the scalar integral square error (ISE) criteria of cost functions, which is proved to be meaningful and convenient measures of dynamic performance and is used to find out the optimum feedback gain for the digital controller. To application of ISE criteria, the performance index J is to be evaluated for several of the gain KI.

The performance index J is

$$J=\int_0^t |\Delta F_S|^2\, dt \quad (1)$$

ΔF_S - System frequency

From the cost curve drawn between K_I and J, the optimal controller gain can easily be determined. The lowest point on the 'U' shaped curve is taken as optimum value of controller gain K_i. The obtained optimal value for Diesel and Wind system are 0.7 and -0.2. The performance index (J) is evaluated for different values of the proportional gain K_p. The lowest point on the 'U' shaped curve is taken as optimum value of controller gain K_P. The obtained optimal value for Diesel and Wind system are 631.7 and 239.9. The optimum value of K_P is kept constant, K_I is varied for different values and the performance index is calculated. From the cost curve is drawn and the minimum value of K_I is computed. The obtained optimal value for Diesel and Wind system are 28.4 and -26. Fig. 6, shows the cost curve of proportional controller for Diesel system and Fig. 7, shows the cost curve of proportional controller for Wind system.

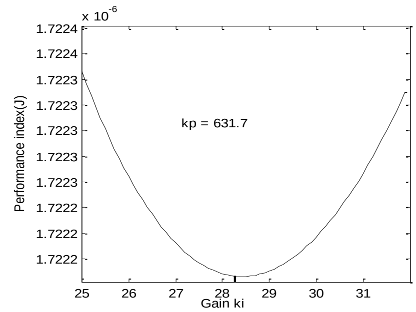

Fig. 6. Cost Curve of Proportional Plus integral Controller for Diesel system

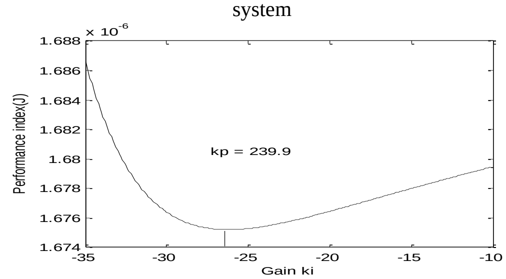

Fig. 7. Cost Curve of Proportional Plus integral Controller for Diesel system

B. PI parameters obtained by GA

Table 1
GA parameters

Number of parameters	2
Total String length	16
Population Size	10
Maximum Generation	50
Cross Over Probability	0.9
Mutation Probability	0.01

Table 2
PI parameters obtained by using GA

K_P	203.449
K_I	0.8548

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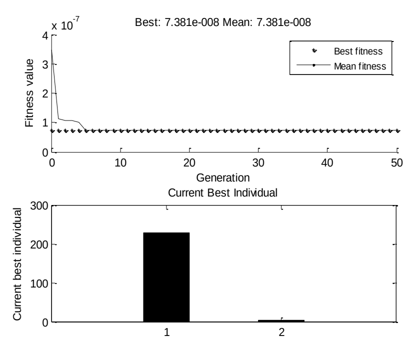

Fig. 8. Graphical representation of Best fitness and Best individual of PI controller by GA

To optimize the controllable water heater the ranges of search parameters are set as follows: KPmin and KPmax are minimum and maximum gains of water heater controller are set as 1 and

300, KLmin and KLmax are minimum and maximum integral parameter of water heater load controller are set as 0.01 and 40. The bounds of Kp and Ki are obtained based on the maximum KP and Ki of pitch and governor controllers. Then the optimization is solved by Genetic algorithm. The parameter of GA is shown in Table 1 and the obtained PI parameters are given in Table 2. Fig. 8 shows the best fitness and best individual of the PI parameter obtained using GA

4. Simulation results and discussion.

The parameter used for modeling is given in the Appendix-I. The Simulink diagram of isolated wind-diesel hybrid power system is shown in Fig. 9. The controller gain settings are provided as obtained in the Table 2.

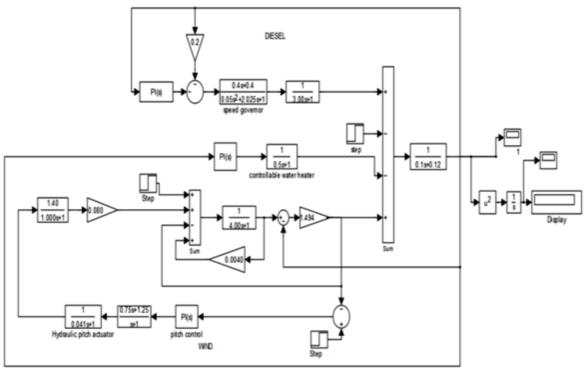

Fig. 9. Simulink model of isolated wind-diesel hybrid power system with controllable water heater

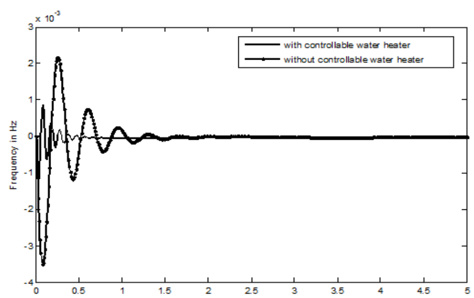

Fig. 10. Frequency deviation of Wind-Diesel hybrid power system with and without controllable water heater

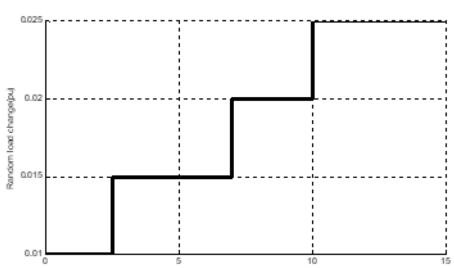

Fig. 11. Random Load power change input pattern

Simulations are carried out for 0.01pu kW step load change in ΔP_L and ΔP_{IW} in two phases. Wind-Diesel hybrid power system with controllable water heater and Wind-Diesel hybrid power system without controllable water heater. The simulation results are superimposed as shown in Fig. 10. It is found that in isolated wind-diesel hybrid power system with controllable water heater improve the system performance and system oscillations are also comparatively small.

To assess the robustness of the proposed controller, the following simulation studies with random load change is carried out. In this case, the system is subjected to the random load change as shown in Fig 11. Simulations are carried out for random load change in ΔP_L for two cases as discussed above and the obtained results shown in Fig 12. This shows that the control effect of wind-diesel hybrid power system with controllable water heater is better than that of without using controllable water heater. The frequency oscillation in the case of using controllable water heater is damped very well.

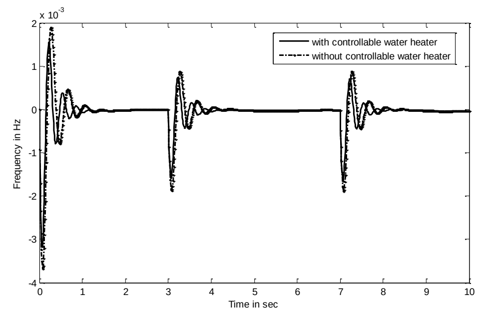

Fig. 12. System frequency deviation against random load power

A. *Sensitivity Analysis*

The performance of the proposed controller has been analyzed under parameter variation. The parameters TD4, TP1, RD, Tw, Tcwh are varied by ±20% from the nominal value one at a time, and simulations are carried out and the results are shown in Fig 13 (a) through (g).

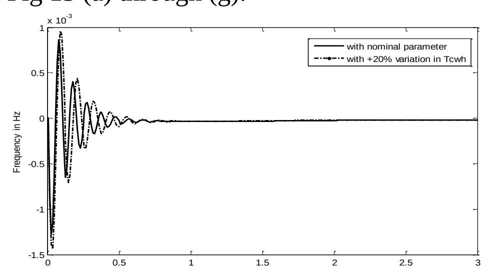

Fig. 13. (a)Wind generator frequency deviation

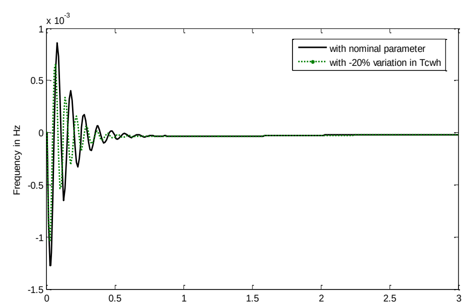

Fig. 13. (b) Wind generator frequency deviation

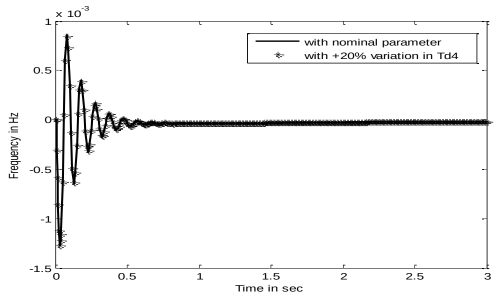

Fig. 13. (c) Wind generator frequency deviation

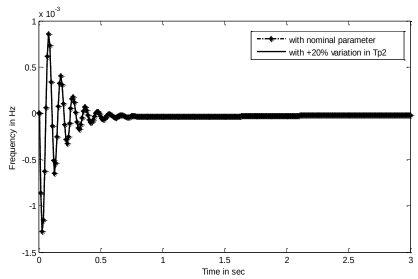

Fig. 13. (d)Wind generator frequency deviation

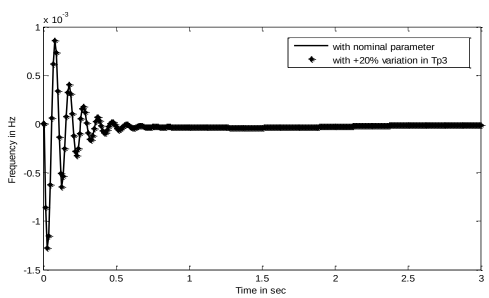

Fig. 13. (e) Wind generator frequency deviation

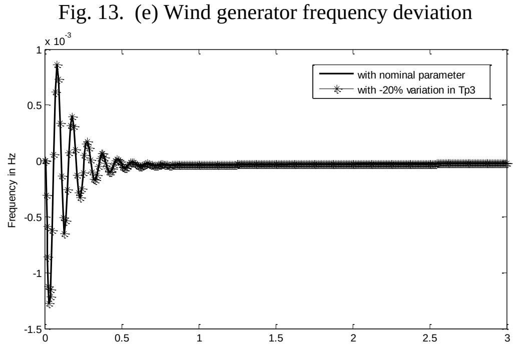

Fig. 13. (f) Wind generator frequency deviation

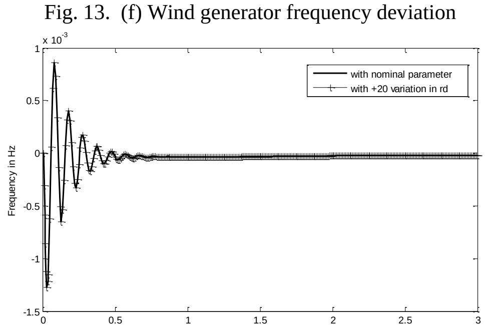

Fig. 13. (g)Wind generator frequency deviation

The above figures depicts the performance of the proposed PI controller under different parameter variations. It is evident that the proposed controller is robust under different operating condition of the power system and less sensitive to system parameter variations.

5. Conclusion

The design of robust PI frequency control of smart water heater controller in the remote Wind-Diesel hybrid power system has been proposed. The inverse additive perturbation has been applied to model applied to model the power system with unstructured uncertainties. Moreover, the performance condition in the damping ratio of the system is applied to formulate the optimization problem. To achieve the proposed PI controller parameters, the genetic algorithm is employed to solve the optimization problem. Simulation studies have been done to confirm the performance and robustness of the proposed robust PI controller are much superior to that of convectional controller under random wind power input and variations of system parameters.

Appendix - I
System Parameters

T_{D1}	=	1.000s	T_{D2}	=	2.00s
T_{D3}	=	0.025s	T_{D4}	=	3.00s
R_D	=	5.000Hz/pu kW	T_W	=	4.00s
K_{PC}	=	0.080pu kw/deg	K_{P1}	=	1.25
T_{P1}	=	0.600s	K_{P2}	=	1.00
T_{P2}	=	0.041s	K_{P3}	=	1.40
T_{P3}	=	1.000s	K_{IG}	=	1.494
K_{TP}	=	0.0040	T_{CWH}	=	0.5s
K_D	=	0.4	M	=	0.1
D	=	0.12			

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