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Adjustment of PID Coefficients in Order to Control of Load Power of Micro-Turbine in Island Mode Using PSO

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Abstract: This study is aimed to introduce the new controller in order to control of output power of one of the most important types of distributed generation namely micro-turbine, during system load variations. Micro-turbine output power should be control against the load variations in island mode condition and a controller should be designed for this purpose. Here, the PID Controller is used which its coefficients are optimized based on particle swarm optimization algorithm. In order to use this algorithm, at first, problem is written as an optimization problem which includes the objective function and constraints, and then to achieve the most desirable controller, Particle Swarm Optimization (PSO) method is applied to solve the problem. Simulation results are done for various loads in time domain, and the results show the efficiency of the proposed controller. Simulations show improved accuracy of the proposed controller performance to achieve this goal.

Key words: Controller design, distributed generation, micro-turbine, optimization, particle swarm optimization

INTRODUCTION

With increasing of electric power demand and consider the concerns of fuel problems, Distributed generation is the tiptop technique in order to providing electricity to consumers and retailers (Teja and Balaj, 2011) . The fundamental plants for the penetration of DG technologies are the high efficiency of the energy conversion process and the limited emission of pollutants as compared to conventional power plants. Also, they provide a number of important local benefits. The integration of the increasing portion of DG within the existing infrastructure requires a full understanding of its impact on the distribution feeders and its interaction with the loads. Such studies require accurate modeling of Distributed Generation (DG) sources including distribution system. Distributed generation using micro-turbine is a typical and practical solution because of its environment-friendliness and high energy efficiency (Gaonkar and Patel, 2006).

Until now, only few works were undertaken on the modeling, simulation and control of micro turbines. There is also a lack of adequate information on their performances. A dynamic model for combustion gas turbine has been discussed in (Rowen, 1983; Hannet and Afzal, 1993; Working Group, 1994; Hannett *et al*., 1995).

In Teja and Balaj (2011), in order to feed to vector controlled induction motor drive and other static loads, micro turbine based Distributed generation system is implemented. The Micro turbine provides input mechanical energy for the generator system. Aspects of dynamic modeling and simulation of fuel cell and micro-turbine units as a part of a multi-machine electrical network investigated in (Ahmed and István, 2003).

Lecture (Guda *et al*., 2005) demonstrated the development of a micro turbine model and its operation with a permanent magnet synchronous generator. A non-linear model of the micro-turbine is considered and implemented in NETOMAC software (Nikkhajoei and Iravani, 2002).

In (Suter, 2001) , proposed an active filter for MT. Adaptive control of fuel cell and MT is well described in (Jurado and Saenz, 2003). Authors demonstrated the development of a MT model from the dynamics of each part which is suitable for studying various operational aspects of the same (Gaonkar and Patel, 2006).

In this study a simple PID Controller for micro-turbine power control has been used except that the controller design has not been achieved through trial and error. But the problem has been proposed as an optimization problem and then solved by using particle swarm optimization. About the advantages of the proposed control, we can point followings:

- Controllers are simple
- Being robustness against load changes
- Fast transient response
- Zero steady error

SYSTEM DESCRIPTION

Originally, there are two kinds of small gas turbines, high speed single shaft turbines and split shaft turbines. In the single shaft turbines, the alternator generates a very

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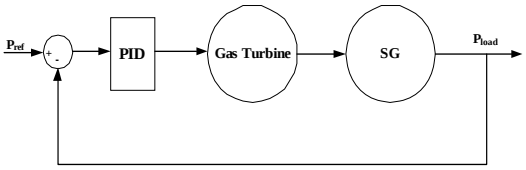

Fig. 1: Study system contain of gas turbine and synchronous generator

high frequency three phase signal ranging from 1500 to 4000 Hz. The high frequency voltage is first rectified and then inverted to a normal 50 or 60 Hz voltage. In the split shaft design, a conventional induction or synchronous machine is mounted on the power turbine via gearbox and the power inverters are not required (Saha *et al*., 2008).

The study system in this paper that the proposed algorithm applied to this system is shown in Fig. 1. This system contain PID controller, split shaft gas turbine and synchronous generator. The simplified single shaft gas turbine including all its control systems is shown in Fig. 2. All of parameters in this figure are given in Table 1.

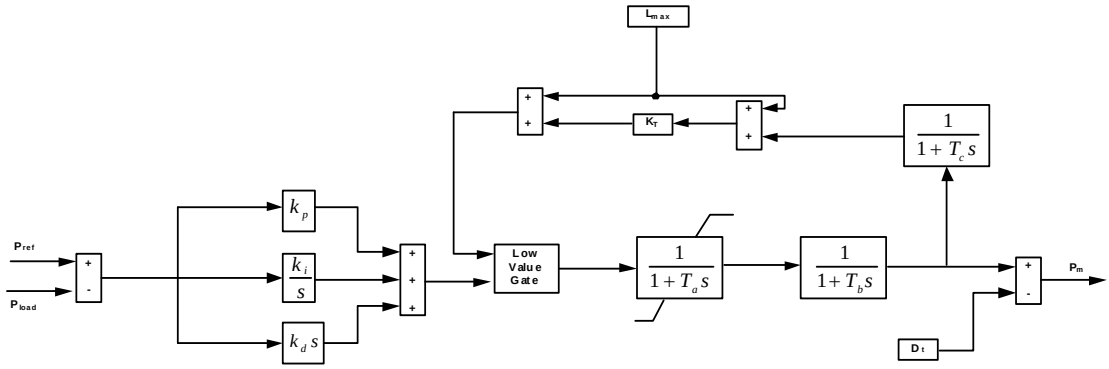

Fig. 2: Single shaft gas turbine including all its control systems

Table 1: Parameters of shaft gas turbine

Parameters	Value
Rated power	100 KW
Real power reference	1.0
Damping of turbine,	Dt0.03
Fuel system lag time constant ,	Ta10.0 s
Fuel system lag time constant ,	Tb0.1 s
Load limit time constant,	Tc3.0 s
Load limit, lmax	1.2
Maximum value position, Vmax	1.2
Minimum value position, Vmin	-0.1
Temperature control loop gain, KT	1.0

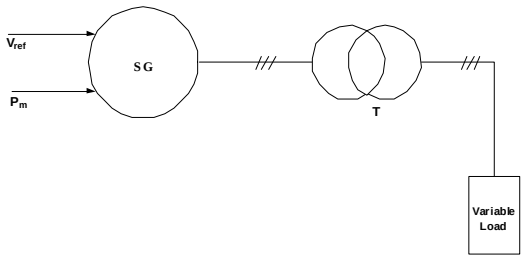

Fig. 3: Synchronous generator, transformer and local load

Figure 3 shows the synchronous generator, Transformer and local load. A step-up transformer is located between synchronous generator and local load in order to change the voltage level. Vref and Pm are the input of Synchronous generator that Vref is set to 1 p.u and Pm provides bye gas turbine. All parameters of synchronous generator, transformer and local load present in Table 2.

Table 2: Synchronous generator and load parameters

Parameter	Value
Rated power	100 KW
Rated voltage	440 V
Frequency	60 Hz
Number of poles	2
Damping factor, KD	0.06 p.u.
Inertia constant	0.822 s
Internal resistance, R	0.04 p.u.
Internal reactance, X	0.3 p.u.
3-ph source base voltage	11 KV
Dist. trans. nominal power	150 KVA
Frequency	60 Hz
Dist. trans. primary voltage	11 KV
Dist. trans. secondary voltage	440 V

CONTROLLER DESIGN

PSO algorithm: Particle swarm optimization has been used to solve many optimization problems since it was proposed by (Eberhart and Kennedy, 1995). PSO is one of the most recent developments in the category of combinatorial met heuristic optimizations (Gaing, 2003). In PSO, each individual is referred to as a particle and

represents a candidate solution to the optimization problem (Yoshida *et al*., 2000).

In first, a population of random solutions ‘‘particles’’ in a D-dimension space are composed. Each particle is a solution. The ith particle is represented by Xi = (xi1, xi2, . . . , xiD). Situation of each particle will be change in next stage. The best situation of each particle will be determined by fitness function. If the fitness functions has minimum value so far it is called best situation and save in Pbesti. The global version of the PSO keeps track of the overall best value (gbest), and its location, obtained thus far by any particle in the population (Mandal *et al*., 2008). PSO consists of, at each step, changing the velocity of each particle toward its Pbest and gbest according to Eq. (1). The velocity of particle i is represented as Vi= (vi1, vi2,...,viD). Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward Pbest and gbest. The position of the ith particle is then updated according to Eq. (2) (Binghui *et al*., 2007):

$$v_{id} = \omega \times v_{id} + c_1 \times rand0 \times \left(P_{id} - x_{id}\right) + c_2 rand0 \times \left(P_{gd} - x_{id}\right) \quad (1)$$

$$x_{id} = x_{id} + cv_{id} \quad (2)$$

where, Pid and Pgd are Pbest and gbest, c1 and c2 are constant values, ω will be determined by this equation:

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{Iter_{\max}} \times iter \quad (3)$$

ωmax and ωmin are the maximum and minimum value of ω respectively. At first ω start with large value that in the end of problem the value of the ω will be minimum.

Using PSO to adjust controller parameters: With so much development in controlling systems and making applicable of these controllers, in power system, simple controllers are still considered desirable controllers. In most cases in the power systems, compensators are PID controllers. And these controllers can be implemented easily in analog and digital systems . In this study, PID controller is used to control voltage of load voltage of micro-turbine in island condition. The overall controller schematic is shown in Fig. 4.

Controller general form is expressed in Eq. (4). The controller parameters must be optimized include: k_p,k_i,k_d It is clear that the transient mode of the system in the load variations depends on the controller coefficients. Controller design method are not viable to be

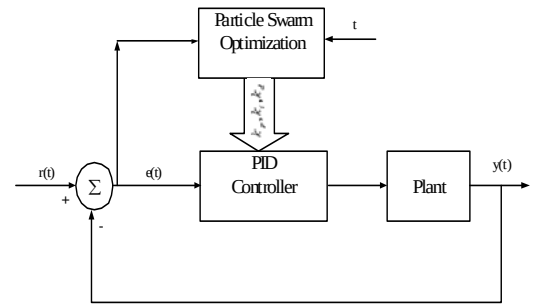

Fig. 4: Scheme of design proposed controller

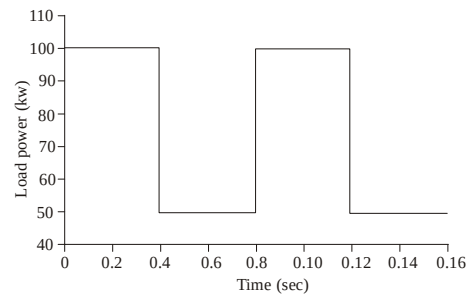

Fig. 5: Worst condition for load power

implemented because this system is an absolute nonlinear system. So these methods would have not efficient performance in the system:

$$G_c(s) = k_p + \frac{k_i}{s} + k_d s \quad (4)$$

In order to design controller using particle swarm optimization for the micro-turbine from the load power curve, we consider the worst condition for load design controllers for these conditions. Figure 5 displays the worst condition for load power in the system.

Now, problem should be written as an optimization problem and then be solved. Selecting objective function is the most important part of this optimization problem. Because, choosing different objective functions may completely change the particles variation state. In optimization problem here, we use error signal.

$$J = \int_0^{t=tsim} \left| P_{ref} - P_{load} \right| dt \quad (5)$$

where, tsim is the simulation time in which objective function is calculated. We are reminded that whatever the objective function is a small amount in this case the answer will be more optimized. Each optimizing problem is optimized under a number of constraints. At this problem constraints should be expressed as:

Minimize J subject to!

$$\begin{aligned} k_p^{\min} &< k_p < k_p^{\min} \\ k_p^{\min} &< k_i < k_i^{\min} \\ k_d^{\min} &< k_d < k_d^{\min} \end{aligned} \tag{6}$$

where, k_p , k_i are in the interval [0.01 300] and k_d in the interval [0.001, 10].

In this problem, the number of particles, dimension of the particles, and the number of repeatations are selected 20, 3 and 40, respectively. After optimization, results are determined as below:

$$k_p = 153.5404,\ k_i = 263.4650,\ k_d = 0.024194 \tag{7}$$

SIMULATION RESULTS

To show good performance of the proposed algorithm, we consider variable load in order to supply by micro-turbine in island mode. Desired load power is shown in Fig. 6. As can be seen, desired load is changing between the range of 0.15 to 0.9 per unit which change within 14 seconds, and the numbers of its changes are considered more to show the performance of the proposed controller.

Simulation output results obtained from the proposed algorithm which is expressed in Eq. (7) are shown in

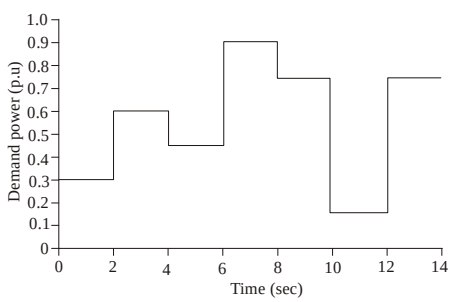

Fig. 6: Power demand for micro-turbine in island mode

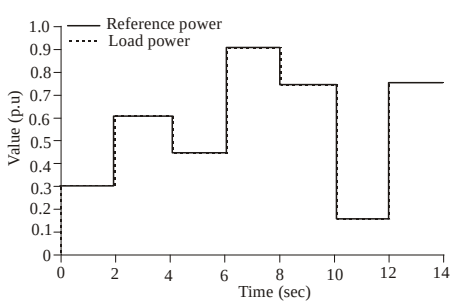

Fig. 7: Reference and output power related to the proposed controller

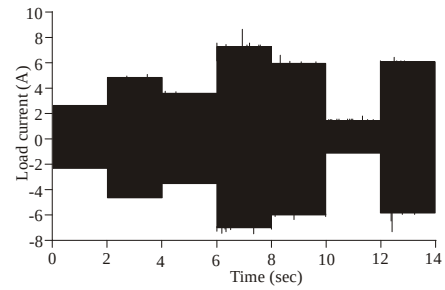

Fig. 8: Load instantaneous current related to the proposed controller

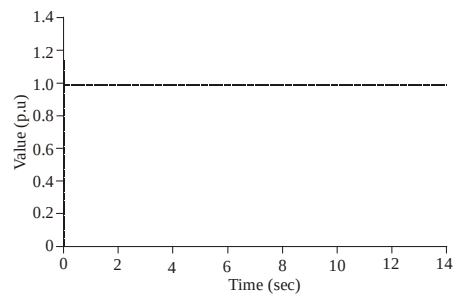

Fig. 9: Micro-turbine output voltage related to the proposed controller

Fig. 7, 8 and 9. Figure 7 depicted the output power of micro-turbine that provides the demand loads in island mode and reference power. From this figure, it can be seen that by changing load power; supplied power change quickly to keep stable the output frequency of the micro-turbine under the desired voltage and this show good performance of the proposed controller albeit simplicity. In Fig. 8 instantaneous of output current of load for phase (a) is shown, according to the figure it is obvious that controller response is appropriate and it could control the output current of mention system properly. In Fig. 9, the load voltage is plotted which the high efficiency of the proposed algorithm shown clearly.

CONCLUSION

In this study, a new controller based on particle swarm optimization and PID controller to control the micro-turbine output power in island mode was proposed. This controller is chosen because of its simplicity and because the implementation of this controller is simple and it could obviate the problem of the previous controller and its efficiency is higher than previous controllers. PSO algorithm was utilized to design the PID controller to have the most optimized state. In solving this problem, at first problem was written in the form of the optimization problem which its objective function was defined and

written in time domain and then the problem has been solved using PSO. And the most optimal mode for gain coefficient of controller were determined using the algorithm

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