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Provide the Optimal Steam Turbine Speed through Controlling the Governor Input Signal

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ABSTRACT

The frequency of the system is related to the turbine speed. The rotor speed of the synchronous generators is equal to the speed of the turbine and its control is mainly done by the governor's speed control system. The purpose of this study was to take a positive step towards controlling the speed of the turbine by controlling the governor's input signal. For this purpose, a PID controller with performance capability was designed in both transient and lasting conditions of the system. Controller equations along with linear state equations of the power plant were located in the optimization process. In this way, proper and optimal coefficients were determined according to the objective functions. Optimization was done by the particle pool algorithm. System performance analysis and comparison of outputs were done by the simulation method. Simulation results showed the optimal efficiency of the proposed method.

Keywords: *Particle Coordination Algorithm, Steam Turbine, Speed Controller, PID Controller.*

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1. INTRODUCTION

The problem of the power system stability mainly maintains the synchronized state between synchronous machines (Condor, Prob. 1997, 1:21). The stability of the power system creates the limits for the generator's performance, which, if passed through these limits, it will endanger the system. One of the main variables for generator stability is frequency. For a satisfactory performance of a power system, the frequency should remain approximately constant. Controlling the system frequency depends on controlling the turbine speed. The system frequency depends on the true power balance. Since frequency is a common factor throughout the system, any change in the actual power demand of a point is reflected in the frequency throughout the system. A large number of generators provide the system's power, so tools should be provided to divide demand for power changes between the units. A speed governor provides the speed of each production unit with the initial control function of the speed, while the additional control in the main control center drops the stationary error of the frequency (Condor, 1997, 1:10).

In this study, to improve the system performance, the rotor speed of the synchronous generator was attempted by using the governor's complementary control. The frequency of the system is related to turbine speed. In synchronous generators, the rotor speed is equal to the turbine speed and is controlled by a turbine and governor speed control system. An excessive increase in true power demand, the exceeding frequency of the stable generator’s performance, and worse, exiting the synchronization, threaten the generator. To overcome this problem, the turbine speed was increased using control methods, but with the excessive change in the turbine speed, the system frequency and active power output of the generator were out of range, then the turbine speed was required to improve the stable operation of the generator (and as a result, the speed of the rotor was controlled in such a way that, firstly, the constraints and stability limits were met, and secondly, the generator's delivery capacity was optimally adjusted.

So far, many studies have been done on all aspects of controlling the synchronous generator and steam turbine, and numerous researchers have consistently tried to express innovative ideas or improve previous ideas. For example, in a paper written by Farhangi, R and Abdollahi R; (2010), a novel method based on the emotional learning in humans, turbine was provided to improve the performance of the frequency control system (LFC) in the power grid, taking into account the production rate and steam reheat rate. Also, a relatively new method based on an online timed crank model was introduced to control the AC turbogenerator by Ren, et al. (2005), in which the controller consisted of several nonlinear controllers, was achieved using the interconnection of several online PID controllers. Each of the PID controllers was designed for a linear sub-model and, in general, provide better performance than a single PID controller, or a fixed constant controller designed for a single work point. In a research carried out by Rashid Nejad Heidari and Fallahzadeh (2015), a fuzzy adaptive controller was designed and tested for the turbine speed control system, which was based on the theory of self-adaptive control and combination of the traditional PID controller and Fuzzy control method. Sumina et. al. (2009) presented a real-time dynamic simulation for implementation and testing the control algorithms. The dynamic simulation was used to simulate the control of a power plant in real-time. in this study, implementing a control and testing algorithm for a controller was conducted. The dynamic behavior of the synchronous generator was simulated using real-time MATLAB software and the control algorithm was implemented on a DSP. In a study carried out by Farahnak Fomeni (2013), methods were suggested for the participation of a combined cycle turbine in the frequency control. Bensenouci, A., and Besheer, A. H. (2012) also, provided the structure of the power system and PID based on the ant system. Jones, K. O., and Bouffet, A. (2007) provided a simple inspirational approach for designing PID controllers to control an AC power turbine generator system. Chemistry research, Coral (2011) presented the application of the genetic algorithm method in the PID controller of the steam turbine speed control system. Murgaš, J; et al. (2004) investigated a decentralized control for a nonlinear turbine generator based on the Lyapunov stability theory under conditions where the nonlinear complex model of the control system was decomposed into two subsystems of the synchronous generator and turbine. Moreovre, Naka, S., et al. (2001), used the PSO algorithm in designing a PID controller to search for the best PID control parameters.

In this paper, a single generator, connected to infinite Xin was considered and a PID controller was used to control the optimal turbine speed through controlling the input signal to the speed controller. The parameters of this controller were optimized through programming in MATLAB software using the particle pool algorithm. We formulated the controller design similar to an optimization problem and obtained three attributes of Kp (proportional gain), Ki (integral gain), and Kd (derivative interest) for the PID controller.

2. SIMULATING A SIMPLE POWER PLANT

In this research, in order to implement a dynamic simulation, the state equations of a simple power plant included the 7th grade synchronous generator, infinitely connected to the shin through the transmission line, and simple models of an excitation system, an AVR automatic voltage controller, a turbine, and a governor, (all were of grade 1), were extracted and rotated around a linear point. Then these equations were implemented through computer programming and the state of space was simulated in Matlab's Simulink environment. Details of calculation and linearization of the above-mentioned equations around the point of work were presented by Karari, M; 2005. The simulation and power plant modeling in the MATLAB environment were done using the linear model equations. We implemented equations in the state space block created in MATLAB software. The rotor speed was defined as the system output.

3. PROBLEM SOLVING STRATEGY WITH PARTICLE CLUSTERING ALGORITHM (PSO)

This algorithm started with a group of random particles, then searched for the optimal answer in the problem space by updating the generations. Depending on the nature of the problem, each particle was defined as a multidimensional particle with two values representing the spatial position and particle velocity. At each stage of the population movement, each particle was updated with the two best values. The first value, the best answer in terms of suitability, was achieved so far for each particle and called P_best. The other best value, obtained by the algorithm was the amount, achieved by all particles in the population so far, this was the best overall, called G_best (Jafari Sirizi, M; et. al.; 2009).

The first step was to solve the initial population formation problem. In the PSO algorithm, particles were moved in the d-dimensional search space (d is the number of optimization variables). Each particle could be a possible answer to the optimization problem. Each particle was introduced only with its position and speed. The position of the particles in the matrix called X. X, was a matrix n×d, representing the position of the particles (n represents the total number of particles in the population).

The initial population X consisted of n distinct particles, in which the total number of particles was considered to be 100. Each particle at any given time had a value for each of the controller coefficients, given that we had 3 variables (proportional, derivative, and integrals of the controller). Each particle consisted of a 3-dimensional vector:

$$X = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & \vdots & \vdots \\ \vdots & \vdots & \vdots \\ x_{n1} & x_{n2} & x_{n3} \end{bmatrix} \qquad (2)$$

For example, in the above matrix, the first particle is in the form of $[x_{11} \quad x_{12} \quad x_{13}]$. To form a randomized population, all vector values are randomly selected for each particle.

The next step was to solve the initial speed problem. The velocity of each particle in the matrix, called V. V, was also a matrix X of n×3 representing the particle convergence rate. In fact, V represented the velocity of position change of elements. At this stage, the velocity matrix was formed by relation (3). For this purpose, two primary and random populations were formed. The initial velocity matrix was obtained by subtracting the two primary populations.

$$V = X_1 - X_2 \qquad (3)$$

After the formation of the initial population and the initial velocity, the suitability level of each particle should be evaluated. The suitability of each particle in each population was investigated based on the cost function. A particle, producing less cost was more worthy. Relationships related to the cost function were expressed in the next section. Accordingly, a matrix called P_best was defined that contained n, the value for n particles in each population. After calculating the suitability of each particle, it was time to determine the amount of G_best. G_best showed the best position in the whole group. The values of P_best and G_best were updated at each step of the algorithm, and at any stage that obtained a better value, the resulting value was replaced with the previous value.

$$P\_best = \left[P\_best_1, P\_best_2, \cdots, P\_best_n\right]^T \quad (4)$$

$$G\_best = \max(P\_best) \quad (5)$$

After finding two values of P_best and G_best, the speed and the new location of each particle were updated according to the following relationships (Jafari Sirizı, M, et. al., 2009; Sahavati, Ghareh Petyan and Hosseini, 2008; and Shakari, A, 2014):

$$v_{id}(t+1) = k[w(t).v_{id}(t) + C_1.rand_1\left(P\_best_i(t) - x_{id}(t)\right) + C_2.rand_2\left(G_{best}(t) - x_{id}(t)\right)] \quad (6)$$

$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1) \quad (7)$$

The above relations, 6 and 7, represent two values the velocity and spatial position, respectively, associated with the dimension d of the i-th particle. C1 and C2 are acceleration or balance coefficients between the two social and individual forces, respectively and when C1 coefficient is higher than C2, individual's impact on the individual will be smaller and when it is smaller the impact on the individual will be higher than the community. In this study, the C1 and C2 coefficients were considered to be 1.5. w is the inertial weight (the desire for no path change) in a particle, and rand1 and rand2 are random numbers distributed with a uniform distribution between zero and one. The variable t represents the number of current replays. According to the obtained equations, it can be concluded that each particle, when moving, considers the direction of its previous move, the best position it has and the best situation experienced by the whole group.

The coefficient k in equation (6) is used to ensure convergence and is 0.9. Depending on the definition of the C1, C2 and w coefficients, different versions of the PSO algorithm are created. The coefficient w is to control the diversity of the exploration (reaching different and possible solutions in the problem space) and particle convergence. To avoid divergence, over time, elements with smaller steps are required to search the search space, so the value of the coefficient w changes in each repetition. At the inception, this parameter is set to the largest value in order to expand the scope of the exploration in the broader problem space and then linearly (with a constant gradient) decreases until the last one is repeated, and its size in each repetition of equation (8) has been calculated by Haghari and Honar; 2014 and Shahadati, Ghareh Petyan, and Hosseini; 2008:

$$w(t) = w_{\max} - \frac{w_{\max} - w_{\min}}{t_{\max}}.t \quad (8)$$

In this research, the order is considered to be 0.8 and 0.2. The maximum number of repetitions is 35 times. The optimization algorithm stops if any of the following two conditions are observed:

1. Steps are repeated 35 times. In this case, the best answer is chosen as the optimal answer.
2. The value of the cost function exceeds 1000. In this case, the algorithm must be restarted from scratch.

4. COST FUNCTION

The cost function is the most important part of all algorithms for optimization and search. In all applications, if the cost function is not a suitable function, even if the optimization algorithm is well designed, it will not be possible to achieve the optimal final response. In this paper, the most important problem in controlling the turbine speed is, firstly, the control of high-power or transient in the transient state response, and, second, the constant output of the generator in a state-of-the-art mode error. From the perspective of the manufacturer and the consumer, the sustainability of the transient state response and the static state error are not the same; therefore, the cost function can not be considered for the two modes in the same way. With regard to active power in power plant contracts, the amount of active power production in a steady state is much more important than a temporary increase or decrease in power generation. According to the contents of the preceding sections, this also applies to turbine speed. The turbine is a bare mechanical body with relatively high temporal constants and is largely resistant to fast-moving transitions. For this reason, 80% of the turbine speed control assigns the importance of the cost function to a state-of-failure error and 20% to the transient response. This causes the cost function's weight to be designed in two transient and permanent modes to satisfy the requirements of the network. The cost function is defined by the equations in which g1 and g2 are weighted coefficients. T is the total number of data during the simulation time and w is the turbine speed (rotor speed). The first part of the f1 function is related to the output and f2 for the mean error magnitude (fault-tolerant mode). The Fcost function is the total cost function:

$$f_1 = g_1 \frac{\left|w_{\max} - w_{ref}\right|}{w_{ref}} \quad (9)$$

$$f_2 = g_2 \frac{1}{t} \sum_i^t \frac{\left|w_i - w_{ref}\right|}{w_{ref}} \quad (10)$$

$$F_{\cos t} = f_1 + f_2 \quad (11)$$

Figure (1) shows the value obtained for the cost function over 25 stages of the optimization algorithm.

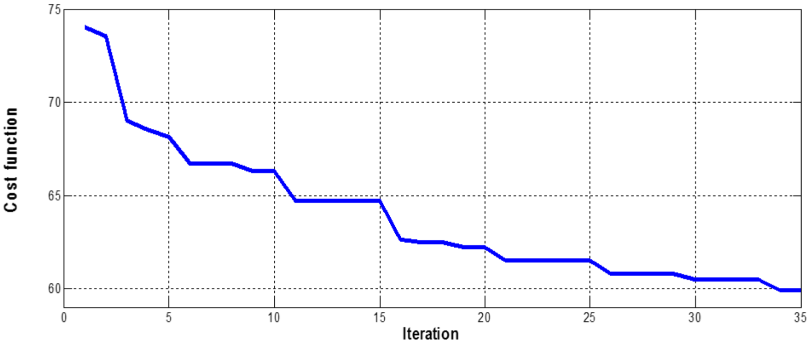

Figure 1: The value obtained for the cost function after each step of the particle pool optimization algorithm.

5. SIMULATION

Using a state equation introduced by Karari, 2005, a simple power plant is modeled in the simulation environment of the MATLAB software. To analyze the performance of the controller, we implemented the power system before and after adding the controller. A simulation has been performed for 250 seconds. To monitor the behavior of a controller under transitional conditions caused by a disturbance or disturbance, 100 seconds after the simulation starts, a step change is applied at a value of 0.5 ppm in the reference value. The imposed change to the system will be eliminated 50 seconds later (ie, in 150 seconds) and the reference value will return to the initial value of 1 perion.

In this section, we displayed the rotor speed signals and generator rotor speed changes after running an optimization and simulation program in two situations before and after the control.

Figure 2 shows the simulation results for rotor speed and shape (3) simulation results for rotor speed changes of the synchronous generator before the control. It is seen that in this situation, the rotor speed variations and fluctuations are very high. In practice, this changes the rotor speed (and therefore the turbine speed) to the system towards instability.

Figure 4 shows the simulation results for the rotor speed. In this figure, simultaneously, the rotor speed (red line) and the reference value of the rotor speed (blue line) are shown after adding the PID controller.

Figure 5 shows the simulation results for rotor speed changes of the synchronous generator after the control. It is seen that in this situation, the velocity fluctuations are well-drained and the rotor speed changes in steady-state are almost zero. The rotor speed variations in transient conditions caused by the change in the reference value from 1 to 1.5 prions and also in the transient state due to the return to the initial value of 1 perion are acceptable. This amount (in the worst case) reaches less than 0.6 prions. In practice, for active power (and thus the speed of the turbine and the rotor), transitions to a few perions, if taken at the right time (lack of time to meet), usually do not cause instability.

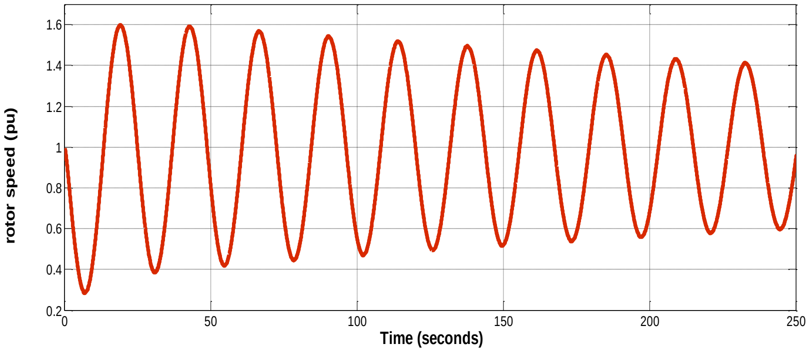

Figure 2: Rotor speed of the generator before applying the control (perion per second).

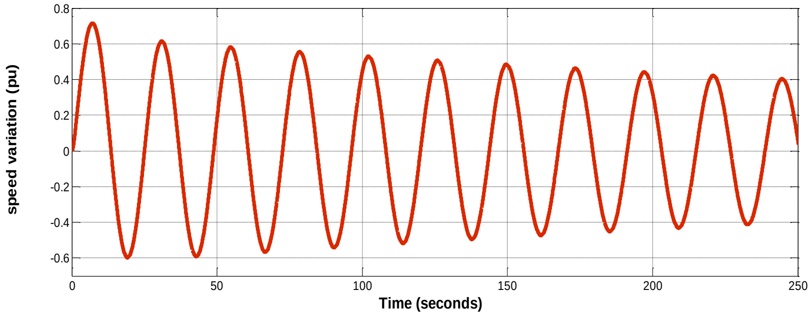

Figure 3: Rate of rotor speed change relative to the reference value before the control (degree / s).

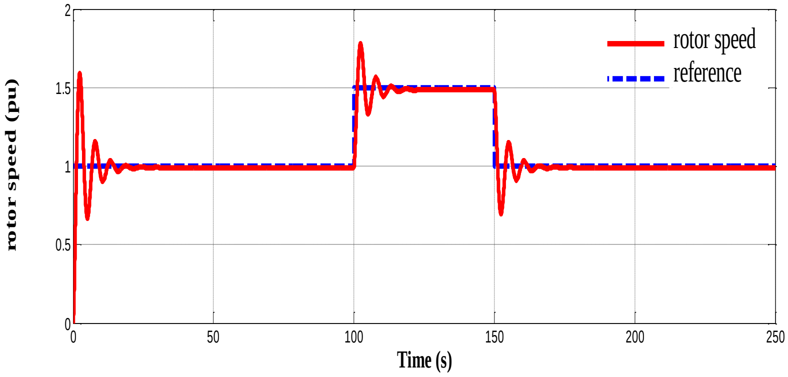

Figure 4: The rotor speed of the generator after applying the control (red line) and the reference value of the rotor speed (cross-sectional blue line), (perion per second).

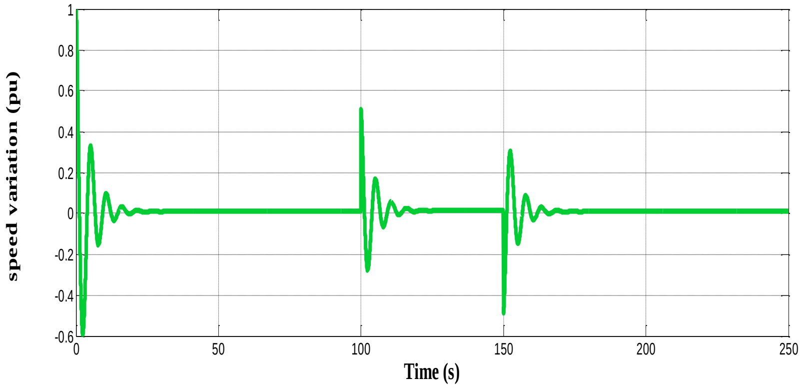

Figure 5: Rate of rotor speed change relative to reference value after control (perion per second).

6. CONCLUSION

In this paper, a PID controller was used to control the turbine speed of the steam power plant. Due to the turbine connection of the power plant to the rotor of the generator through the shaft, the turbine speed is equal to the rotor speed. Therefore, to calculate the turbine speed, the rotor speed of the generator is measured. In order to control the optimum turbine speed, the governor's input was set via a PID controller. By designing an optimization problem, the parameters of this controller were calculated using the particle pool algorithm. Three characteristics of Kp, Proportional gain, Ki, integral gain, and Kd were obtained for PID controller. In order to analyze the designed controller behavior, Simulation software was used to simulate a simple power plant state equation. In order to check the behavior of the controller under transitional conditions due to a disturbance or disturbance, 100 seconds after the start of the simulation, a step change was applied at 0.5 ppm in the reference value. The imposed change to the system was 50 seconds later (ie 150 seconds), and the reference value was returned to the initial value of 1 perion. Before the control, the system had severe fluctuations. The designed controller was able to easily rotate the rotor's power output and restore the generator to stable performance. Confirming the results was obtained by simulating the controller's satisfactory performance. The rotor speed variations in transient conditions caused by the change in the reference value from 1 to 1.5 prions and also in the transient state due to the return to the initial value of 1 perion were acceptable. This amount (in the worst case) reached less than 0.6 prions.

Table 1 shows the optimal values for the PID controller coefficients of steam turbine speed after completion of the 35-stage implementation of the particle pool optimization algorithm. According to the carried out tests, repetitions of more than 35 had no significant effect on the results, and the results obtained after 30 repeat steps were also acceptable. Finally, the maximum number of repetitions of the algorithm was 35.

Table 1: The optimal value obtained for the PID controller

Gain:	**Kp**	**Ki**	**Kd**
Value:	15.012	2.333	16.980

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