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Research Article

Multi-objective PID Optimization for Speed Control of an Isolated Steam Turbine using Gentic Algorithm

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Abstract: This study focuses on multi-objective optimization of the PID controllers for optimal speed control for an isolated steam turbine. In complex operations, optimal tuning plays an imperative role in maintaining the product quality and process safety. This study focuses on the comparison of the optimal PID tuning using Multi-objective Genetic Algorithm (NSGA-II) against normal genetic algorithm and Ziegler Nichols methods for the speed control of an isolated steam turbine. Isolated steam turbine not being connected to the grid; hence is usually used in refineries as steam turbine, where a hydraulic governor is used for the speed control. The PID controller for the system has been designed and implemented using MATLAB and SIMULINK and the results of the design methods have been compared, analysed and conclusions indicates that the significant improvement of results have been obtained by the Multi-Objective GA based optimization of PID as much faster response is obtained as compared to the ordinary GA and Ziegler Nichols method.

Keywords: Genetic algorithms, isolated steam turbine, multi-objective optimization, PID controllers

INTRODUCTION

PID-Proportional, Integral and Derivative controllers alone contribute 90% of the total controllers used today (Åström and Hägglund, 2001; Zhao *et al*., 2011) and their simplicity of design and the ease of implementation complements their application. Optimal tuning of the PID parameters is an imperial factor, which can be formulated as an optimization problem (Krohling and Rey, 2001).

In this study, an isolated steam turbine has been considered i.e., the turbine is not connected to the grid and the speed is controlled using a hydraulic governor. The hydraulic governor regulates the steam flow in the turbine (Basu and Samiran, 2012; Ismail, 2012). For optimal operation, the system must be flexible enough to adapt with the changing conditions and regulate the process efficiently. For designing the PID controller, Ziegler Nichols frequency response has been used followed by the optimization using genetic algorithm and multi-objective genetic algorithm. The optimization has been carried out by the minimizing the objective function, stated as “Sum of the integral of the squared error and the sum of the integral of the absolute error” (Das *et al*., 2011). According to the results obtained, considerably better results have been obtained in case of the Multi-objective GA tuned PID controllers.

MATERIALS AND METHODS

Mathematical modelling of the steam turbine and its governing system: Steam/Gas turbine systems are centre to several industrial processes like in refineries, chemical plants, sugar industries etc. and are also termed as drive compressors and generally are of centrifugal type (Ismail, 2012). Speed and power is regulated with the governing system. The main purpose of the governing system is to keep the speed constant as the load varies.

Figure 1 illustrates the governing scheme of the turbine. The governor Valve (CV) regulates the steam flow, a Stop Valve (SV) is also provided for protection to check the accidental steam flow. Figure 2 illustrates the signal flow block diagram for the governing process. The electro-hydraulic convertor is used to convert the output electric/voltage signal to hydraulic pressure or piston position signal and the control valves are operated by the control valve servo motors. The flow of steam is proportional to the opening of the valve; hence the valve regulates the steam flow and is governed by the entire rotor system and the turbine power output and the governing system regulates the turbine mechanical power output (Murty, year).

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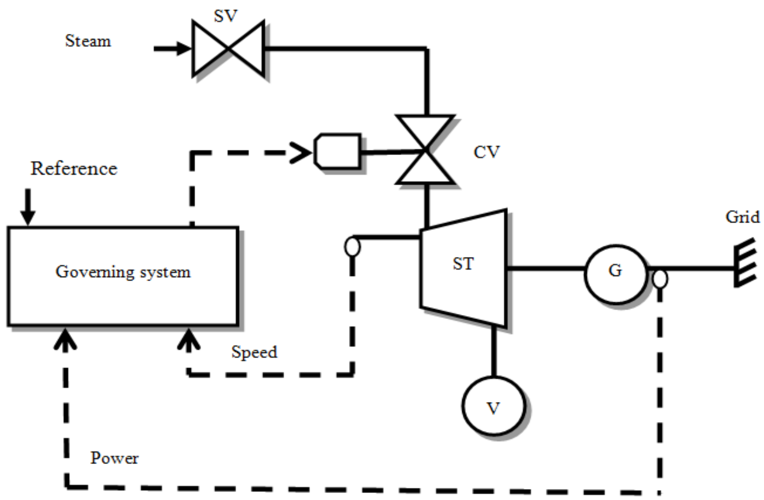

Fig. 1: Turbine speed control

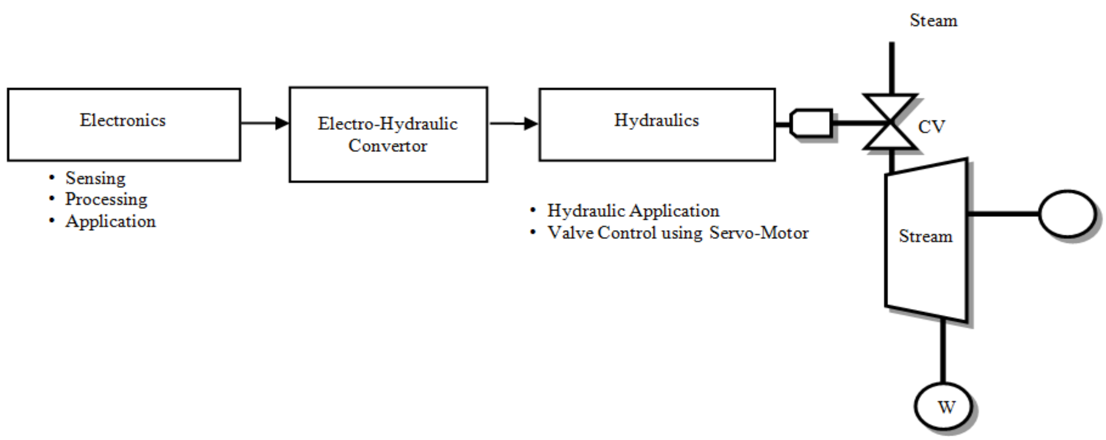

Fig. 2: Scheme for governing the hydraulics

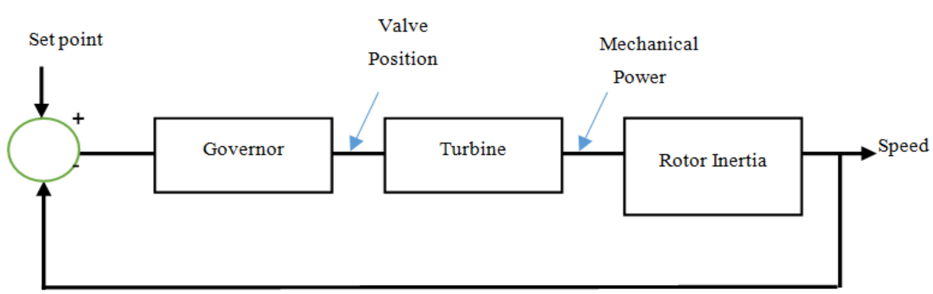

Fig. 3: Modelling of the steam turbine

The mathematical model of the system (Fig. 3) has been taken from (Ismail, 2012) which has been obtained by obtaining the step response of the system, followed by the determination of the transfer function. The equation obtained can be obtained as a third order transfer function:

$$G(s) = \frac{KK_g}{s(T_g s+1)(T_t+1)} \Rightarrow \frac{1}{s^3+5.4\cdot s^2+3.68\cdot s}$$

Design and optimization of the PID controllers: In process control PID controllers are the most widely used controllers and they alone contribute 90% of the total controllers used today (Åström and Hägglund, 2001; Zhao *et al.*, 2011). The general equation for a PID controller can be given as (Nise, 2004):

$$C(s) = K_p.R(s) + K_i\int R(s)dt + K_d\frac{dR(s)}{dt}$$

Tuning of PID controller using Ziegler-Nichols: Ziegler Nichols tuning is the most operative of all the classical methods available. Being the third order system, the initial parameters have been estimated by using frequency response as suggested by the Ziegler-Nichols (Ziegler and Nichols, 1942). But this method is limited till the ratio of 4:1 for the first two peaks in closed loop response, leading to an oscillatory response (Goodwin *et al*., 2001). The parameters obtained are listed in the Table 1. Figure 4 represents the closed loop response obtained using ZN-PID parameters.

Optimization using genetic algorithm: As the ZN tuned PID controllers show an oscillatory response, so they are not fit for direct implementation for the plant. So the parameters are required to be optimized, so better parameters with least over-shoot can be obtained. The use of Genetic Algorithm optimization the PID controllers provides the advantage of its adaptability for changing constraints. The optimization of the PID controller is based upon the minimization of the integral time squared error (Corriou, 2004), ISE can be given as:

$$ISE = \int_0^{T_s} e^2(t)\,dt$$

Minimization of the ISE will discard the larger errors or the parameters with larger amplitude will be suppressed (Corriou, 2004). The optimization of the PID using GA focuses on obtaining the three best optimal values for (*kp*, *ki*, *kd*), so that it globally minimizes the objective function i.e., ISE.

The optimization of the PID controllers has been carried out using Global Optimization Toolbox and SIMULINK, with a population size of 20, scattered crossover, single side migration and roulette wheel based selection. The optimal PID gains obtained using GA are shown in Table 2 while Fig. 5 shows the closed loop response of the GA-PID controller. Figure 6 shows the plot for average and mean fitness value.

Multi objective optimization using GA: Since an oscillatory response has been obtained by Ziegler Nichols and Genetic Algorithm, so the parameters are not optimum for the direct implementation, their organized optimization must be carried out so that an un-oscillatory response can be obtained. Optimization of the PID controllers using Multi-Objective Genetic Algorithm aims at improving the objective function of the both the objectives used by obtaining an optimal Pareto solution. In this study, two objective functions have been used F1 (ISE) and F2 (IAE):

$$ISE = O_1 = \int_0^{T_s} e^2(t)\,dt \quad and \quad IAE = \int_0^{T_s} |u(t)|\,dt$$

Table 1: PID parameters obtained by Ziegler Nichols

PID gains	Value
K_p	11.9232
K_i	7.2806
K_d	4.8815

Table 2: PID parameters obtained by genetic algorithm

PID gains	Value
K_p	30.690
K_i	2.005
K_d	11.990

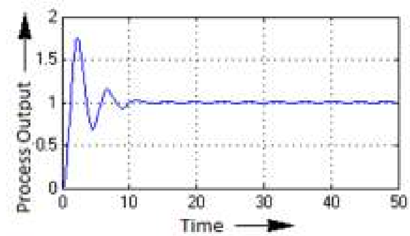

Fig. 4: Closed loop response of the ZN-PID controller

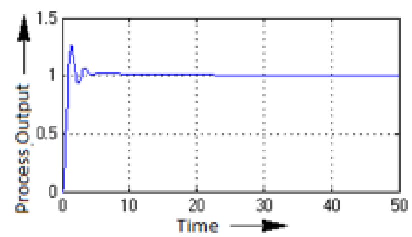

Fig. 5: Closed loop response of the GA-PID controllers

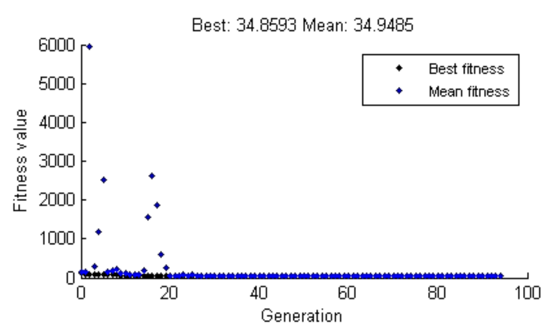

Fig. 6: Plot for beat and mean fitness of individuals

First objective function ISE i.e., Integral Square Error tries to minimize the larger amplitudes by suppressing the larger errors while second objective function IAE i.e., Integral Absolute Error minimizer the smaller errors; thus forcing the solution towards the global best (Corriou, 2004). The optimization uses NSGA-II algorithm boosts attaining the best fitness value using controlled elitist genetic algorithm. It also favours increasing the diversity of the population which prevents the algorithm from being struck in a local solution. Diversity of solutions is controlled by the elite members of the population; while elitism is controlled by Pareto fraction and Pareto front also bounds the number of individuals.

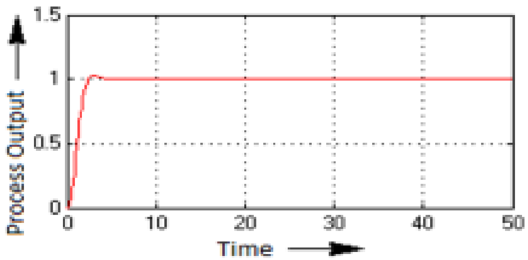

Fig. 7: Closed loop response of the Mobj GA PID controllers

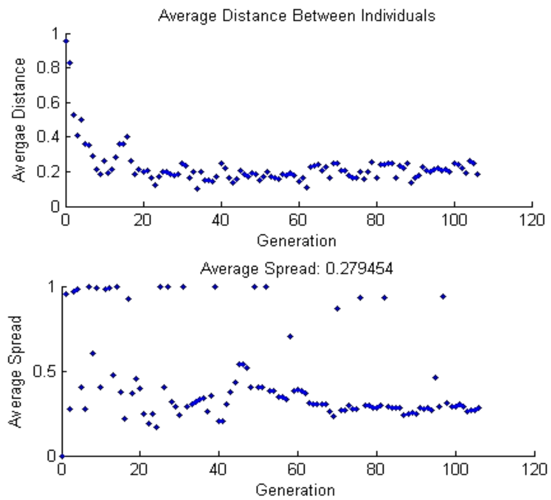

Fig. 8: Plots for (a) average distance, (b) average spread between individuals

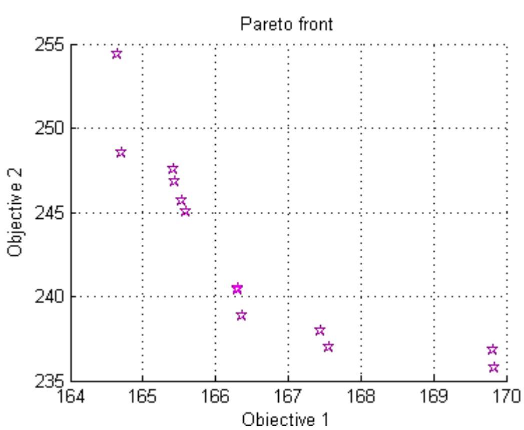

Fig. 9: Pareto front obtained between two objective functions

The implementation of the system and its optimization has been carried out in MATLAB and SIMULINK using Global Optimization Toolbox. Population size of 45 with adaptive feasible mutation function and selection of individuals on the basis of tournament with a tournament size of 2 has been considered. Figure 7 shows the closed loop response of the system with Mobj-GA PID controller. The optimized PID parameters are shown in Table 3. In

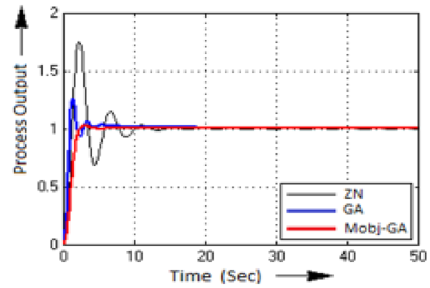

Fig. 10: Compared closed loop response of the ZN, GA and Mobj-PID controllers

Table 3: PID parameters obtained by multi objective GA

PID gains	Value
K_p	8.8249
K_i	0.0087
K_d	6.3699

Table 4: Different set of solutions obtained while optimizing using Mobj-GA

F1	F2	K_p	K_i	K_d
164.644255	254.354383	8.942904	0.031136	6.089032
166.301111	240.420491	8.917526	0.013275	6.284073
167.564667	236.959475	8.824958	0.008220	6.370070
165.600414	245.079052	8.936725	0.018738	6.111041
164.697186	248.552438	8.940119	0.024190	6.106964
165.437430	246.796095	8.943340	0.020817	6.072921
167.448444	237.949146	8.937880	0.009545	6.434774
169.814054	236.803577	8.745358	0.005297	6.504384
166.353877	238.894759	8.918694	0.011672	6.304611
169.836946	235.807806	8.743324	0.004352	6.503594
166.297990	240.484474	8.917726	0.013331	6.283729
164.644255	254.354383	8.942904	0.031136	6.089032
169.836946	235.807806	8.743324	0.004352	6.503594
167.448444	237.949146	8.937880	0.009545	6.434774
165.420239	247.575768	8.943087	0.021674	6.065396
165.534565	245.699817	8.942764	0.019521	6.108190

Fig. 8a, distance between members of each generation is shown, Fig. 8b gives the plot for average Pareto spread, which is the change in distance measure with respect to the previous generations and Fig. 9 shows the Pareto front obtained between the two objective functions. Table 4 shows the various solutions obtained by the optimization using Multi-Objective GA.

RESULTS AND DISCUSSION

The designing and implementation of the PID control closed loops has been carried out in MATLAB and SIMULINK. From the closed loop response shown in figures above, ZN and GA gives an oscillatory response and the response obtained after the multi objective optimization using genetic algorithm reflects the minimum overshoot and settling times. So the PID parameters obtained by the multi objective optimization are perfect for the implementation for the process and also ensures better stability and process safety. Figure 10 shows the compared response of the ZN, GA and Mobj-GA and the Table 5 shows the compared numerical results obtained. Figure 11 shows the compared graphical representation of the results obtained in Table 5.

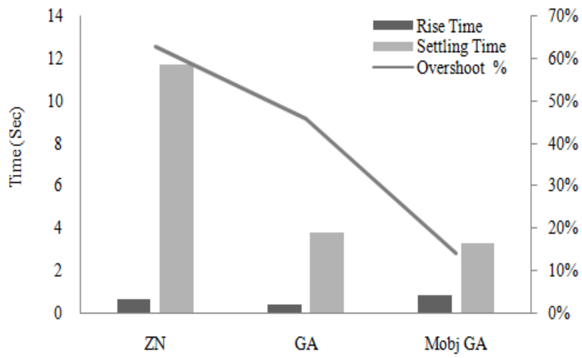

Fig. 11: Compared response values for the ZN, GA and Mobj-PID controllers

Table 5: Comparison of the results

Method of design	Overshoot (%)	Rise time (sec)	Settling time (sec)
Ziegler-Nichols	62.7	0.661	11.70
Genetic algorithm	45.7	0.388	3.77
Multi-objective genetic algorithm	14 .0	0.800	3.27

CONCLUSION

The use of multi objective optimization using genetic algorithms for tuning the PID controllers offer significantly improved response of the speed control of the isolated steam turbine. The response obtained is lesser oscillatory with significantly reduced overshoot percentage of 14 from 62.7% (ZN) and better settling time as compared to the response obtained by Ziegler Nicholas and GA tuned PIDs but rise time valves for GA-PID are better but the over-shoot percentage is 3 times higher as compared to Mobj-PID controller response. Thus Mobj-GA PID controllers offers improved stability and better process safety.

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