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Full Length Research Paper

An analysis on the application of PID controller in the frequency contribution of gas turbine power plant

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Conventionally, frequency correction is made by water turbine power plants. This paper addresses the role of the gas turbine power plants in frequency correction within the power networks. It gives those conditions that are necessary for a gas turbine power plant that attends in frequency correction task. It studies the functional behavior of the governor system by using extensive simulations in MATLAB environment and some experimental measurements. Simulation results show that the proposed approach improves operation conditions in frequency contribution of gas turbine, remarkably.

Key words: Frequency contribution, governor, speed droop, isochronous.

INTRODUCTION

Power plants and power networks have attracted a lot of attentions in recent years due to the importance of electrical energy in our life (Hemmati et al., 2010; Broujeni et al., 2011; Eslami et al., 2010). Meanwhile, frequency correction is one of the most critical points in power systems researches. Quick response to the frequency correction within the power plant is an important issue. It can prevent damages to the power transmission lines, equipments and house hold appliances. Since in a water power plant, the governor system can quickly respond to any need for frequency correction, this task is given to it. In the water plant, governor can change MW product in a matter of milliseconds. Nowadays, because of geographical dispersal of the water power plants, drought and the priority which is given to the stored water behind dams, for agricultural and drinkable water needs, emphasis on using gas turbine power plants for frequency contribution has been increased.

In a power grid system, load frequency control (LFC) plays an essential role. It provides better conditions for power exchange and supply in trading electricity. Delay in such systems could reduce system performance and even cause frequency or other parameters instability within the system (Sheldrake, 2003; Ai-Hamouz et al., 1993). The dynamic behavior of the power systems and also their effects in industrial loads depend on disturbances and in particular on changes in the operating point (Chang and Weihui, 1997). The goal of the LFC is to maintain zero steady state errors in a multi area interconnected power system. Furthermore, the power system should fulfill the proposed dispatch conditions. Power systems are divided into control areas connected by tie lines. All generators are supposed to create a coherent group in each control area. Considering experiments on the power system, it can be seen that each area needs its system frequency to be controlled (Murat et al., 2008). Many studies have been carried out in the past years on load frequency control. In the literature, some control strategies have been suggested based on the conventional water and steam power plants. However, in this study, we are going to extract those stability conditions that can be applied to main component of gas turbine power plant such as turbine, generator and fuel valve actuator. These conditions let these components to operate with less stress.

Governing systems for gas turbines

The following discussions outline important principles behind governing of gas turbines. In all power systems the requirement is that the steady state speed deviation,

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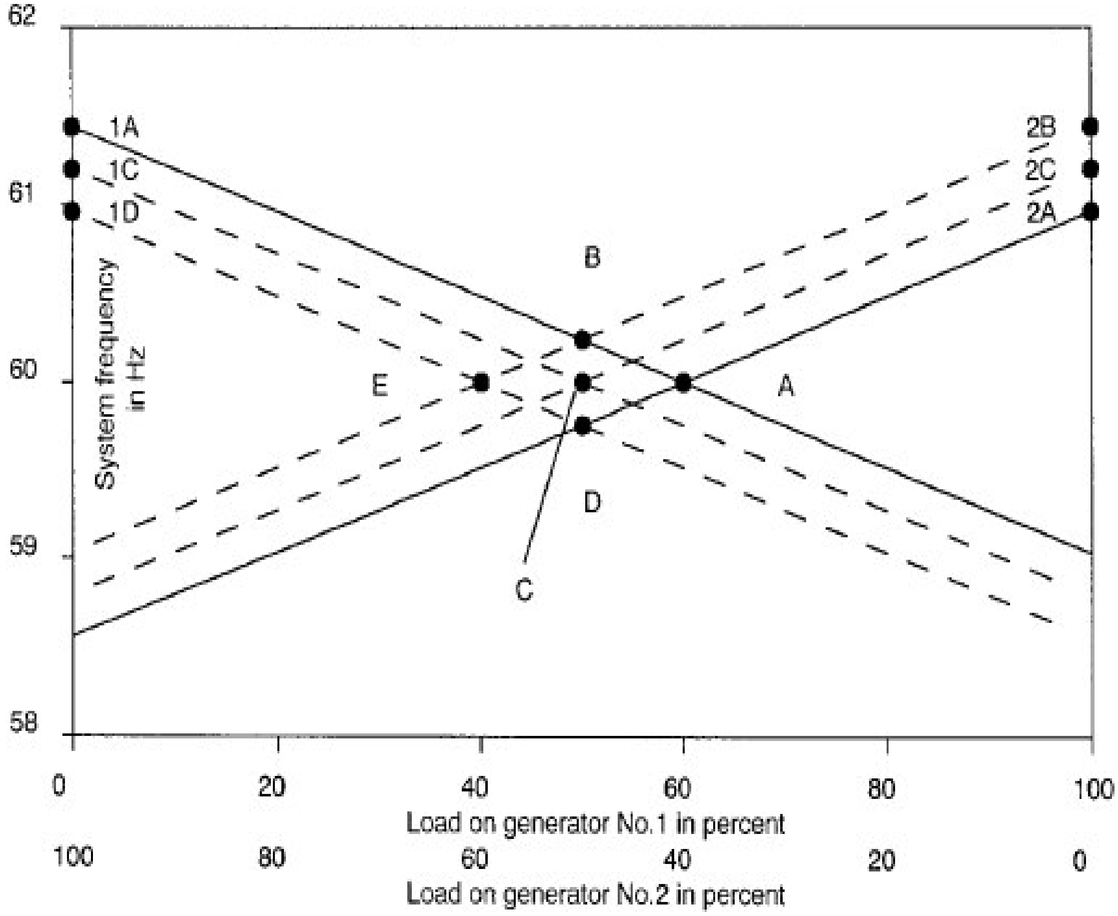


Figure 1. Load sharing between droop-governed gas turbines.

and as the result of that, the frequency is kept small regarding the incremental changes in power demand, even if these power increments are quite large e.g. 20%. There are two main methods used for speed governing of the gas turbines, namely droop governing and isochronous governing.

$$SD=\frac{\Delta f/f_n}{\Delta MW/MW_n}*100=\frac{MW_n}{f_n}*\frac{\Delta f}{\Delta MW}*100 \qquad (1)$$

Droop governing handles only a specific error in rotor speed to create the necessary feedback control of the fuel valve. Droop means that a fall in shaft speed and hence electrical frequency generator will occur as the load is increased. It is customary that a droop of about 4% should occur when 100% load is applied. Droop governing provides the simplest method of sharing load among groups of generators connected to the same power system. The speed droop is described by the following equation:

In which, Δf is steady-state frequency deviation, ΔMW refers to change of active power generation caused by turbine governor as a result of the frequency deviation Δf, f_n is rated frequency and MW_n is unit rated power.

This method of governing is the most commonly used method in power systems, because it provides a reasonably accurate load sharing capability among groups of generators (Ang et al., 2005). Isochronous governing causes the steady state speed error to become zero, thereby producing a constant speed at the shaft and a constant frequency for the power system. Isochronous governing is also a form of 'integral control'. This method is the best suited to a power system that is supplied by one generator. This type of power system has very limited application. However, there are situations where one isochronously governed generator could operate in parallel with one or more droop-governed generators. The droop-governed generators each have a fixed amount of power assigned to them for the special system frequency. This is regulated by setting their set points. As the request on the whole system changes, positively or negatively, the isochronously governed generator will take up or reject these changes, and the steady state frequency will remain constant. This hybrid type of load sharing is seldom used in the oil industry. Figure 1 shows how the load can be shared

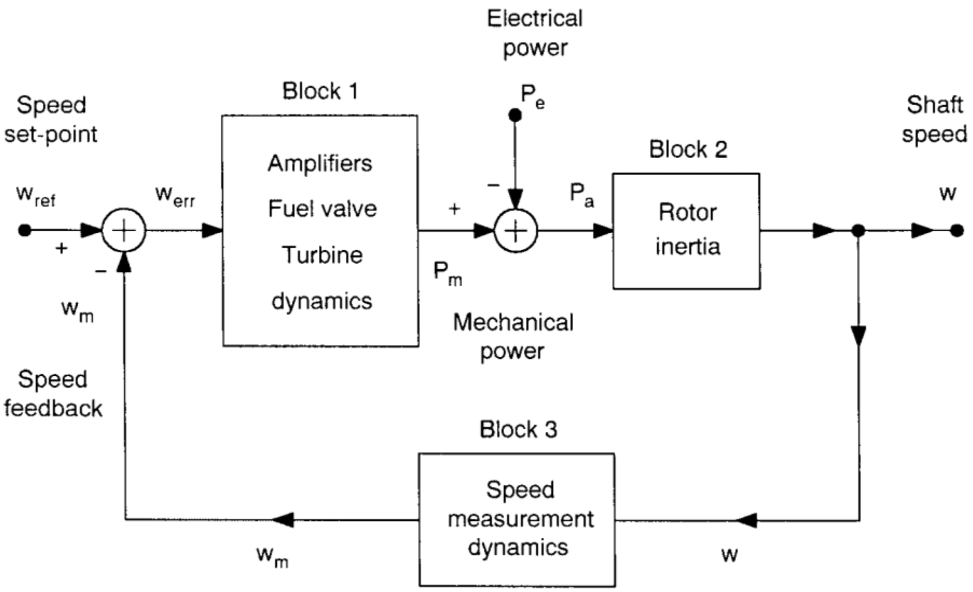


Figure 2. Basic control system block diagram of a gas turbine.

between droop governed gas turbines.

Consider a number of generators connected to the same bus bars. For the purpose of generality, it will be assumed that each of the generators has a different power rating and that each governor has a different droop

MATHEMATICAL MODELLING OF GAS TURBINE SPEED GOVERNING SYSTEMS

Control systems used for speed governing of gas turbines have become highly involved in electronic circuitry. Electromechanical fuel value control has largely replaced methods based on hydraulic control. The reliability of electronic and electrical devices has been improved so that they are mostly preferred to hydraulic and mechanical devices, where their use is appropriate.

The most well-known design of the computer programs used for dynamic studies of power systems are capable of representing control systems and machinery dynamics to a reasonably high level of detail. Manufacturers of gas turbines are normally providing detailed mathematical models of the machines and their control systems. A typical problem with the modeling of gas turbine is to achieve at the linearization of different component such as combustion and turbine. Obviously, the overall control system performance depends on the proper choice of each component. Accurate power sharing and constant speed control can be achieved by using a particularly designed controller. This controller incorporates load measurement of each generator, measurement of common system frequency and a sub-system to reduce the power mismatches of each generator to zero. The controller regularly or even continuously trims the speed set points of each gas turbine to maintain zero mismatches. A slowly operating integrator can be superimposed onto these set points to adjust them simultaneously so that the frequency is kept constant. This is a form of 'proportional integral' control (Bequette, 2003). The basic control system of general gas turbine generator systems is shown in Figure 2.

The mathematical model has six parameters that can be described as follows: ω = shaft speed, ωref = reference speed, Pe = electrical power at the generator shaft, Pm = mechanical output power of the gas turbine, Pa = accelerating power and Pf = friction and wind age power.

The modeling of the complete gas turbine including its control system and its interaction with the driven generator can be divided into several main functions (Ibrahim et al., 2011). The model shown in Figure 3 is one of the most commonly used models of gas turbine speed droop. It represents a single-shaft gas turbine while Figure 4 represents a realization of a two-shaft machine (Unbehauen and Kocaarslan, 1990; Sheldrake, 2003; Anderson et al., 1994; Murat et al., 2008) that has been extracted by Matlab software package and has been supported by experimental results.

Control system of Figure 4 has two major parts, that is, speed error sensing circuit and fuel valve mechanism.

Speed error sensing circuit

The output of the inertia block is the speed change that is, $e\omega$ generated by integration of the mismatch between Pe and Pm. The governor responds by actual speed of the shaft that is given in per unit term. The actual shaft speed is compared to the reference or set-point speed resulting in the error $e\omega 2$.

Fuel valve mechanism lag

The fuel valve actuator and its mechanism may have sufficient inductance or inertia to introduce a perceptible lag in the valve stem response to its input signal. The equivalent time constant is a specific value that is result of an experimental tuning process (Huang and Shah, 2000; Philip, 1999).

SIMULATION AND EXPERIMENTAL RESULTS

Governor is aimed to decrease turbine tension. To evaluate our proposal, we first made some actual tests in

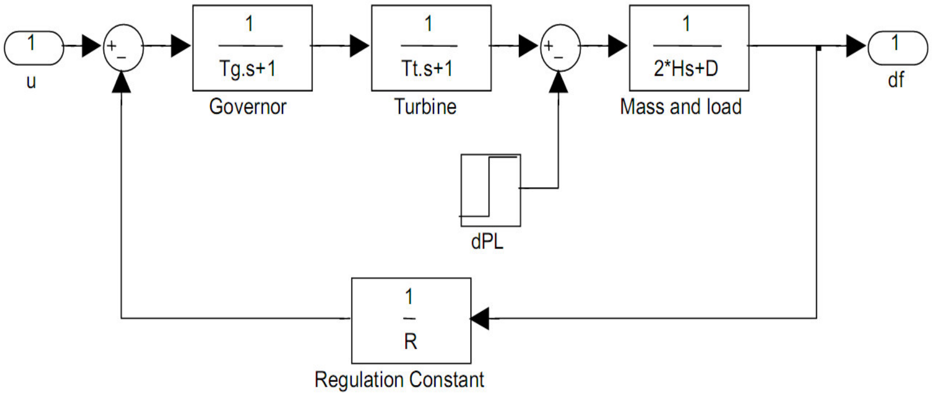


Figure 3. A single area power system with the controllers (PL = 0.01).

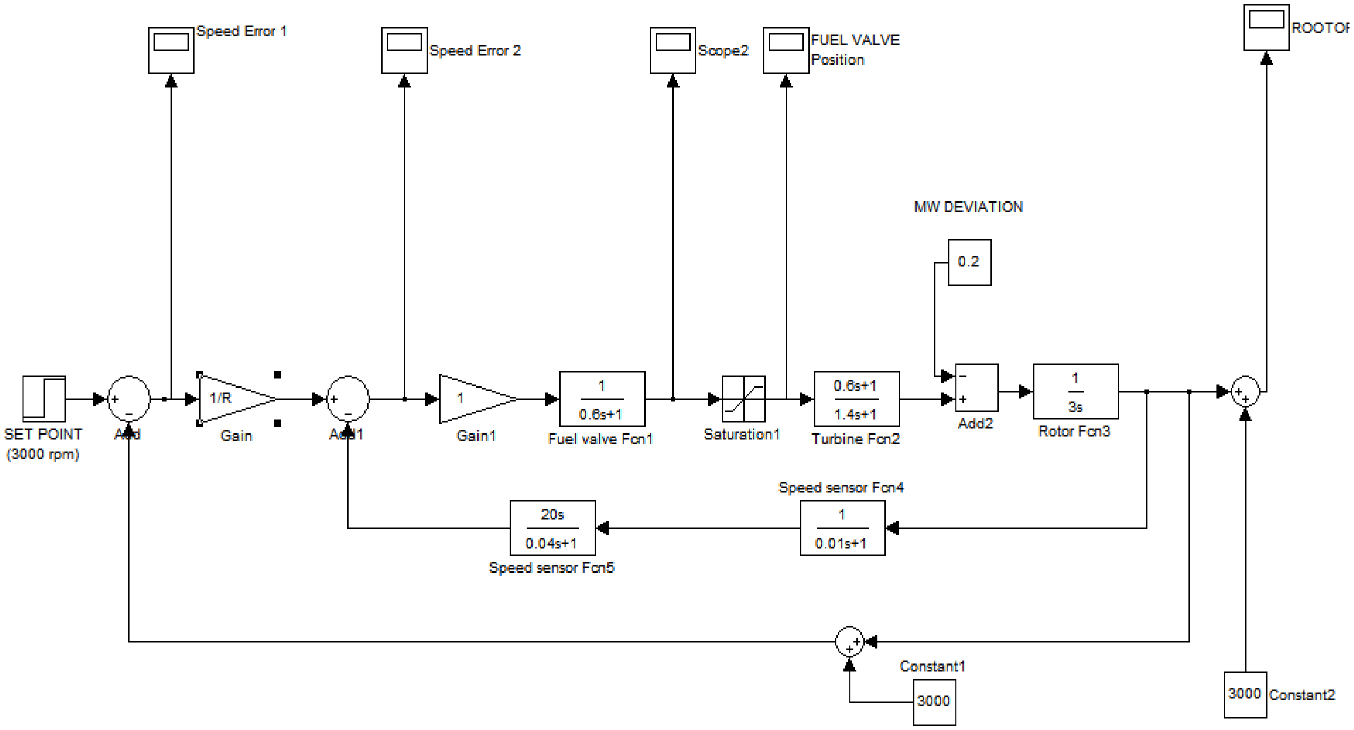
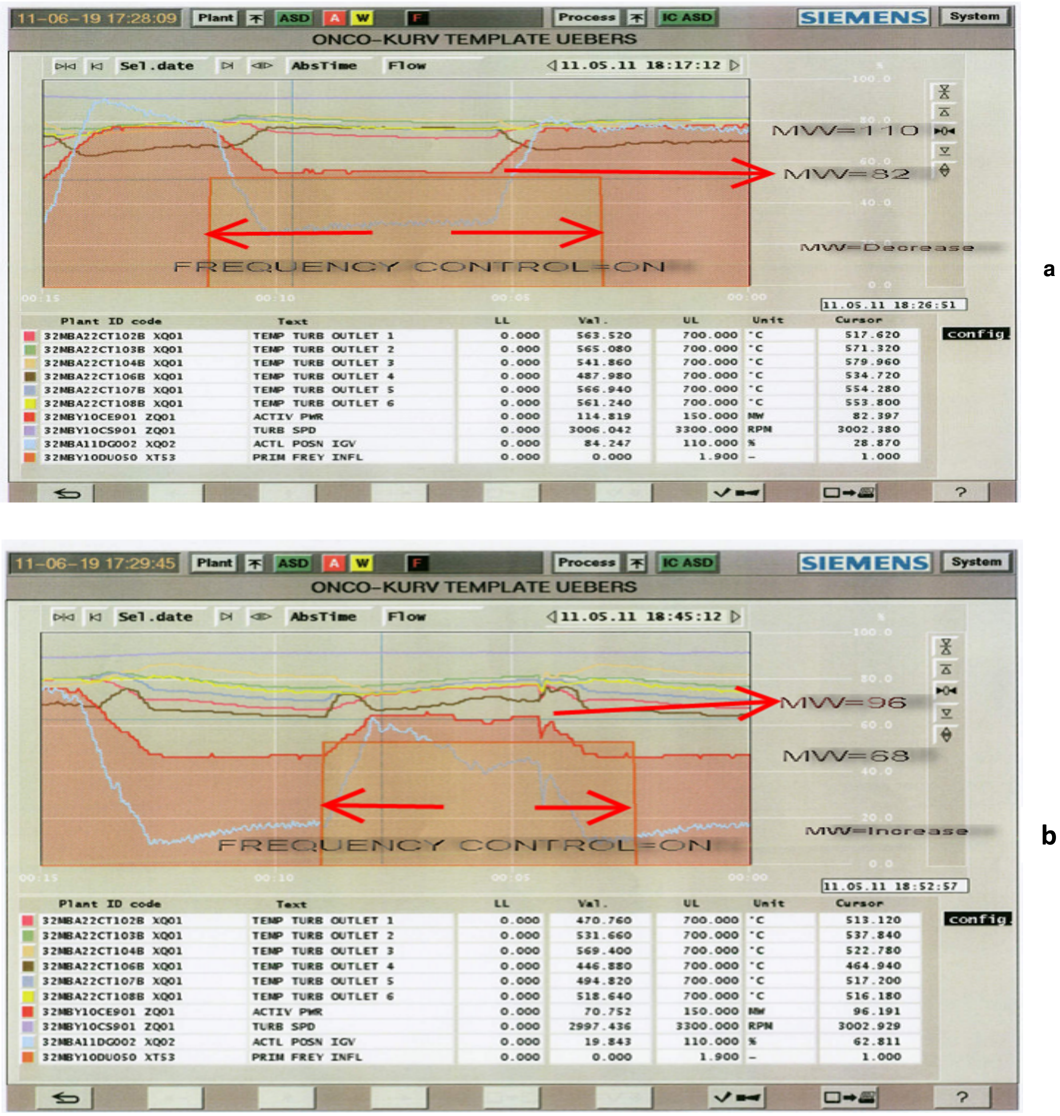


Figure 4. Control system for the speed governing of a two-shaft gas turbine.

a power plant and achieve stress level of different components for various operation conditions. Then we use Matlab software package to simulate the proposed model in various operation conditions and compare them with the experimental results. Table 1 shows behavior of a real power plant for different operation conditions in frequency contribution. It presents the operation conditions of different components of gas turbine power plant for various speed droops. This table can be used to choose the value for speed droop that cause the best operation condition. As we see in this table speed droop=0.2, is the best value for this scenario in which the turbine experiences the less tension. Our study showed that in a governor system, frequency wise participation of the gas turbine power plants along with proper adjustment of the droop speed with minimal load change and lowers than 30% of their nominal load capacitance gives the best response. Figure 5 shows an experimental result given from a power plant that has been tuned optimally by mentioned considerations. On the other

Table 1. Behavior of a real power plant for different operation conditions in frequency contribution.

Power plant nominal capacitance	Speed droop	MW Increase for frequency contribution	Fuel valve stress	Turbine stress	Evaluation
159 MW	1	65	0-6	0-1.3	Not acceptable
	0.5	30	0-3	0-0.55	Acceptable
	0.2	12	0-2	0-0.3	Quite acceptable
	1	160	0-6	0-3	Very weak
	0.5	80	0-3	0-0.6	Acceptable
	0.2	30	0-2	0-0.5	Acceptable



Plant ID code	Text	LL	Val.	UL	Unit	Cursor
32MBA22CT102B XQ01	TEMP TURB OUTLET 1	0.000	563.520	700.000	°C	517.620
32MBA22CT103B XQ01	TEMP TURB OUTLET 2	0.000	565.080	700.000	°C	571.320
32MBA22CT104B XQ01	TEMP TURB OUTLET 3	0.000	541.860	700.000	°C	579.960
32MBA22CT106B XQ01	TEMP TURB OUTLET 4	0.000	487.980	700.000	°C	534.720
32MBA22CT107B XQ01	TEMP TURB OUTLET 5	0.000	566.940	700.000	°C	554.280
32MBA22CT108B XQ01	TEMP TURB OUTLET 6	0.000	561.240	700.000	°C	553.800
32MBY10CE901 ZQ01	ACTIV PWR	0.000	114.819	150.000	MW	82.397
32MBY10CS901 ZQ01	TURB SPD	0.000	3006.042	3300.000	RPM	3002.380
32MBA11DG002 XQ02	ACTL POSN IGV	0.000	84.247	110.000	%	28.870
32MBY10DU050 XT53	PRIM FREY INFL	0.000	0.000	1.900	–	1.000

Plant ID code	Text	LL	Val.	UL	Unit	Cursor
32MBA22CT102B XQ01	TEMP TURB OUTLET 1	0.000	470.760	700.000	°C	513.120
32MBA22CT103B XQ01	TEMP TURB OUTLET 2	0.000	531.660	700.000	°C	537.840
32MBA22CT104B XQ01	TEMP TURB OUTLET 3	0.000	569.400	700.000	°C	522.780
32MBA22CT106B XQ01	TEMP TURB OUTLET 4	0.000	446.880	700.000	°C	464.940
32MBA22CT107B XQ01	TEMP TURB OUTLET 5	0.000	494.820	700.000	°C	517.200
32MBA22CT108B XQ01	TEMP TURB OUTLET 6	0.000	518.640	700.000	°C	516.180
32MBY10CE901 ZQ01	ACTIV PWR	0.000	70.752	150.000	MW	96.191
32MBY10CS901 ZQ01	TURB SPD	0.000	2997.436	3300.000	RPM	3002.929
32MBA11DG002 XQ02	ACTL POSN IGV	0.000	19.843	110.000	%	62.811
32MBY10DU050 XT53	PRIM FREY INFL	0.000	0.000	1.900	–	1.000

Figure 5. Experimental results in actual operation of a power plant in the droop test: (a) MEGA WAT is increasing from 82 to 110 MW (b) MEGA WAT is decreasing from 96 to 72 MW.

hand, Figures 6 to 11 show different stress curves of gas turbine detected over different components. We can see that these figures follow our claims given in Table 1. For example as shown in Figure 9, when the power plant system operates in the speed droop=0.03 and drift MW=50% of nominal capacitance, it sees less tension

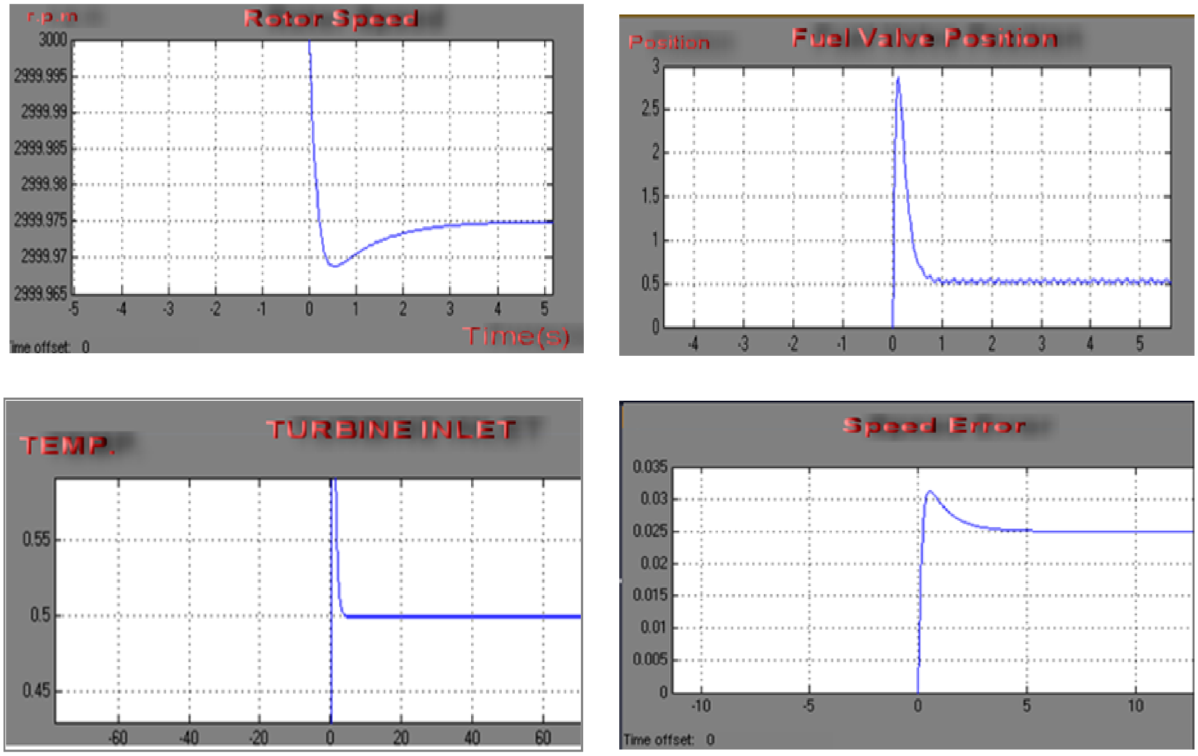


Figure 6. Stress curves for R=5% and MW drift =50%.

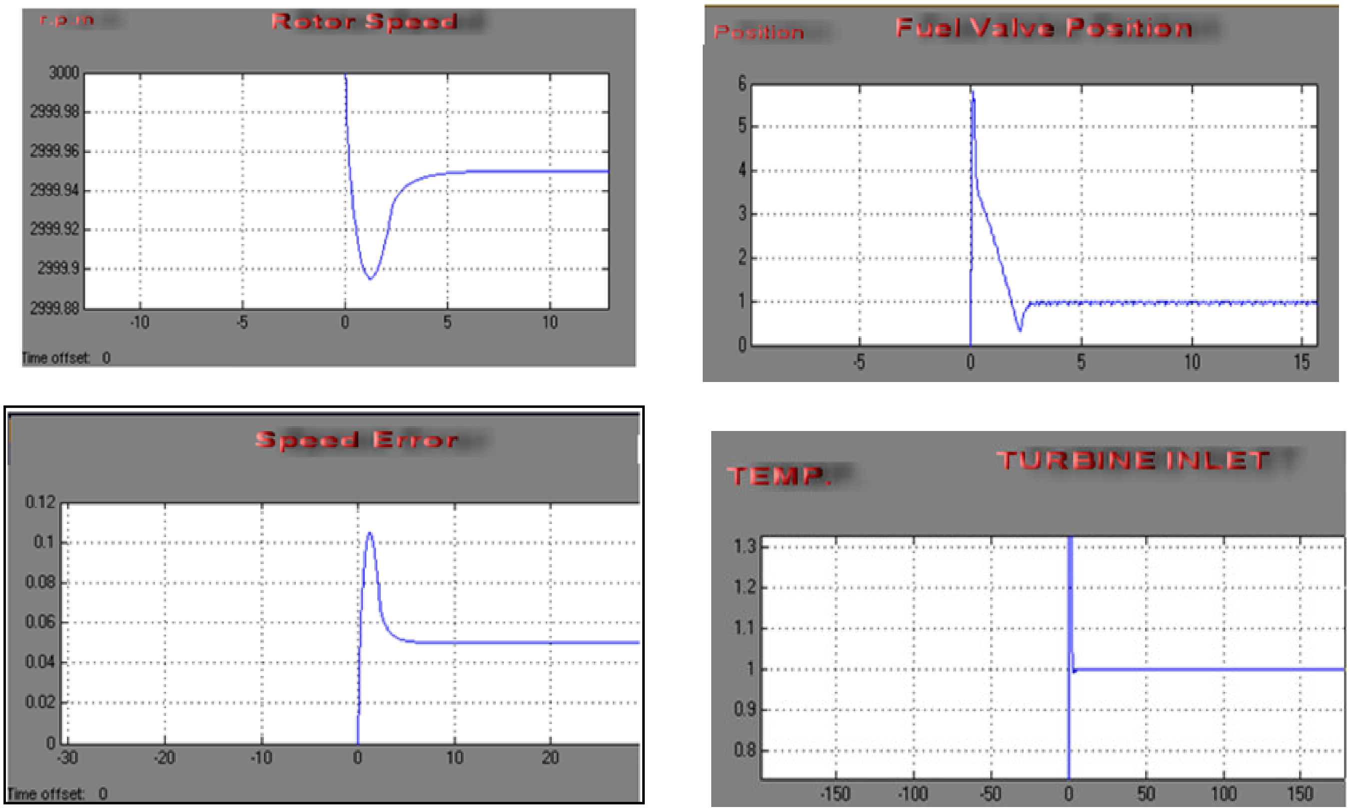


Figure 7. Stress curves for R=5% and MW drift =100%.

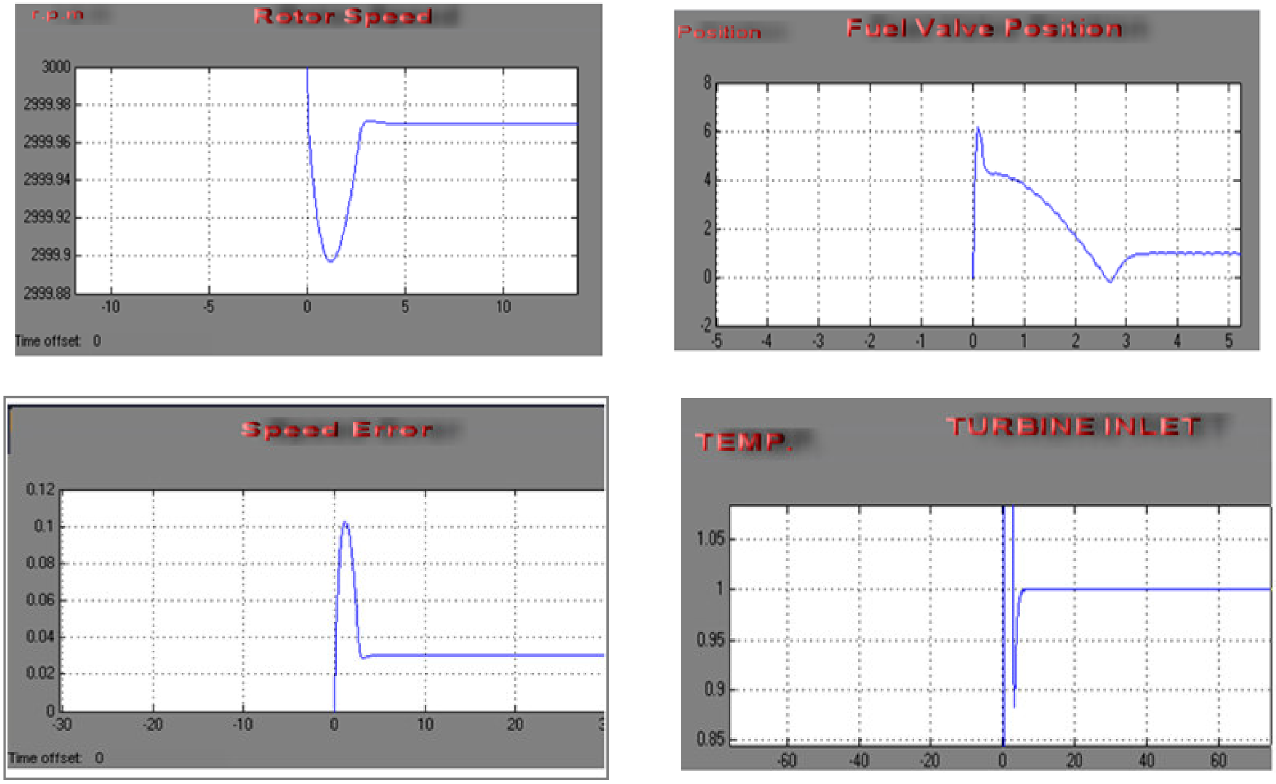


Figure 8. Stress curves for R=3% and MW drift =100%.

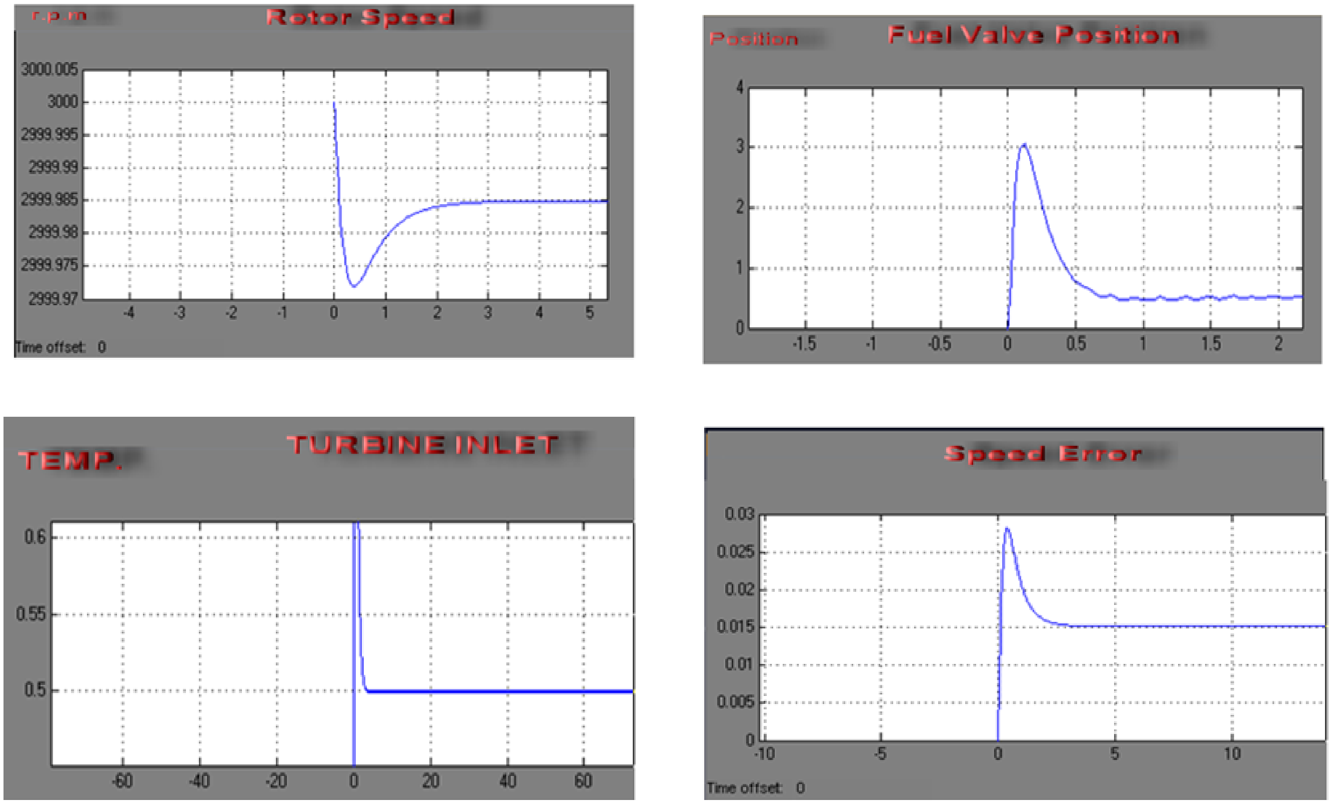


Figure 9. Stress curves for R=3% and MW drift =50%.

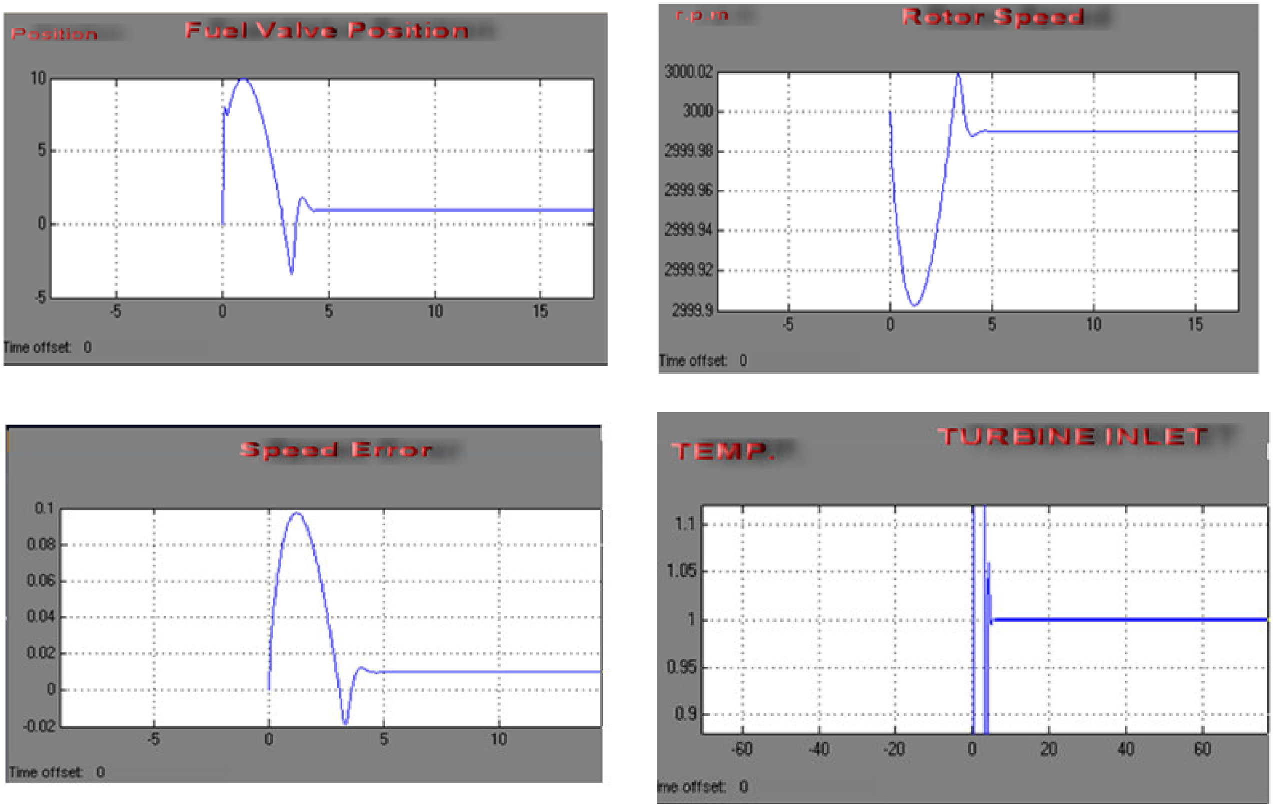


Figure 10. Stress curves for R=1% and MW drift =100%.

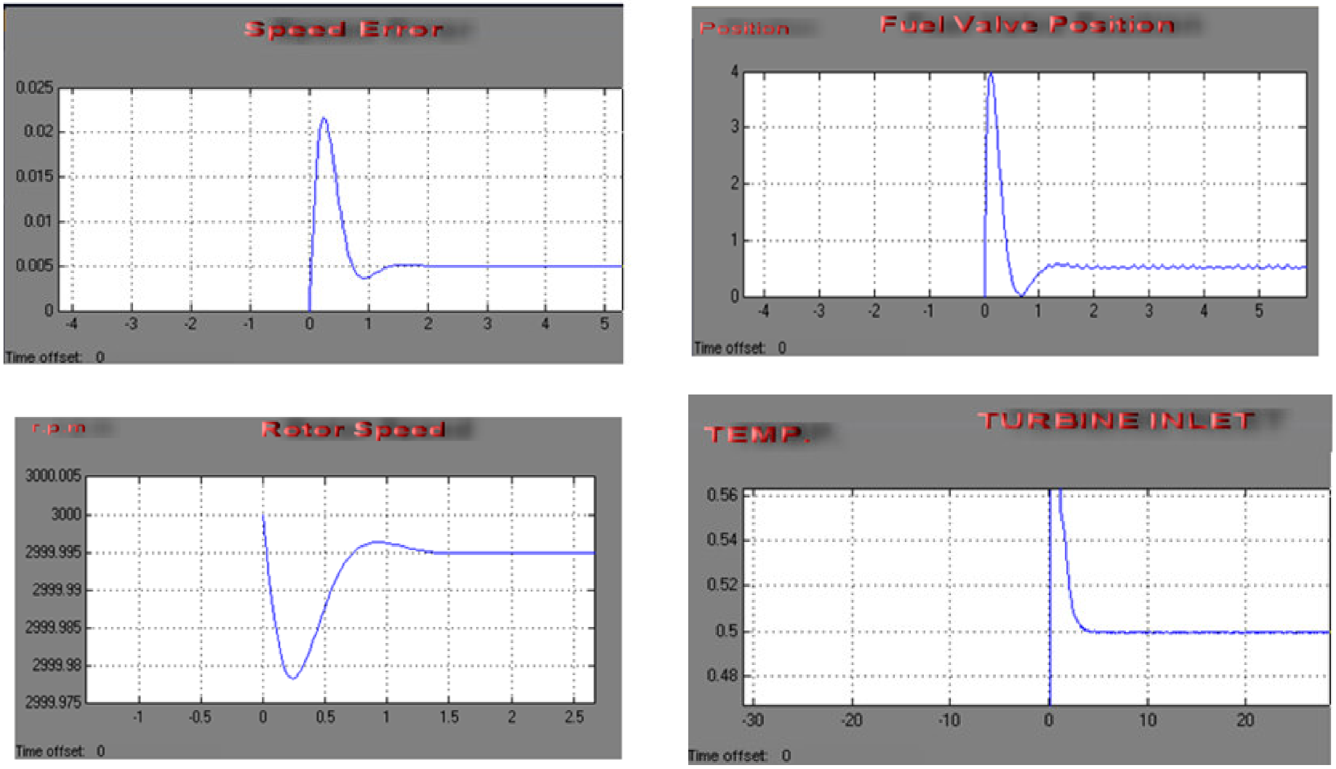


Figure 11. Stress curves for R=1% and MW drift =50%.

when compared with other figures.

Conclusions

Although, conventionally, water power plants are responsible for frequency correction of power network, it has some limitations. This paper proposed that gas turbine power plants can also take part in this mission. To this end, it employed some mathematical models along with extensive simulative study and even experimental measurements in an actual operation to draw those conditions that are necessary for a gas turbine power plant that attends in frequency correction issue. Simulation results and experimental measurements showed that in the proposed operation mode the power plants can take part in frequency correction, while they suffer from a little and acceptable tension.

As directions of future works in this area it seems that we can employ other types of controllers such as fuzzy controller and neural networked based learning controller to improve quality of the proposed approach. On the other hand we can apply some optimization algorithms such as particle swarm optimization (PSO) to direct the power system to its optimum point based on dynamic of the environments. In this case the controller monitors environmental conditions such as local loads, MW drifts, current frequency and so on, then tunes system's parameters in such away that its performance is directed to the optimum point.

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