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A Genetic Algorithm for Optimum Design of PID Controller in Multi Area Load Frequency Control for Egyptian Electrical Grid

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***Abstract-* This paper addresses the basic Load Frequency Control (LFC) model for the Egyptian electrical grid at 2024 after adding the first Nuclear Power Plant (NPP). The paper proposes a Genetic Algorithm (GA) technique used to determine the optimal tuning of the PID controllers parameters to improve the dynamic stability problem. Five types of energy sources transfer function block diagram models "thermal, hydraulic, gas, nuclear, wind" are simulated as a multi area power system by using MATLAB/SIMULINK to study the stability of the system. The performance of the proposed method is assessed compared to conventional PID controller in terms of Frequency response. A comparison with conventional PID controller shows that the proposed approach strategy can reduce the amplitude of oscillation and effectively enhance system stability.**

Keywords--Egyptian grid; Load Frequency Control (LFC); PID controller; genetic algorithm.

I. INTRODUCTION

Large scale power systems are normally composed of control areas or regions representing coherent groups of generators. In a future combination of electricity in Egypt, the generation normally comprises of a mix of thermal, hydro, nuclear, gas and wind or renewable power generation. However, owing to their high efficiency, nuclear plants are usually kept at base load close to their maximum output with no participation in the system Automatic Generation Control (AGC). Gas power generation is ideal for meeting the varying load demand. Gas plants are used to meet peak demands only. Thus the natural choice for AGC falls on either thermal or hydro units [1-4]. Since the time of construction of the nuclear plant takes from six to seven years, so this was a study on 2024. According to the latest load forecast research results in Egypt for year 2024 is approximately 60 GW, were in line with expectations with loads of the company's Egyptian electricity holding the Egyptian ministry of electricity [5, 6]. This paper study the system performance of Egyptian grid at 2024 by tracking the change in system frequency values for each case mentioned above, and try to maintain the difference in the change within a reasonable values by adding PID controller. MATLAB/SIMULINK program tool has been used for simulate the Egyptian electrical grid model as a transfer function block diagram [7]. Genetic Algorithms (GAs) are global optimization techniques that utilize concurrent search from multiple-points rather than from a single-point. GA is independent of the problem complexity. The main necessity of the GA is to specify the objective function and to place finite bounds on the parameters. GA is widely used for robust Power System Stabilization.

Optimization using GA techniques are widely applied in many real world problems such as image processing, pattern recognition, classifiers, machine learning. There are various forms of GA for different purposes. In this paper Genetic Algorithm techniques have been used to enhance the stabilization of the power systems by optimal tuning for the PID controller's parameters.

II. EGYPTIAN ELECTRICAL GRID DATA

Before the start in our study there important information about Egypt's current electrical grid and future expectations for the electrical grid in 2024 must be present and are as follows.

A. *A current combination of the Egyptian electrical grid*

After reviewing the annual report for the year 2014 of the company's Egyptian Electricity Holding the Egyptian Ministry of Electricity show that the total production of electricity in Egypt for the year 2014 is almost 30 GW and the current combination of the sources of electricity production in Egypt as follows in Table I [5].

TABLE I. A CURRENT COMBINATION OF THE EGYPTIAN ELECTRICAL GRID.

Source type	Total production in GW	Total production in %
Thermal	20 GW	60%
Gas	7.5 GW	27%
Hydraulic	2.8 GW	10%
Wind and Renewable	GW 1	3%

B. The proposed combination of the Egyptian electricity grid at 2024

After study the current combination of the Egyptian grid, also review the future plans of the Ministry of Electricity in the construction of various types of plants for the production of electrical energy over the next ten year, and also predicted the total loads of the Egyptian grid in 2024 where it was almost 60 GW [6]. Taking into account all the circumstances and requirements for the production of electrical energy in 2024 from the fuel sources and construction time of a new different types of power plants, it has been found an urgent need to start building the first nuclear power plant in Egypt to overcome the increasing in the loads and decreasing in the fuel sources. Knowing that the construction of this station time about seven years, so our simulation must have been make at 2024. So the chart of the Egyptian electrical grid will be changed to become at 2024 as shown in Table II.

TABLE II. A PROPOSED COMBINATION OF THE EGYPTIAN ELECTRICAL GRID AT 2024.

Source type	Total production in GW	Total production in %
Thermal	33 GW	55%
Gas	18 GW	30%
Hydraulic	3.2 GW	6%
Nuclear	1.2 GW	2%
Wind and Renewable	4.2 GW	7%

III. MODELING OF POWER SYSTEM

Action will be design of the Egyptian electrical grid in year 2024 in the form of transfer function block diagrams as a one area power system, Electricity produced divided in the Table 2 proportions indicated in the table and illustrated in Fig.1 [8].

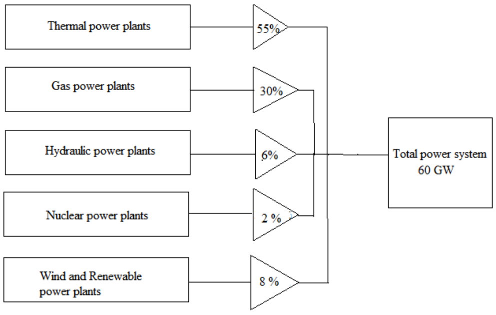


Fig.1: Proposed combination energy sources of the Egyptian electrical grid at 2024.

A. thermal model

A single area thermal power system has two main parts that are speed governor and turbine. In starting it is assumed that this system is linear for simplicity. The transfer function block diagram model of thermal governor is shown as in Fig. 2 [7-9].

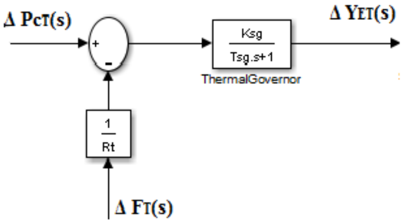


Fig. 2. Thermal power plant speed governor block diagram.

Where,
K_{sg} : Thermal speed governor gain.
R_T : Thermal speed regulation of the governor.
T_{sg} : Thermal speed governor time constant.

The turbine transfer function is characterized by two time constants. For ease of analysis, it will be assumed here that turbine can be modeled to have a single equivalent time constant. Fig. 3 shows the transfer function model of a steam turbine without reheat and with reheat unit respectively. Typically the time constant T1 lies in the range 0.2–2.5 s [7-9].

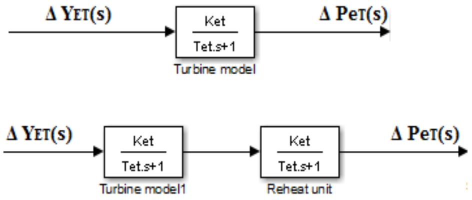


Fig. 3. Thermal power plant steam turbine block diagram.

Where,
T_t : Thermal turbine time constant.
T_r : Thermal re-heater time constant.
K_r: Coefficient of thermal re-heat steam turbine.

B. *HYDRAULIC MODEL*

As for the requirement of hydro-electric power system modeling for load frequency control, speed governor and turbine should be modeled. The model development of different components of single area hydro system is explained as in Fig. 4 [10, 11].

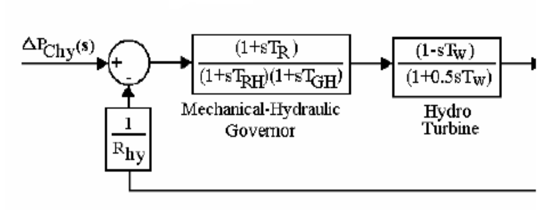


Fig.4. Hydraulic power plant block diagram.

Where,

T_{Rg} : Hydraulic speed governor rest time.
T_{RH} : Hydraulic transient droop time constant.
T_{GH} : Main servo time constant.
T_w : Hydraulic water time constant.
R_{hy} : Hydraulic speed governor regulation parameter.

C. *GAS MODEL*

As for the requirement of gas power system modeling for load frequency control, speed governor, valve positioner, fuel system and turbine should be modeled These are modeled as shown in Fig. 5 [12, 13].

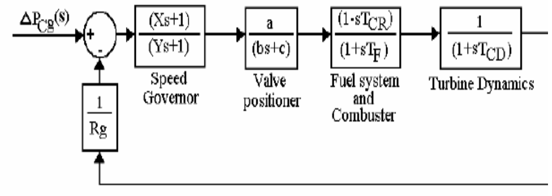


Fig. 5. Gas power plant block diagram.

Where,

X and *Y* : Gas speed governor lead and lag time constants.
a, b and *c* : Gas valve positioner constants.
T_F : Gas fuel time constant.
T_{CR} : Gas combustion reaction time delay.
T_{CD} : Gas compressor discharge volume time constant.
R_g : Gas speed governor regulation parameter.

D. *Nuclear model*

As for the requirement of nuclear power system modeling for load frequency control, speed governor and turbine should be modeled. The transfer function block diagram model of governor is shown as in Fig. 6 [11].

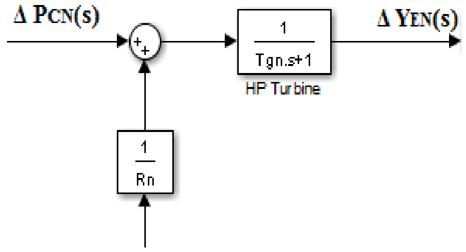


Fig.6. Nuclear Power Plant Speed Governor block diagram.

The Mathematical model considered for nuclear unit tandem-compound turbines, one HP section and two LP section with HP reheater as shown in Fig. 4.14. The HP exhausts Moisture Separator Reheater (MSR) before entering the LP turbine. The MSR reduces the moisture content of the steam entering the LP section, thereby reducing the moisture and erosion rates. High pressure steam is used to reheat the HP exhaust as show in Fig. 7.

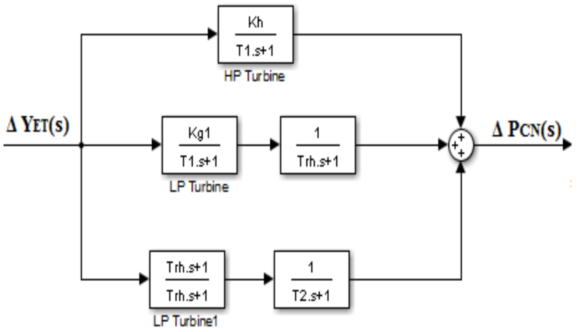


Fig. 7. Nuclear power plant turbine block diagram.

Where,

ΔP_{CN} : Change in speed changer setting of nuclear system.
R_n : Speed regulation of nuclear governor.
T_{gn} : Governor time constant of nuclear system.
T_1 : HP nuclear turbine time constant.
K_h : Coefficient of HP re-heat nuclear steam turbine.
K_{g1} : Coefficient of LP re-heat nuclear steam turbine.
T_{rh} : LP nuclear turbine time constant.

E. *Wind model*

As for the requirement of wind power system modeling for load frequency control, speed governor, and turbine should be modeled. These are modeled as shown in Fig. 8 [14, 15].

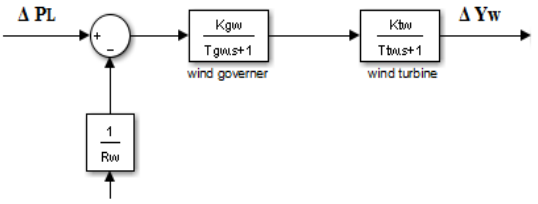


Fig. 8. Wind power plant block diagram.

Where,

K_{gw} : Wind speed governor gain.
T_{gw} : Wind speed governor time constant.
T_{tw} : Wind turbine time constant.
K_{gw} : Wind turbine gain.
R_w : Wind governor speed regulation.

F. *Load and generator model*

The generator dynamics is modeled by swing equation and given in equation (1):

$$\frac{2H}{w_s}\frac{d^2\Delta\delta}{dt^2} = \Delta Pm - \Delta Pe \qquad (1)$$

For small perturbation the above relation can be represented by a block diagram as shown in Fig. 9 [7].

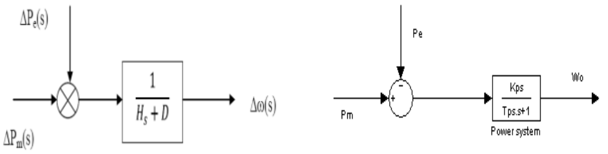


Fig. 9. Generator and load ”power system” block diagram.

Where,
Fr : Nominal system frequency.
Pr : Rated power of the system “MW”.
Δδ : change in power angle**.**
ΔPm : Change in mechanical power.
ΔPe : Change in electrical power.
H : inertia constant of the generator ”MW-s/MVA” .
D : System damping “load frequency characteristic” pu MW/Hz.
Kps: Power system gain =1/D Hz/pu MW.
Tps : Power system time constant = 2H/(Fr*D) sec.

can put an initial vision or suppose block diagram model for the Egyptian electrical grid as a five area power system at 2024 as shown in Fig. 10 and Fig. 11 [16].
To apply this model will be classified our power system load generation to five parts for the five areas as follow:

Thermal area power system:
Fr = 50 Hz, **Pr** = 33000 MW, **H** = 6 MW-s/MVA
Hydraulic area power system:
Fr = 50 Hz, **Pr** = 3600 MW, **H** = 3 MW-s/MVA
Gas area power system:
Fr = 50 Hz, **Pr** = 18000 MW, **H** = 3 MW-s/MVA
Nuclear area power system:
Fr = 50 Hz, **Pr** = 1200 MW, **H** = 6 MW-s/MVA
Wind area power system:
Fr = 50 Hz, **Pr** = 4200 MW, **H** = 5 MW-s/MVA

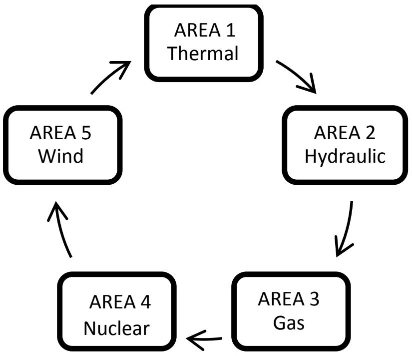


Fig. 10. Egyptian electrical grid as a multi area flow chart**.**

V. CASE STUDIES ON THE OUR MODEL

To complete study the dynamic stability and reliability on the system after adding the first NPP to the Egyptian grid, three cases of study. To do sensitivity analysis or study the effect of varying various parameters on the dynamic responses of the Egyptian electrical grid, 1%, 5% and 10% step load perturbation in the thermal model has been done as shown in Fig 11. PID controller has been added to the system in the two cases to overcome the effect of this disturbance,

The dynamic performance of LFC has been made based upon a linearized analysis. The simple LFC model does not consider the effects of the physical constraints. Although considering all dynamics in frequency control synthesis and analysis may be difficult and not useful, it should be noted that to get an accurate perception of the LFC subject it is necessary to consider the important inherent requirement and the basic constraints imposed by the physical system dynamics, and model them for the sake of performance evaluation [7].

IV. THE BLOCK DIAGRAM MODEL FOR THE EGYPTIAN ELECTRICAL GRID AT 2024

From the previous study of the different types of energy sources to produce the electricity and how to simulate in a transfer function block diagram models, now we

and the change in the system frequency will be seen in the results section before and after PID controller.

VI. PID CONTROLLER

In this study PID controller is used as a supplementary control for LFC and AVR. The PID controllers are widely used in industry because of its clear functionality, easy implementation, applicability, robust performance and simplicity. The transfer function of PID controller is

$$G_c(s) = K_p + \frac{K_i}{s} + K_d s \qquad (2)$$

Where $G_c(s)$ is the controller output and tracking error signals in s-domain. K_p is the proportional gain, K_i is the integral gain and K_d is the derivative gain. In PID controller, proportional part reduces the error responses to disturbances, the integral part minimizes the steady-state error and the derivative term improves the transient response and stability of the system. To get the optimum performance from the considered system, the gains of the PID controller must be tuned in such a way that the close loop system produces desired result. The desired result should have minimum settling time, no overshoot and zero steady state error. These parameters of the PID controller can be designed by some methods like try and error, and Ziegler–Nichols method, that called conventional methods. The parameters of the PID controller can be designed using developed Genetic Algorithm (GA) [17, 18].

VII. GENET1C ALGORITHM

Genetic Algorithms (GAs) are based on Darwin’s theory of natural selection and survival of the fittest. It is a heuristic optimization technique for the most optimal solution (fittest individual) from a global perspective but more importantly, it provides a mechanism by which solutions can be found to complex optimization problems fairly quickly and reliably. The GA is an optimization and stochastic global search technique based on the principles of genetics and natural selection. A GA allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the “fitness” (i.e., minimizes the cost function). The method was developed by John Holland (1975) over the course of the 1960s and 1970s and finally popularized by one of his student, David Goldberg (1989). Generally in GA, there are three basic operations like reproduction, crossover and mutation. A proposed GA technique flow chart that shows these operations see in Fig. 12.

A. Reproduction: It is a process in which a new generation of population is formed by selecting the fittest individuals in the current population. This is the survival of the fittest mechanism. Strings selected for reproduction are copied and entered to the mating pool.

B. Crossover: Mating is the creation of one or more offspring from the parents selected in the pairing process. The current members of the population limit the genetic makeup of the population. The most common form of mating involves two parents that produce two offspring. The new offspring may replace the weaker individuals in the population. With the cross over operation, GA is able to acquire more information with the generated individuals and the search space is thus extended and more complete.

C. Mutation: Random mutations alter a certain percentage of the bits in the list of chromosomes. Mutation is the second way a GA explore a cost surface. It can introduce traits not in the original population and keeps the GA from converging too fast before sampling the entire cost surface.

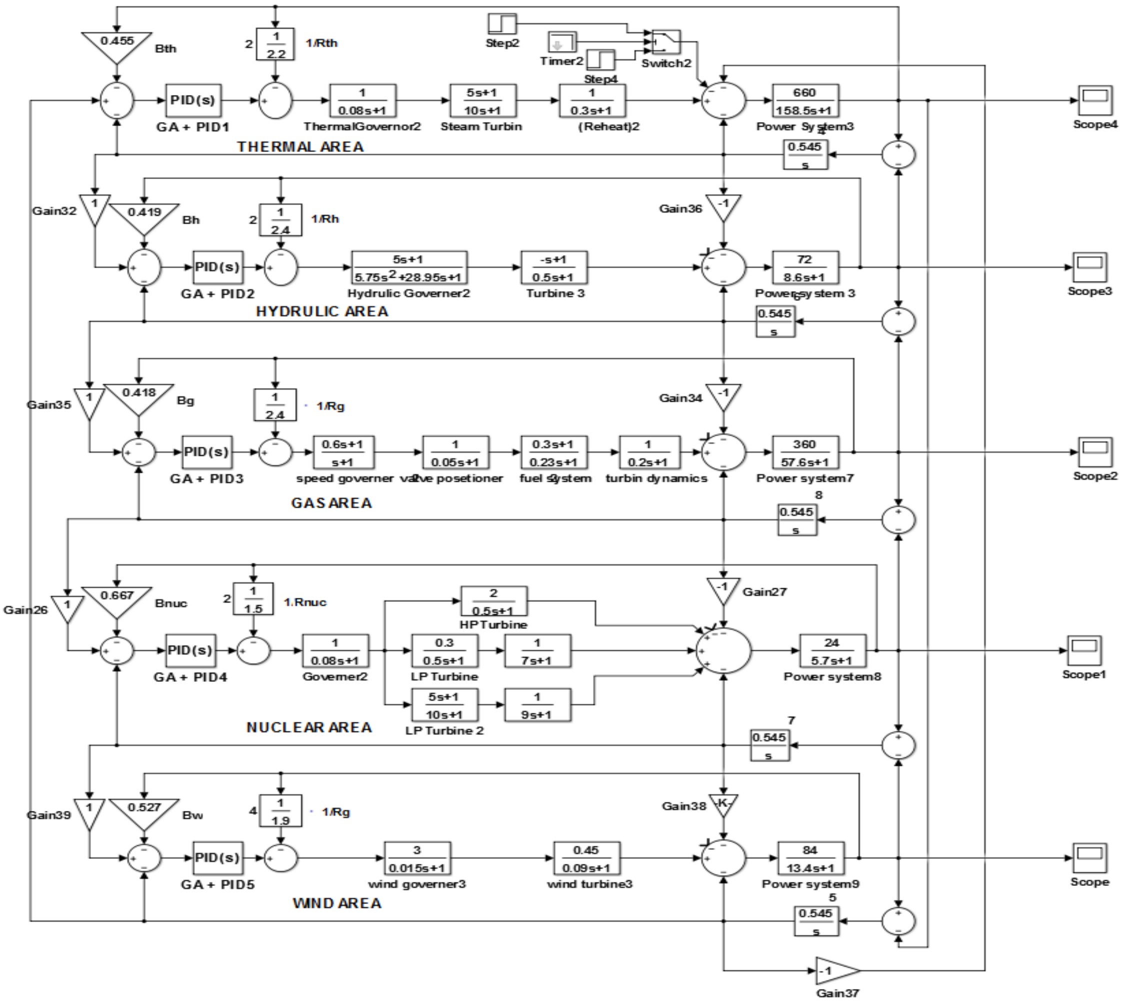


Fig. 11. Egyptian grid at 2024 as a multi area block diagram model with thermal disturbances.

GA based minimization approach to determine the values of K_p, K_i, K_d has been developed in this paper. The parameter of PID controller has been tuned according to GA based performance indices [19, 20].

VIII. SIMULATION AND RESULTS

The simulation of LFC was done for two cases "1%, and 10%" step load perturbation in the thermal area, and will see the results in the following paragraphs.

A. The frequency response for 1% load perturbation

After five second 1% load perturbation happen on the thermal area in our model the frequency response for the five area power system Shown in Fig. 6.13 (a, b, c, d, e), where the change in frequency 'delta F' curve don't return to zero again in each area its mean system not stable. Five PID controllers have been added to the system one for each area to overcome the effect of this disturbance, and the change in the system frequency will be seen in Fig, 6.13 (a, b, c, d, e) after putting the PID controller. The controller parameters tuned by two methods conventional method and AI method "GA technique" to get the best results for the system stability, the PID controller parameters used shown in Table III.

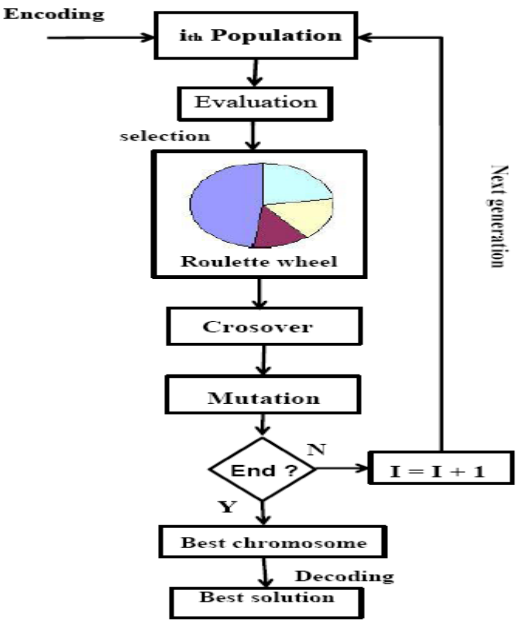
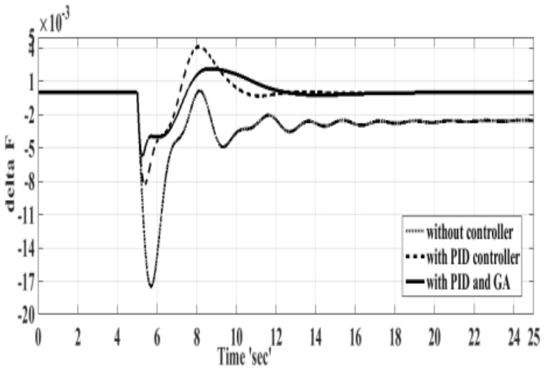


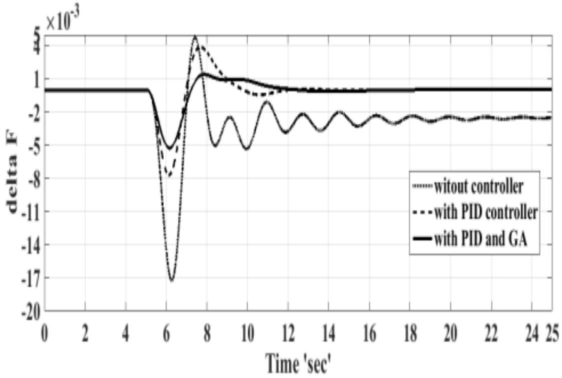
Fig. 12. Genetic algorithm technique flow chart

TABLE III. PID CONTROLLERS' PARAMETERS FOR 1% THERMAL LOAD PERTURBATION.

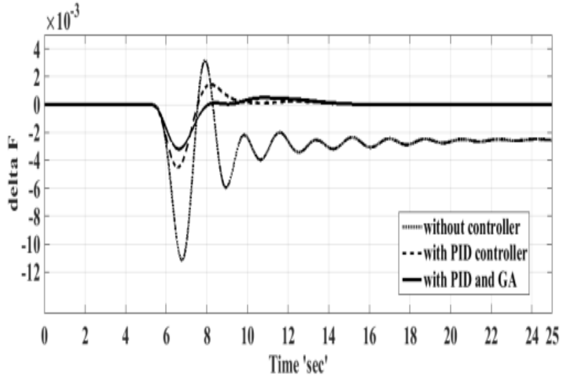
PID no.	PID parameters	Conventional values	GA values
PID1	K_{P1}	0.58	0.72
	K_{I1}	1.60	1.61
	K_{D1}	4.11	2.53
PID2	K_{P2}	0.25	0.25
	K_{I2}	1.60	1.58
	K_{D2}	0.012	0.03
PID3	K_{P3}	0.20	0.20
	K_{I3}	1.66	1.66
	K_{D3}	0.61	0.61
PID4	K_{P4}	1.34	1.34
	K_{I4}	1.50	1.50
	K_{D4}	0.92	0.92
PID5	K_{P5}	1.16	1.16
	K_{I5}	1.55	1.56
	K_{D5}	0.90	1.28



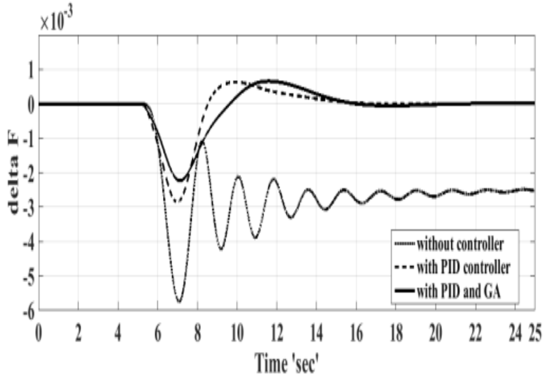
(a). Frequency response of thermal area.



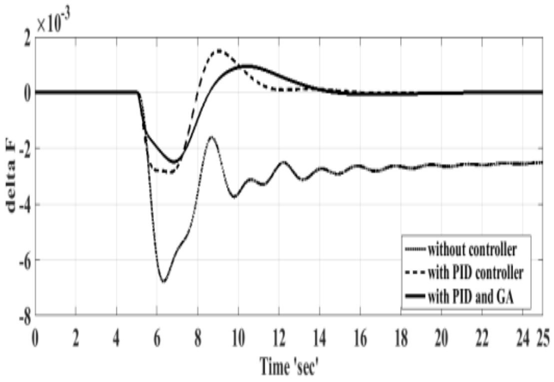
(b). Frequency response of hydraulic area.



(c). Frequency response of gas area.



(d). Frequency response of nuclear area.



(e). Frequency response of wind area.

Fig. 13. Frequency response of five areas for 1% load perturbation on thermal area.

Table IV show the maximum over shot and settling time for each area in our model after 1% load perturbation on thermal area happen and adding PID controller in each area.

TABLE IV. FREQUENCY RESPONSE RESULTS FOR EACH AREA FOR 1% LOAD PERTURBATION

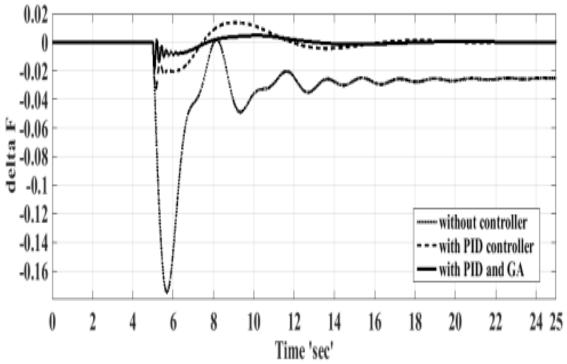
Area	Results	Δ F	F (Hz)
Thermal	Max. over shot	-0.0057	49.71 Hz
	Settling time	10 sec	
Hydraulic	Max. over shot	-0.005	49.7 Hz
	Settling time	10 sec	
Gas	Max. over shot	-0.0033	49.8 Hz
	Settling time	10 sec	
Nuclear	Max. over shot	-0.0022	49.9 Hz
	Settling time	10 sec	
Wind	Max. over shot	-0.0025	49.87 Hz
	Settling time	10 ec	

B. *The frequency response for 10% load perturbation*

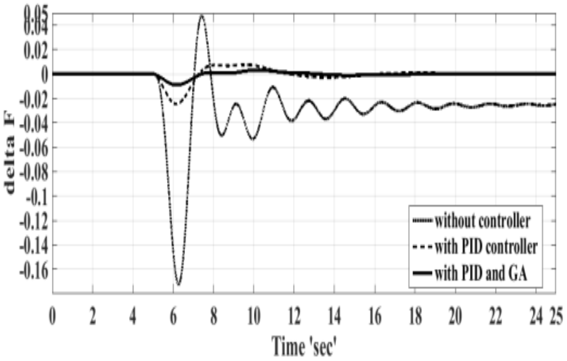
After five second 10% load perturbation happen on the thermal area in our model the frequency response for the five area power system Shown in Fig. 6.14 (a, b, c, d, e), where the change in frequency 'delta F' curve don't return to zero again in each area its mean system not stable. Five PID controllers have been added to the system one for each area to overcome the effect of this disturbance, and the change in the system frequency will be seen in Fig, 6.14 (a, b, c, d, e) after putting the PID controller. The controller parameters tuned by two methods conventional method and AI method "GA technique" to get the best results for the system stability, the PID controller parameters used shown in Table VI.

TABLE VI. PID CONTROLLER'S PARAMETERS FOR 10% THERMAL LOAD PERTURBATION.

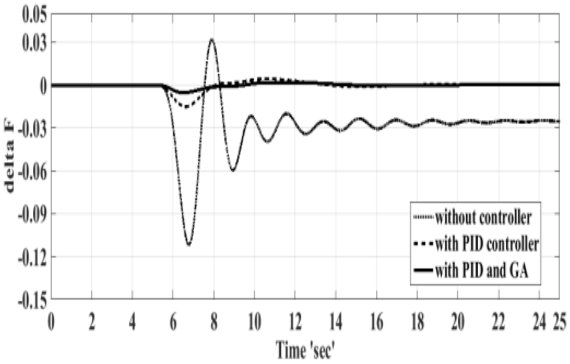
PID no.	PID parameters	Conventional values	GA values
PID1	K_{P1}	1.95	6.95
	K_{I1}	3.95	8.47
	K_{D1}	6.45	19.45
PID2	K_{P2}	0.21	0.12
	K_{I2}	1.58	1.42
	K_{D2}	0.012	0.02
PID3	K_{P3}	0.20	1.59
	K_{I3}	1.66	1.56
	K_{D3}	0.61	0.11
PID4	K_{P4}	1.34	1.08
	K_{I4}	1.50	0.91
	K_{D4}	0.92	0.30
PID5	K_{P5}	1.16	1.37
	K_{I5}	1.56	1.53
	K_{D5}	0.90	0.91



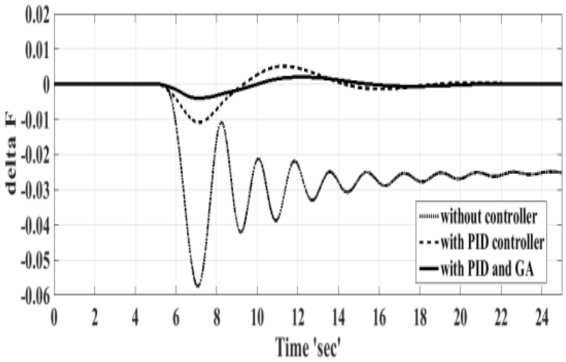
(a). Frequency response of thermal area.



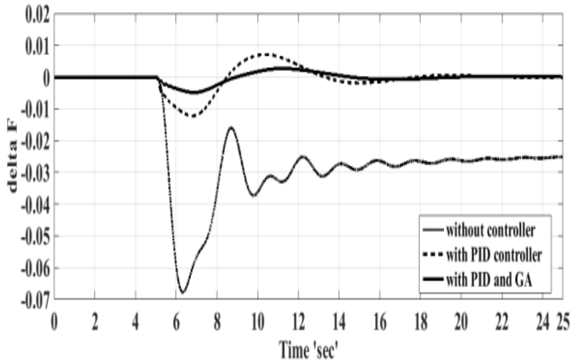
(b). Frequency response of hydraulic area.



(c). Frequency response of gas area.



(d). Frequency response of nuclear area.



(e). Frequency response of wind area.

Fig. 14. Frequency response of five areas for 10% load perturbation on thermal area.

Table VII show the maximum over shot and settling time for each area in our model after 10% load perturbation on thermal area happen and adding PID controller in each area.

TABLE VII. FREQUENCY RESPONSE RESULTS FOR EACH AREA FOR 10% LOAD PERTURBATION.

Area	Results	Δ F	F (Hz)
Thermal	Max. over shot	-0.018	49.1 Hz
	Settling time	15 sec	
Hydraulic	Max. over shot	-0.008	49.6 Hz
	Settling time	15 sec	
Gas	Max. over shot	-0.005	49.75 Hz
	Settling time	10 sec	
Nuclear	Max. over shot	-0.004	49.8 Hz
	Settling time	15 sec	
Wind	Max. over shot	-0.005	49.75 Hz
	Settling time	15 sec	

IX. CONCLUSION

After finish this analysis by make different load perturbation '1%, and 10%' on the thermal area in our model, it's clear that as increasing in the load perturbation as increasing in the maximum over shot and settling time for all areas of our model, also the PID controllers remain the system stay stable after that disturbances because the maximum overshot frequency and the settling time do not exceed "1 Hz" and "15 sec" for each area of our model and it is in the allowable range.

It's clear that when GA technique used for tuned PID controllers increase the accuracy of the frequency response results than the conventional tuning methods. Moreover, GA technique is faster than the conventional method and highly complex, dynamic behavior and nonlinearity for power systems, together with their almost continuously time varying nature, have posed a great challenge to power system control engineers for decades.

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