Simulation model of Al-Dura electro-station plant of 160 MW with Genetic Algorithm method

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ABSTRACT

In the present paper, a thermodynamic analysis of Al-Dura, Baghdad station type (K– 160–13.34–0.0068), power plant has been carried out. The power plant system was simulated and a detailed parametric study undertaken. This study can be helpful to identify the plant site conditions that cause losses of useful energy taken place and also helpful to resolve some problems encountered in steam turbine, capacity unit. Developing nonlinear mathematical models based on system identification approaches during normal operation without any external excitation or disruption is always a hard effort, assuming that parametric models are available. This study included on using soft computing methods that would be helpful in order to adjust model parameters over full range of input–output operational data. In this case, the model parameters are adjusted by applying genetic algorithms as optimization methods. Comparison between the responses of the turbine – generator model with the responses of real system validates the accuracy of the proposed model in steady state and transient conditions. Simulation results shows that the efficiencies and feasibility of the developed model in term of more accurate and less deviation with the responses of read system in the steady and transient conditions, and the error of proposed function is less than 0.37%. This study presents the usage of the Cycle – tempo and Matlab/Simulink package to implement the model of the power plant. Finally, many recommendations have been suggested for improved plant performance.
Keywords: Steady state, Transient conditions, Simulation model, PID controller, Genetic Algorithm

INTRODUCTION

The steam turbines have been widely employed for power generation due to their efficiencies and costs. With respect to the capacity, application and desired performance, a different level of complexity is offered for the structure of steam turbines. For power plant applications, steam turbines generally have a complex feature and consist of multistage steam expansion to increase the thermal efficiency. It is always more difficult to predict the effects of proposed control system on the plant due to complexity of turbine structure. Therefore, developing nonlinear analytical models is necessary in order to study the turbine transient dynamics. These models can be used for control system design synthesis, performing real-time simulations and monitoring the desired states [1]. System identification during normal operation without any external excitation or disruption would be an ideal target, but in many cases, using operating data for identification faces limitations and external excitation is required [2]. Genetic algorithms (GA) have outstanding advantages over the conventional optimization methods, which allow them to seek globally for the optimal solution. It causes that a complete system model is not required and it will be possible to find parameters of the model with

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nonlinearities and complicated structures [3]. In the recent years, genetic algorithms are investigated as potential solutions to obtain good estimation of the model parameters and are widely used as an optimization method for training and adaptation approaches.

M S Jamel et. al, [4], carried out a simulation of a 200 MW gas – fuelled conventional steam power plant located in Basra, Iraq. The thermodynamic performance of the considered power plant is estimated by a system simulation. A flow – sheet computer program, "Cycle – Tempo" was used for this study. Orosun Rapheal and Adamu Sunusi Sani, [5], modeled physical boiler system as a multivariable plant with two inputs (feed water rate and oil – fired flow rate) and two outputs (steam temperature and pressure). The plant parameters ware modeled by identification based on experimental data collected directly from the plant. The identified model was subjected to test, using the validation input data; simulated model outputs for both temperature and pressure agree closely with the actual plant outputs with error of 8% and 9% respectively. Furthermore, Proportional Integral Derivative (PID) Controller was developed to control the identified model. The influence of the steam and water extractions on the turbine behavior as well as the importance of an accurate model for the steam and water extractions were carefully studied. Heat and mass balances of the Nuclear Power Plant are presented [6]. The comparison between steady state simulations and the real plant data indicated a satisfactory accuracy of the model and of the thermodynamic approach used. The Neuro fuzzy system (NFs) and subtractive clustering were used to calculate energy properties within the experimental steam power plant. Neuro fuzzy models are constructed from each subsystem of thermodynamic properties [7], such as saturated water or superheat steams.

Ali Chaibakhsh and Ali Ghaffari, [8], considered a steam turbine of a 440 MW power plant with once – through Benson boiler for the modeling approach. They characterized the transient dynamic of steam turbine, by developing a non – linear mathematical model firstly, based on the energy balance, thermodynamic principles and semi – empirical equations. Then, the related parameters of developed models were either determined by empirical relations or they were adjusted by applying Genetic Algorithm (GA).

The main objectives of the present work to build up the theoretical model to simulate steam turbine power station. Using two analytical and simulation techniques that implicitly satisfy the traditional designer parameters and provide enough flexibility and accuracy to represent any steam turbine power plant. As well as Using the two packages Matlab and Cycle – tempo to predict the optimal state of parameters that was used by turbine systems based on genetic algorithms.

Turbine Performance under Transient Conditions:

The model performs initially steady state analysis, based on input specifications defined by the user like power output or initial steam and condensing pressures, and more specific parameters regarding either power block or boiler and turbine efficiency, which can be set according to default values or modified voluntarily. The result is summarized by the heat and mass balance of both power block and steam generator at rated operation. New stable results are calculated according to the heat input and on the variable load at transient condition. In practical at load variations, both mass flow rate pressures are expected to decrease simultaneously. During operation, a turbine may run an appreciably long time with varying steam flow rate in start – up and shut – down regimes, often with substantial deviations of the initial and final steam parameters from the rated values. The rated conditions can also be disturbed owing to salt deposition in the steam path or when a turbine is run with some blades in turbine stages having been removed or when the geometry of blade cascades has been distorted due to cross flexure of blade edges. In order to estimate property, the variations in the efficiency and reliability of the operation of a turbine and its stages under transient conditions, i.e. deviating strength calculations for these off – design conditions [9]. Transient performance is calculated in an iterative resolution of steam generator and steam turbine models, since they are interrelated through the thermodynamic properties of live steam calculated with the Matlab and tempo –

cycle program. For transient condition, the extraction pressure and inlet pressure to each turbine section is calculated using Stodola's Cone law as follow [7];

…. (1)

Where: (P) the pressure and (v) the specific volume. The sub index (a) stands for the inlet value, (b) for the outlet value and (0) for the design values, and n for the wet steam. The calculation of the polytrophic exponent is (Traupal);

….. (2)

Where: the overall efficiency of the turbine, and k, is the isentropic expansion index equal to 1.135 for wet steam, and 1.3 for dry superheated steam.

The simulation model

The modeling of steam turbine plant is built using firstly the techniques of Matlab version (V2013a) with m– files Simulink and the second techniques is Cycle – Tempo (Release 5) software Simulink to describe the thermodynamics, mass and heat balances for all component, at steady and unsteady (Transient) states. This program is used to Simulink the steam power plant with typical station of 160MW power capacity. The simulation model used to solve this station for steady state conditions using software Matlab and cycle – tempo programs, while for unsteady state (transient case), the Matlab program will be used for the cases 60%, 80% and 100%. The Genetic Algorithm that, will be used for tuning the PID (Proportional + Integral + Derivative) controller is built using m – file that drives the simulation of steam turbine model [10].

The simulation model can be captured in terms of mass and energy equation, semi – empirical equation and equation of state. There are many dynamic models for individual components, which are simple empirical relations between system variables with a limited number of parameters. In addition, an optimization approach based on genetic algorithm is performed to estimate the unknown parameters of models with more complex structure based on practical data. The power model consists of models for steam turbine, a control system, a generator and a power grid. To formulate components' models, unsteady conservation equations for a mass, energy and momentum that have been used. In order to implement the model in Simulink and to maintain the amount of simulation time within the time available, some models were developed in both advanced and simplified versions. All models' components are connected through ports enabling and propagating current steam parameters (temperature, pressure…….etc.) and / or mass / energy flow rates, fig. (1):

High pressure steam turbine section

To build a model for the high – pressure turbine including several steps, fig. (2). A relationship between mass flow and the pressure drop across the HP turbine was developed by Stodola formula [7];

….. (3)

Where, K_1 is a constant that can be obtained by the data taken from the turbine responses, and λ can be defined as formula;

… (4)

by plotting λ via inlet mass flow rate based on the experimental data (taken from cycle – tempo prog.), the slop of linear fitting is captured as K_1=276.98, is shown in fig.(3).

Then, K ……(5)

The transfer function of the input and output pressure is;

….. (6)

The input and output pressure relation for high pressure turbine based on practical data (taken from cycle – tempo prog.), as shown in fig.(4). While shows a quite linear relation with the slope of S= 0.29407.

Then, time constant τ is determined by formula [11];

…... (7)

Where;

….. (8)

Noting that the time constant for high pressure cylinder are normally between 0.1 and 0.4s[12] . By the dynamic model of high pressure turbine, the pressure, mass flow rate and temperature of steam at input and output of each section is required. The input and output relation for steam pressure and steam flow rate are defined in previous section. the steam temperature at turbine output (T_{out}) can be captured in the terms of entered steam pressure and temperature. By assuming that the steam expansion in high pressure turbine is an isentropic process , it is simple to estimate the steam temperature at discharge of HP turbine by using ideal gas pressure-temperature relation by formula;

…… (9)

Then, find the out temperature (T from last stage in high pressure turbine.

…… (10)

Then, we found the enthalpy and entropy , by using the thermodynamic property equations for steam (superheated and saturated) . The energy equation for adiabatic expansion , which relates the power output to steam energy (P_{HP}) declining by passing through the high pressure turbine, determine by formula;

….. (11)

Then ,

…. (12)

And find the mass flow rate at any stage in high pressure cylinder by using heat and mass balance.

Intermediate and low – pressure turbine section

The intermediate and low-pressure turbines have more complicated structure in where multiple extractions are employed in order to increase the thermal efficiency of turbine. The steam pressure consecutively drops across the turbine stages. The condensation effect and steam conditions at extraction stages have considerable influences on the turbine performance and generated power. In this case, developing mathematical models, which are capable to evaluate the released energy from steam expansion in turbine stages, is recommended. The steam thermodynamic properties can be estimated in term of temperature and pressure as two independent variables. A variety of functions to give approximations of steam/water properties is presented, which are widely used in steam power plant applications. To build a model for I – pressure cylinder included several steps. Find the thermodynamic properties of steam and water (enthalpy, liquid phase h_f , enthalpy, vapor phase h_g , enthalpy, tow- phase h_{fg} , entropy, liquid phase s_f , enthalpy and vapor phase h_g) . The relation between the input mass flow rate from reheated to I – P cylinder and the mass flow rate at all extraction based on experimental data (using Cycle- tempo program). Intermediate and low pressure models can be seen in figures (5 &6).

The transfer function of the input and output mass is;

—— —— ….. (13)

Where, G_{IP} is the mass flow rate inlet the intermediate pressure cylinder, The time response of the transfer function. Noting that the time constant for IP & LP cylinder calculated from equations (7&8). The time constant (τ) of the delay between the intermediate and low pressure turbines is in the order of (0.3 − 0.6) s [12].

By considering the steam expansion at turbine stages to be an ideal process, the energy equations for steam expansion in turbine, which relates the power output to steam energy declining across turbine stages can be captured. Therefore, the work (P_{iP}) done in IP turbine can be captured as follows;

…… (14)

Then, the power (P_{IP}) for IP turbine can be determine by the formula;

…… (15)

Finally the mass flow rate at any stage in intermediate pressure cylinder by used heat and mass balance. To build a model for the L – pressure cylinder included several steps. The transfer function of the input and output mass is;

—— —— …….. (16)

Now, the low-pressure turbine consists of two extraction levels. The work (P_{IP}) done in LP turbine can be captured as follows;

…… (17)

Where, is the mass flow rate inlet the low pressure turbine.

Then, the power (P) for LP turbine determine by formula;

….. (18)

Then the overall generated mechanical power ( ) can be captured by summation power in turbine stages determine by formula;

…... (19)

Reheater model

The superheated steam from main steam header is fed toward the high pressure turbine , and from high pressure turbine is discharged into the cold reheat header. The steam temperature in cold reheat line is (359.92°C). The outlet reheated steam temperature should be constant 535°C , at the full load condition; the outlet reheated steam pressure is 3.62MPa. the reheated dynamics increase nonlinearity and time delay of the turbine and should take into account as a part of turbine model. The parameters of this model are determined either from construction data such as fuel and water steam specification. We have developed accurate mathematical model for subsystems of boiler based on the thermodynamics principles and energy balance. The equation for the superheated temperature model is as follows, fig(7);

— …… (20)

Where: , —, —,

The heat flow can be captured by using calorific value, lower heating value (H of the fuel and the temperature output from the high pressure turbine (T , the temperature output from the reheater (T_4) , the mass flow input to reheater (ṁ). In this model the steam quality has significant effects on output temperature and should be considered in related equations. The transfer function for fuel flow rate and steam quality is as follows;

— — …… (21)

Generator model

The turbine – generator speed is described by the equation of motion of the machine rotor , which relates the system inertia to deference of the mechanical and electrical torque on the rotor, fig.(8).

Applying the swing equation of asynchronous machine to small perturbation, we have;

— …... (22)

Where: M is called inertia constant, and is torque angle or swing angle , is acceleration power (MW) , is mechanical power input in (MW) and electrical power output in (MW) .

— (S.S.S limit)(Steady state stability limit) …... (23)

Then;$P_e = P_{max} \sin\delta =$ — $\sin\delta$ …… (24)

The electrical power can be captured in term of terminal voltage (V), machine excitation voltage (E), direct axis synchronous reactance (X). Where; M —

Then the equation (22) can be written for the system operating electric frequency (H) ;

— — ….. (25)

Dividing throughout by (G) machine rating (base) in MVA.

— — In pu (δ it is measured by radian) ……. (26)

Computer Program

To describe the performance of each study, a computer program has been written to work under Mat lab software and compare the results with the Cycle – tempo software. The program enables at each node through the thermodynamic cycle by using the appropriate thermodynamic relations. And build the Simulink and model by using the two programs for the steam turbine at steady state and transient with changing the load and taken the GA at power, pressure and mass rate. A flow – sheet computer program, "Cycle – Tempo" is used for the study. The selected case study is a station (K– 160–13.34–0.0068). The superheated steam enters the one– stage single reheat steam turbine at 13.34MPa, 535°C, 149Kg/s and 3.62MPa, 535°C , for high and intermediate pressure stages, respectively. Steam enters the low pressure stage with a pressure of 0. 6383bar; the condenser pressure is 0.068bar. The simulation process and the most important parameters are described in this section. The parameters can be changed to build and simulate different cases and a flow-sheet computer program, "Cycle – Tempo" (Cycle – Tempo – Release 5), is used for that purpose. It is a well – structured package for steady state thermodynamic modeling and analysis of systems for the production of electricity, heat and refrigeration.

Results and discussion

Figure (9) shows the response of the turbine – generator for a station (K– 160–13.34–0.0068). The load responses in steady state and transient conditions over an operation range between 50% and 100% of nominal load. This figure indicated the behavior of the turbine – generator system. Figure (10) illustrated the response and pressure model at high pressure turbine. This figure indicates that the time responses of the proposed transfer function. As well as a good agreement between real and model. Figures (11), (12) and (13) reveal the response of pressure – mass model to H.P.T, I.P.T and L.P.T of this station. All these figures are clearly seen, that the results indicates a good agreement between real and pressure – mass model data. As shown there is a good agreement between model and practical data and it can see that the time response of PID tuning by using genetic Algorithm are better than the classical PID controller at two sides of transient response and also for steady state. It is notice that the responses at (PID - GA) lower steady state error and lower over shoots with high speed response. 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. The overshoot reduced from (8.7343 to 3.8132e-03 %) for overall power station but the rise time values for GA – PID are better. The overshoot reduced from (7.1521 to 2.0321e-03%) for pressure control, and from (7.6300 to 4.5911e-04 %), (9.8701 to 3.0248e-04 %) and (8.2143 to 5.0162e-04 %) for masses control at high, intermediate and low pressure respectively. Figures (14), (15) and (16) indicate convectional water – steam cycle for this station. The design calculations are done for three loads and power 100%; 160 MW, 80%; 128MW and 60%; 96MW respectively. These calculations are made by using cycle – temperature program. The using of two programs software, cycle – tempo and Matlab gives same results in simulation of power plant.

CONCLUSION

The conclusions can be drawn from the results of theoretical study were as follows:

1. Simulation results shows that the efficiencies and feasibility of the developed model in term of more accurate and less deviation with the responses of read system in the steady and transient conditions, and the error of proposed function is less than 0.37%.

1. The pressure drop across the turbine stages are approximately linear and can be defined by the first order transfer function.

2. The presented turbine – generator model can be improved for the abnormal condition, such as load rejection or turbine over-speed, so the model can be used for control system design synthesis, performing real–time simulations.

3. The genetic algorithm is executed as an optimization method to adjust the model parameters based on the practical (real) data.

4. The response of pressure model at high pressure turbine indicated that the time response of PID tuning genetic Algorithm are better than the classical PID controller at two sides transient response and steady state response, as well as of intermediate and low pressure cylinder.

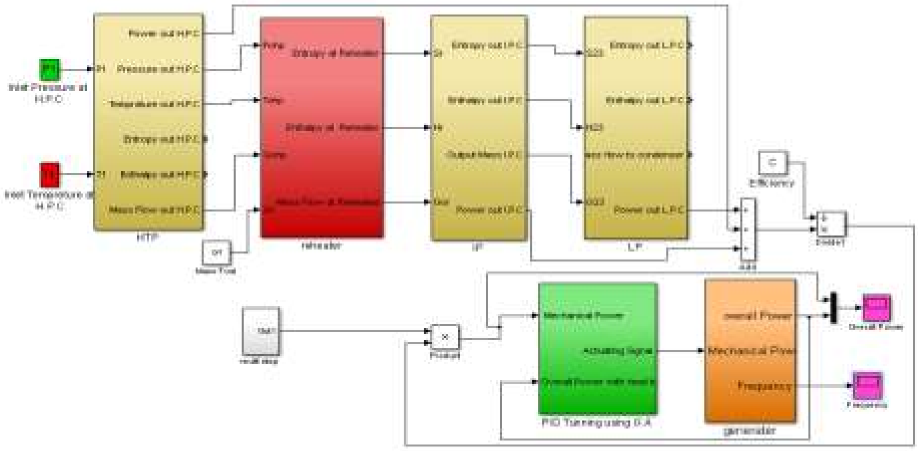
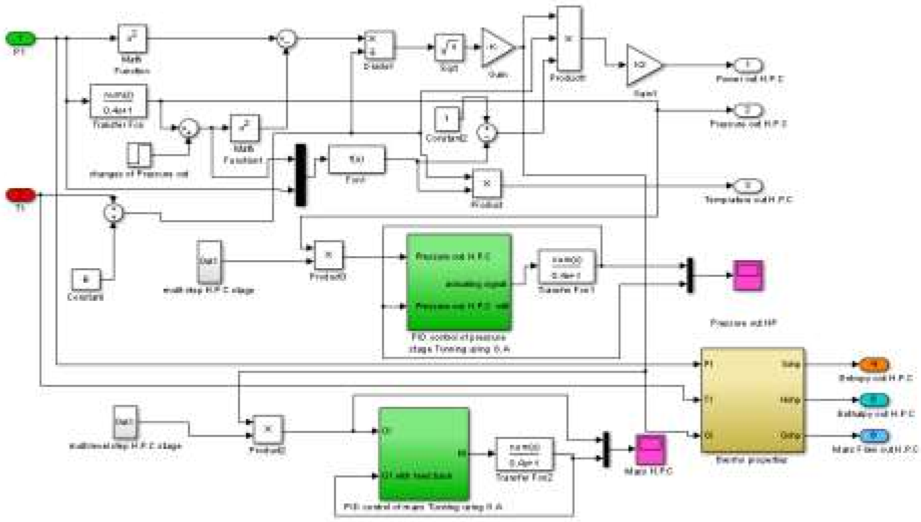
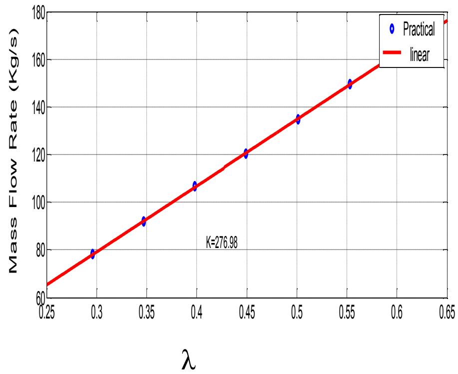


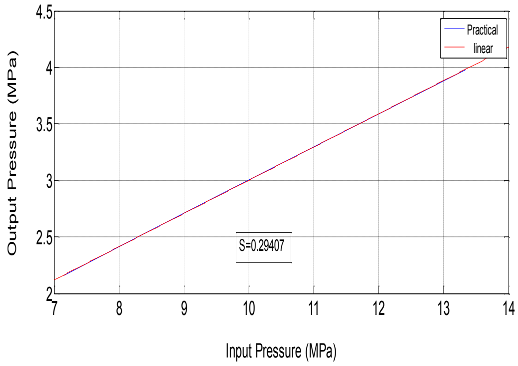
Figure (1). Overall turbine and generator models for (K– 160–13.34–0.0068) power station.



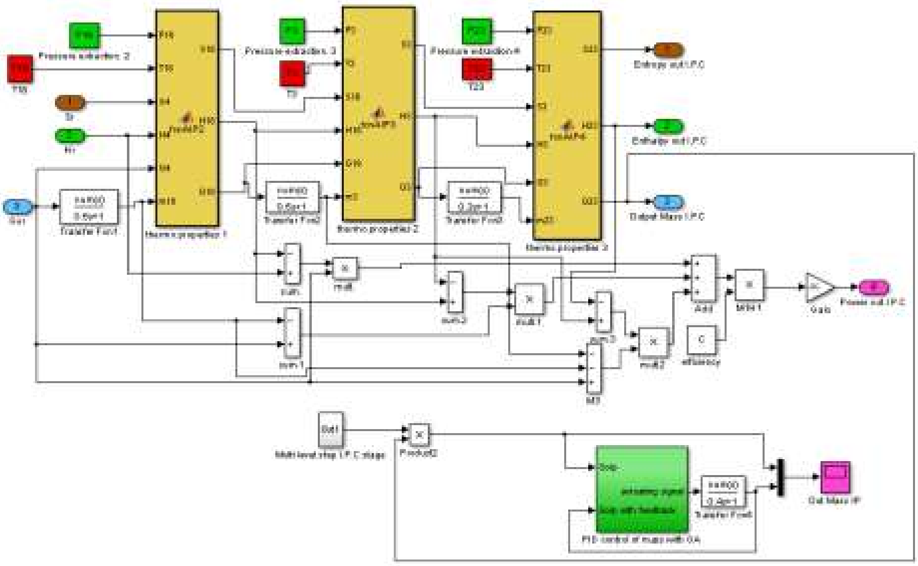
Figure(2) High pressure turbine model.



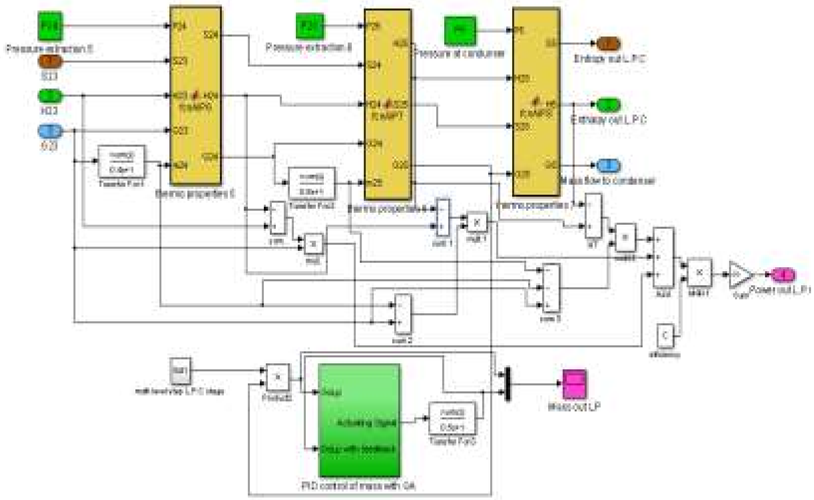
Figure(3).Mass flow rate versos λ for Station (K – 160 – 13.٣4 – 0.0068).



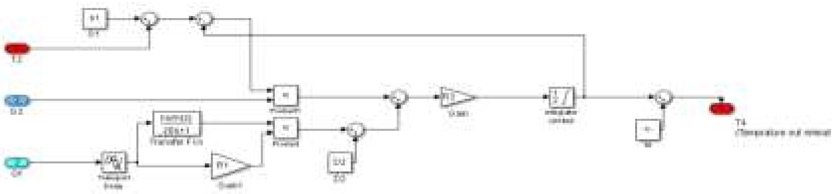
Figure(4).Pressure ratio of the high pressure turbine cylinder input and output for station 160MW.



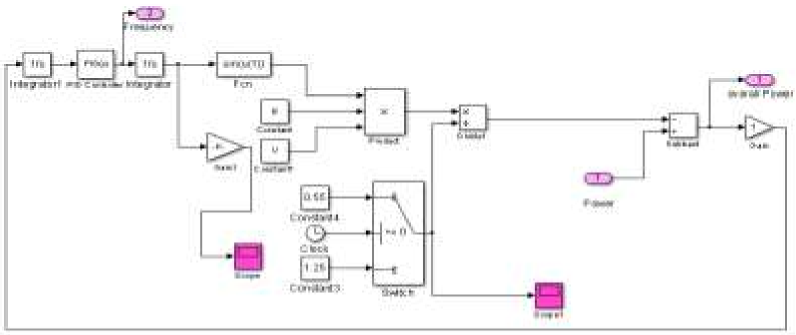
Figure(5).Intermediate pressure turbine model.



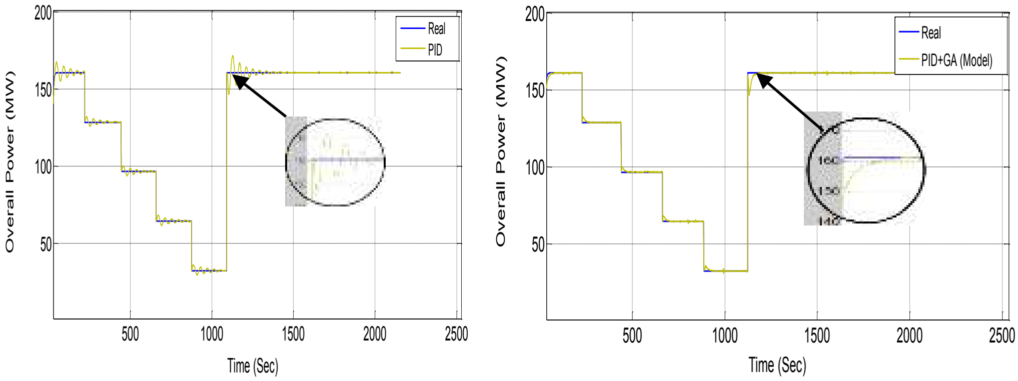
Figure(6).Low pressure turbine model.



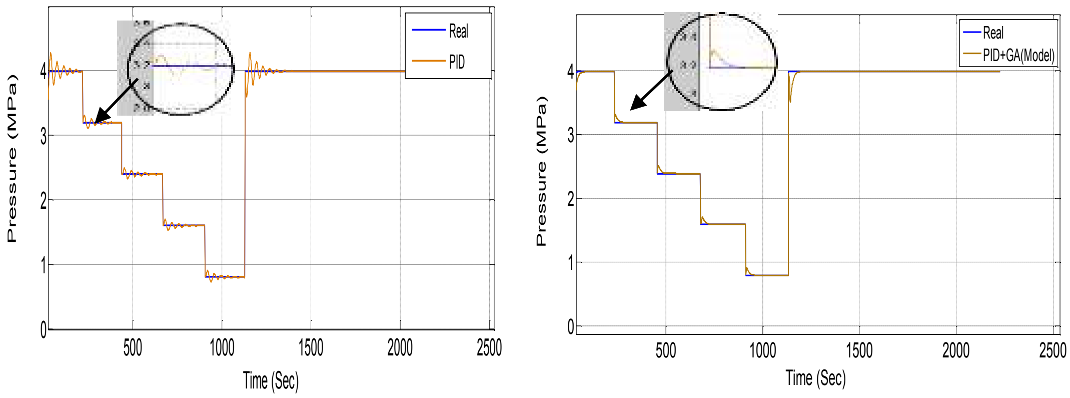
Figure(7).Reheater model.



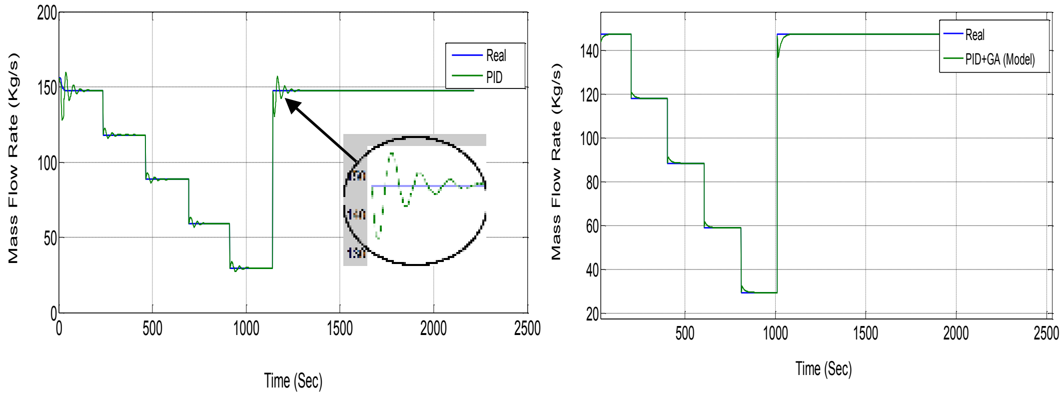
Figure(8).Generator model.



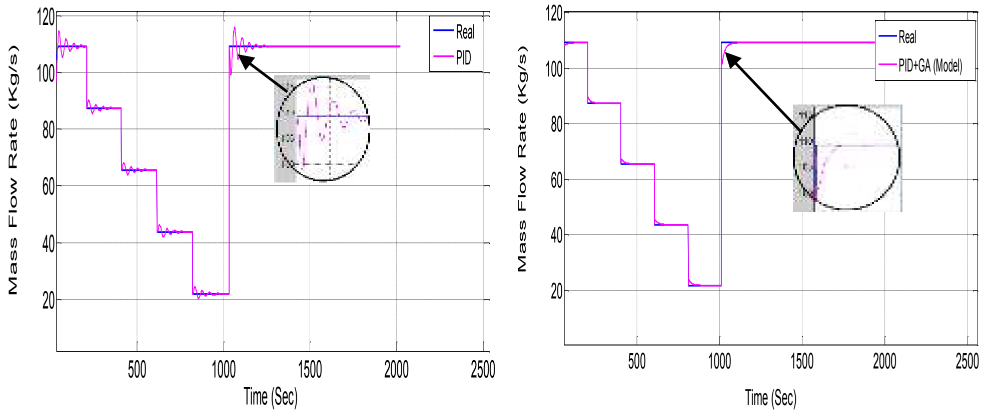
Figure(9). Response of the turbine – generator for Dura power station with PID controller classic and PID -GA.



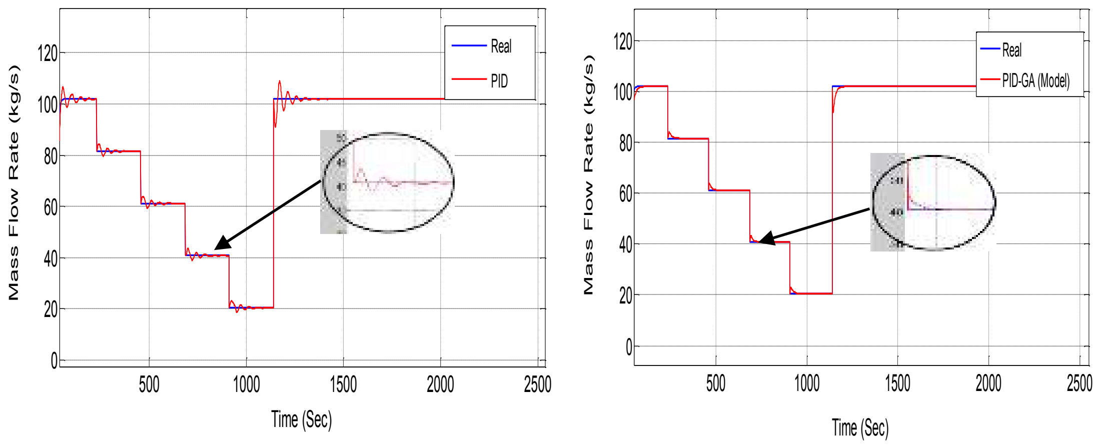
Figure(10).Response of pressure model at H.P.T for station (K – 160 – 13.٣4 – 0.0068) with PID controller classic and PID controller - GA.



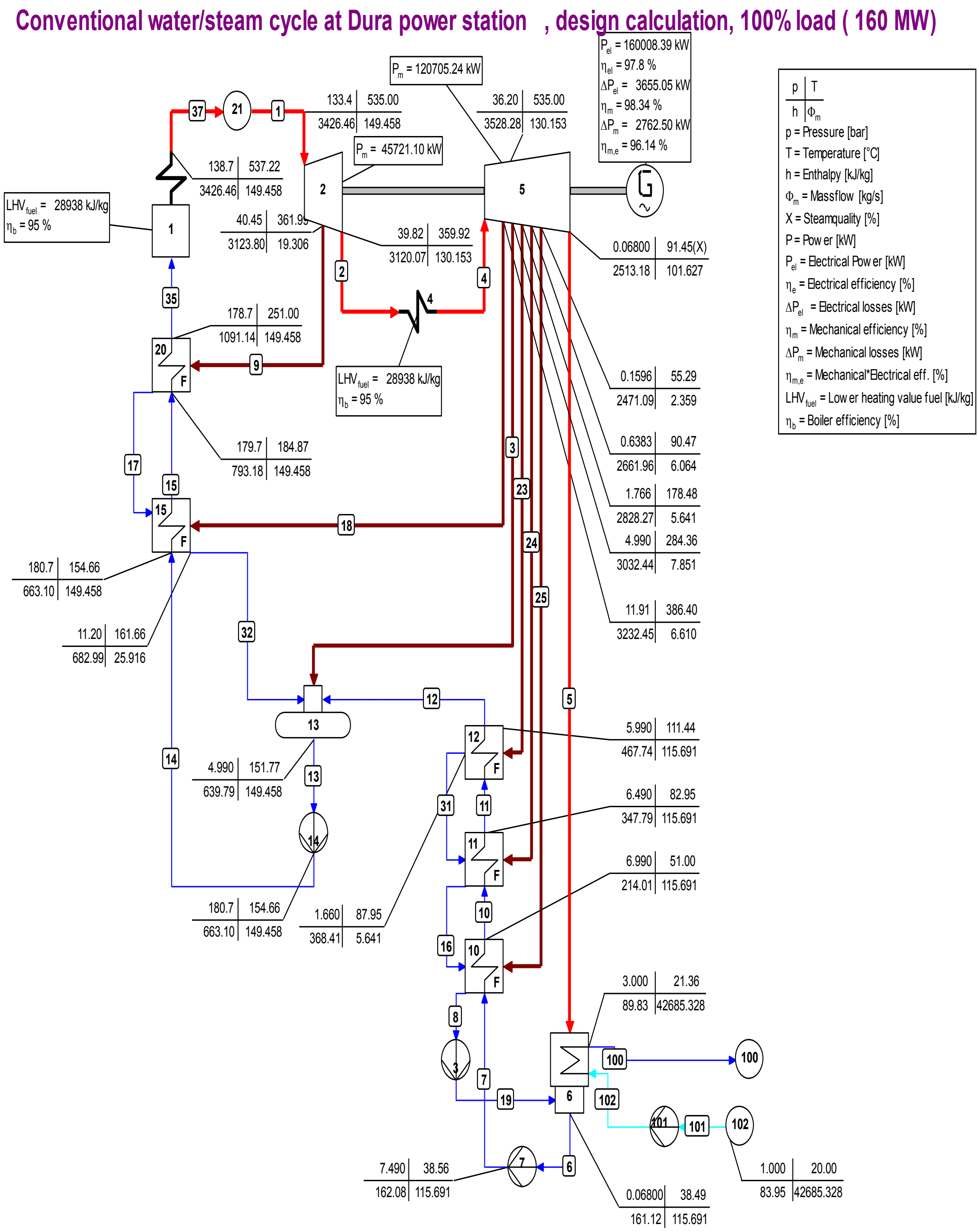
Figure(11).Response of pressure–mass flow model at H.P.T for station (K – 160 – 13.٣4 – 0.0068) with PID controller classic and PID controller -GA.



Figure(12).Response of pressure–mass flow model at I.P.T for station (K – 160 – 13.٣4 – 0.0068) with PID controller classic and PID controller -GA.

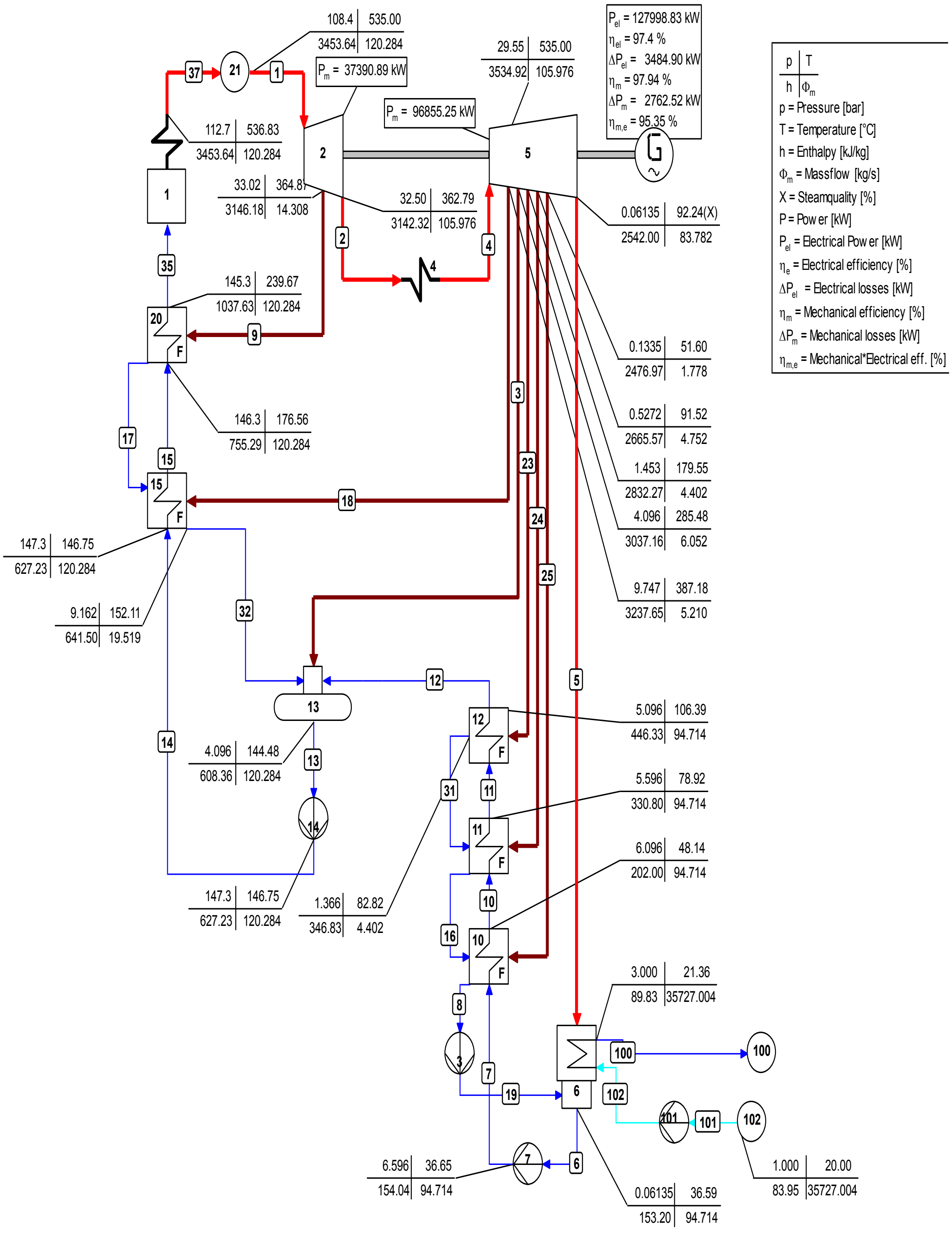


Figure(13).Response of pressure–mass flow model at L.P.T for station (K – 160 – 13.٣4 – 0.0068) with PID controller classic and PID controller tuning by using GA.

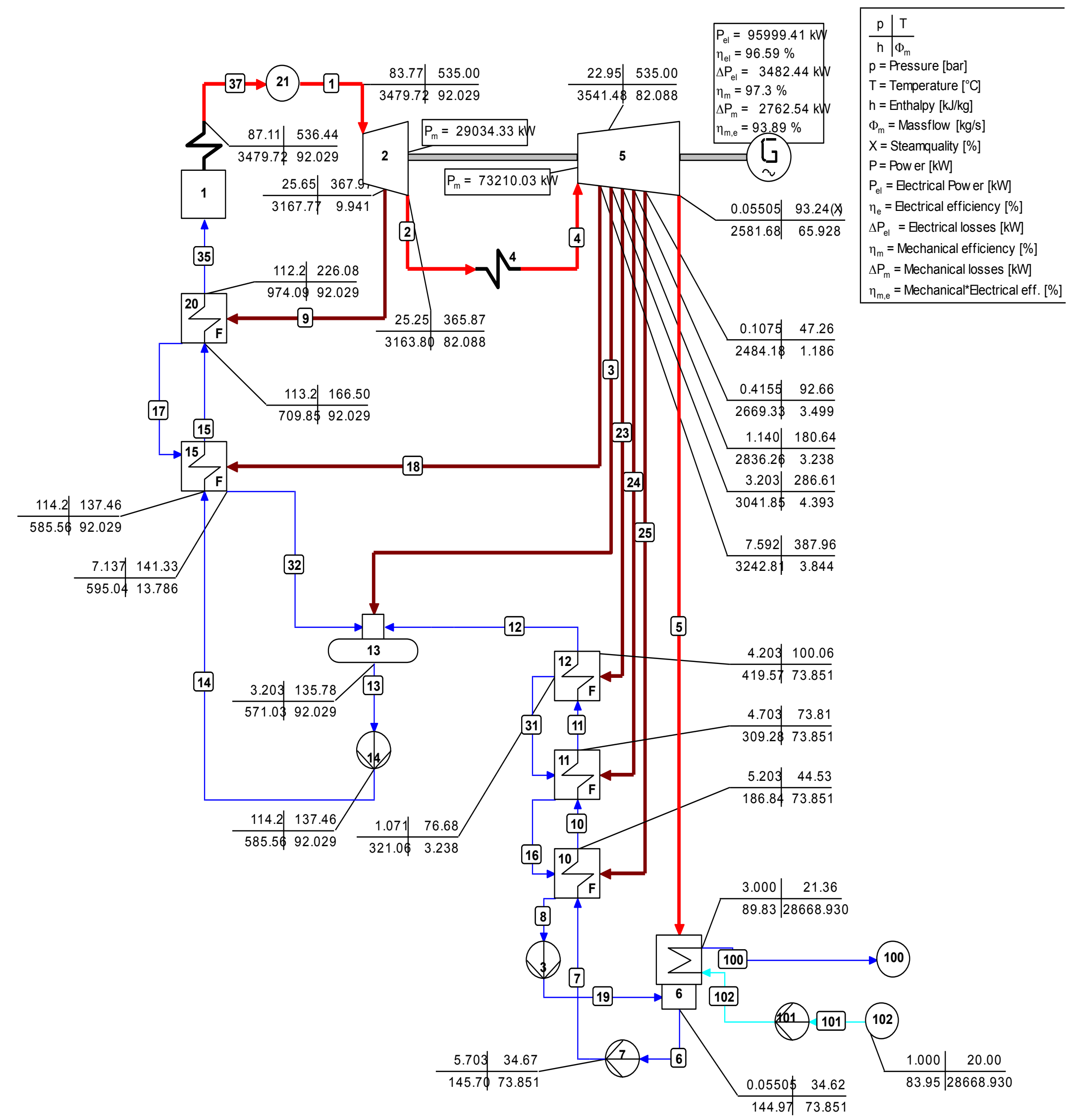


Figure(14).Convectional water – steam cycle at Al-Dura station, at 100% load and power 160MW.

Conventional water/steam cycle at Dura power station, design calculation at 80% load (128 MW)



Figure(15).Convectional water – steam cycle at Al-Dura station, at 80% load and power 128 MW.



Figure(16).Convectional water – steam cycle at Al-Dura station, at 60% load and power 96 MW.

Nomenclature

A, B C,D,E	Constant in equation	–
T	Temperature	^oC
G	Inlet mass flow rate	Kg/s
M	Extraction mass	Kg/s
S	Entropy	kJ/kg.k
H	Enthalpy	kJ/kg
	Enthalpy of main steam	kJ/kg
v	specific volume	
	Enthalpy of reheater	kJ/kg
	Enthalpy of condensate (in the ideal Rankin cycle)	kJ/kg
	Enthalpy of extraction	kJ/kg
	steam flow rate to the condenser	Kg/s
	Mass flow rate at extraction	Kg/s
	Power for IP turbine	MW
	work done in IP turbine	MW
E	Machine excitation voltage	(V)
	Power for LP turbine	MW
	Work done in LP turbine	MW
	Power for HP turbine	MW
P	Pressure	MPa
	Ambient pressure	Bar
	Temperature of the environment	^oC
	Fuel gas temperature	^oC
	Inlet temperature	K
	Final pressure of steam at condenser	MPa
	Heat added to the boiler	kJ/kg
	Heat added to the reheater	kJ/kg
	Specific density	Kg/m
	Density of steam	Kg/m
	Steam quality	%
	volume of steam	m^3
V	Terminal voltage	(V)
	Mass of fuel	Kg/s
	Mass of gas	Kg/s
	Specific heat at constant pressure of gas	kJ/kg.k
	Mass of steam	Kg/s
	Mass of water	Kg/s
	Specific heat at constant pressure of water	kJ/kg.k
	Irreversibility of open Feed water heater	kJ
	Irreversibility of closed Feed water heater	kJ
	direct axis synchronous reactance	(X)
M	inertia constant	Kg.m^2/s
	rotor angle	(rad)
	time constant	(s)
n	polytrophic exponent	–

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