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NUMERICAL ANALYSIS OF THE STEAM TURBINE PERFORMANCE IN POWER STATION WITH A LOW POWER CYCLE

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Abstract

In this paper, an analysis of the temperature and quantity balance of the thermal power plant for the Al-Dura (K-160-13.34-0.0068) station was first studied and used for reference. This work describes a possible way to build a simulation model of the most important parts of power plant Al-Dura (K-160-13.34-0.0068). The Cycle-Tempo and MATLAB/Simulink packages are used to model the energetic and exergetic analysis of the power plant. MATLAB/Simulink software was used to simulate the behaviour of a Steam turbine with high-pressure, intermediate-pressure, and low-pressure steam, with a load response in a stable circumstance over a range of 50% to 100%. The model is based on "Stodol's law" and simulates the pressure and enthalpy alongside the dissimilar turbine phases and the vapor and water extraction. The effect of the vapor and water extraction on the turbine is also elucidated. Areas of essential energy loss and exergy decimation will be resolved. The impact of changing the power plant load on the exergy analysis is determined. The response of suggested purposes to estimate these vapor properties is compared with standard data and showed high accuracy (the modelling error is less than 0.01%).

Keywords: Exergy, Extraction steam, MATLAB/Simulink software, Power plant, Reheated steam.

1. Introduction

Because of the costs and efficiencies of steam turbines, they are utilized in the thermal power plants (TPP) for power generation. A new level for the steam turbine structure regarding application, capacity, and required accomplishment is offered. There is a complex feature in the steam turbines. Multistage steam expansion is included in these turbines to raise thermal efficiency. Because of the turbine structure complexity, it is not easy to discover the influences of the estimated control system. Studying turbine dynamics leads to the progress of nonlinear analytical models. These models accomplish real-time simulations, control system design synthesis, and monitor the required states [1]. The mathematical models are advanced by using identification techniques in power plant applications. The advanced models include complexities that characterize the system well in specific operating conditions [2].

System identification is an optimal goal in normal operation without disruption or foreign excitation. Using operating data is demanded to identify the external excitation and to identify the limitations of faces [3]. Regarding parametric models' availability, it would be advantageous to use soft computing methods. The mathematical modelling is performed by Ghaffari et al. [4], advanced variable parametric models for the steam power generating plant turbine and a boiler subsystem relying on the thermodynamic and physical laws. The GA was accomplished to set the model parameter using experimented data. These models were used for the superheaters part. The simulation conclusions revealed that the progressive way flexibility and influence were less deviation and more accurate. This way was developed for start-up and shutdown modes and such strange conditions. They took into consideration the combustion process and heat exchange in the furnace. Different models were improved for these conditions.

Chaibakhsh and Ghaffari [5] considered a 440 MW plant steam turbine and Benson boiler for the formation approach. These researchers described the dynamic steam turbine by progressing nonlinearly [6-8]. The associated variables of advanced ways were either adjusted by applying a Genetic Algorithm (GA) or determined through empirical relations. Comparing the actual system response validated the progressive method accuracy with the turbine's response generates a steady model. Bartels and Christine [9] improved a simulation model for an industrial turbine used for analysis and training. The simulation was ruled by a Programmable Logic Controller (PLC) linked to a Digital Control System (DCS) and operator screens. Also, it is utilized for assessing system design relying on the actual system data. Barszcz and Piotr [10] improved a plant method of 225MW coal-fired unit. VPP is a Virtual Plant dependent on a method that appeared in the MATLAB/Simulink environment. Depending on the Stodola equation, which was found to extract the transient conditions, the static features presented relationships between the quantities of output and input of an elementary turbine section.

Hataitep [11] used the controller of industrial processes and thermodynamic properties of substances in numerical simulation. The subtractive clustering and Neuro-fuzzy system (NFs) were utilized for counting energy properties in an experiential steam power plant. From the subsystem of the properties of thermodynamics like superheat steams or saturated water, Neuro-fuzzy models are constructed. The comparison between experiential conclusions of the nonlinear Neuro-fuzzy model and many back propagation neural networks (BNNs) improved that the NFs modelling was closer to thermodynamic properties. Omar [12] researched the dynamic responses of SC (Supercritical) power plants through mathematical modelling, simulation, and identification. Improved Genetic Algorithms were utilized in the modelling operation for model response optimization and parameter identification. The model was emphasized for confirmed process states with various data groups gained from the 600 MW SC power plant. A Genetic Algorithm presents a more dependable and plainer identification technique than classical optimization techniques. In this study, three schedules were examined. The first schedule was made for small load changes about symbolical situations, whereas the others were used to manage high load changes. Bartells and Kovach [9] demonstrated the exergy and energy examination of a reheating recovery vapor control cycle. Exergy effectiveness, energy productivity, and the irreversibility picked up from the reproduction have been displayed as charts [13-16]. The temperature differed from 500 to 800 K for every supercritical pressure, and the supercritical pressure was changed from 250 to 400 bar. The parametric search clarified that the exergy and cycle effectiveness rise with raising the temperature and pressure, as the parametric search clarifies it. This was because of reducing exergetic and energetic losses at increased temperature and pressure [17- 21].

Rashidi et al. [22] investigated the exergy usage of a steam cycle with dual reheat and turbine extraction. Six radiators were utilized; three of these heaters were at high pressure, and the other three were at low pressure with a deaerator [23, 24]. The irreversibility and exergy examinations of every part were recognized. Impacts of heater outlet steam temperature, turbine input pressure, and condenser back weight on the first and second law efficiencies were identified [25, 26]. The conclusions identified that the biggest exergy misfortune happened in the heater, followed by the turbine. The conclusions uncovered that the aggregate warm proficiency and the second law productivity lessened as the condenser weight raised for any settled outlet heater temperature. Also, better estimations of the extricated pressure of (the HP, IP, and LP) turbine that presented the greatest first law efficiencies were gained, relying on the wanted heat stack compared to every leave boiler temperature [27, 28].

Abdullah et al. [29] adopted artificial neural network integrated with electric circuits approaches to improve the performance of the steam turbine in TPP. They acquired the operational data of Al-Dura power plant in Baghdad, Iraq. On the other hand, Shaheed et al. [30] analysed another steam turbine performance in Al-Mosyab TPP, Iraq. They performed the performance evaluation based on energy and exergy analysis.

Most of the searches contained steam plant simulations over computational coding and contrasted the conclusions with the workable information of the actual power plant. Also, prior searches were achieved on the one steam plant and either Cycle-Tempo or MATLAB. This research used Cycle-Tempo and MATLAB computer programs and one steam power plant (160 MW). The power plant simulation was compared with practical data for the one real plant, and the results gave good agreement between them. The thermodynamic properties are modelled using the MATLAB program and calculating the energy properties within the practical steam power plant. Exergy and energy analysis are used to analyse the accomplishment of thermal systems. This study included the power stations with a low power cycle because they are available in Iraq. The importance of the Exergy results in this study and the presence of the Simulation in Cycle Tempo program results.

2. Theoretical Modelling

There are two parts; the first involves plant exergy and energy analysis, and the second is a mathematical simulation model with computer programs. Two techniques establish the steam turbine plant modelling; the first is MATLAB versions (V2014a) with m - files Simulink and the second is Cycles, - Tempos (Release 5) program. Simulink is used to characterize the components' mass, heat balances, and thermodynamics in a steady case. The operational data of Al-Dura power station in Baghdad type (K-160-13.34-0.0068) is utilized in the investigation. The station cycle is shown in Fig. 1.

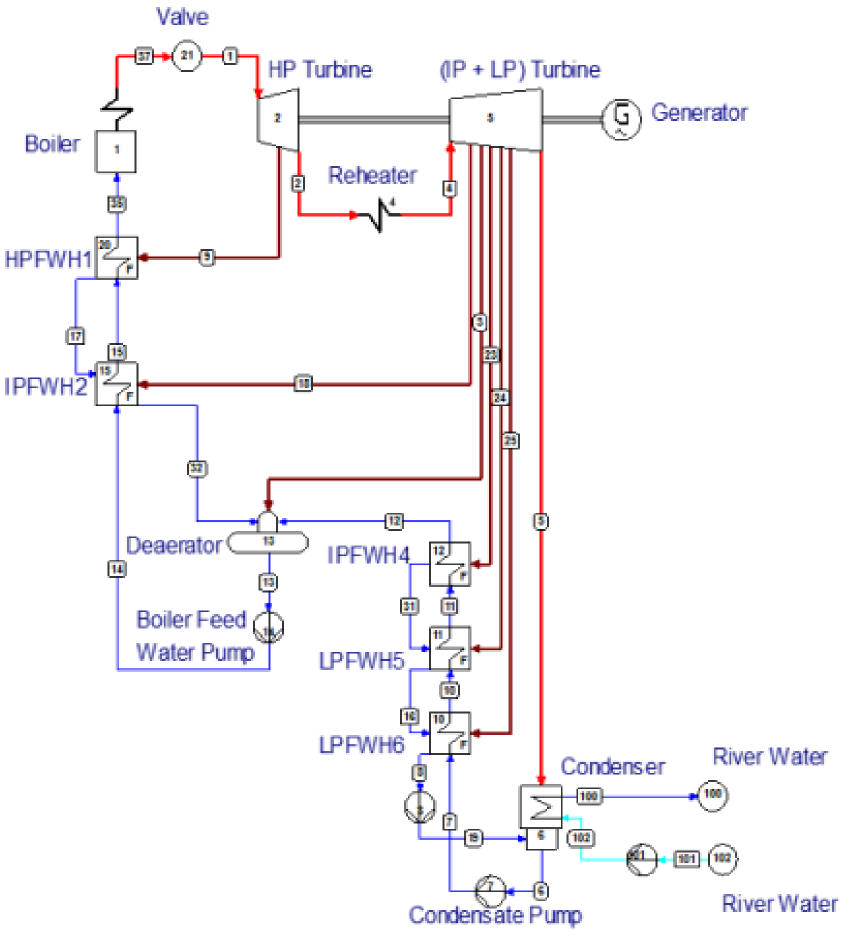

Fig. 1. Steam turbine heating cycle in Al-Dura power plant, (K-160-13.34-0.0068).

The simulation model was used to solve this station for steady state conditions through software MATLAB and Cycle-Tempo programs and different load capacities. The steam turbine type (K-160-13.34-0.0068) is examined and contrasted with the modelling approach. IP, LP, and HP turbines are included in this type. The system comprises feed water heaters, bleeding extractions, and other auxiliary systems. The arrangement of the turbine and steam is clarified in Fig. 2.

There are four LP closed feed water heaters (CFWHS) in the system; one is an open feed heater/deaerator, and the other three are high-pressure closed feed water heaters. Separate 32 MW turbo drivers turn the feed water pump. The feed waters pump pressurizes the water to 29.8 MPa, despite the pressures at the HP turbine inlet falling to 13.34 MPa. The output power control can meet the demand by the feed waters pump speed control together with the flow control valves.

The HPT section contains the superheated steam at 560 ºC and 13.34 MPa pressures. The inlet steam pressure falls about 1.2 MPa through passing over the turbine chest system. After that, the steam extends into the HPT and goes into the heater. The outlet pressure and temperature of the HP section at the full load processes are 300 ºC and 3.51 MPa, respectively. The reheated steam enters the IP section at 540 ºC and 3.42 MPa pressure. Exhaust steam from the IP turbine is supplied to the LP turbine at 231.24 ºC and 0.292 MPa. The inlet pressure and temperature of the condenser are 26.27 ºC and 0.0034 MPa. The taken-out steam from the latter LP and IP extraction points is used for heating the feed waters in LP heater trains.

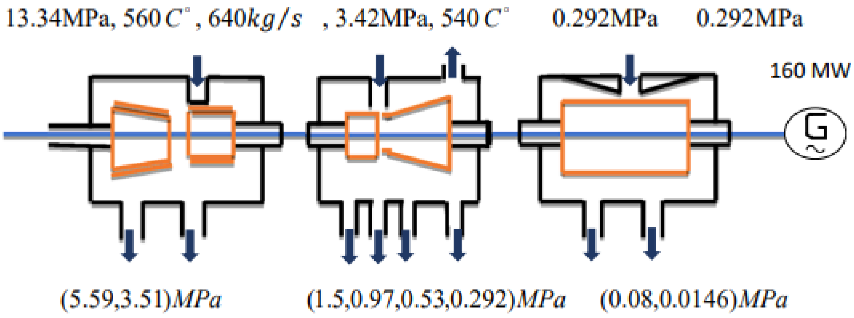

Fig. 2. Steam turbine plant heating cycle in Al-Dura power plant (K-160-13.34-0.0068).

For this model, the following assumptions are taken into consideration:

- The reference environment temperatures (To) are 25 ˚C, and pressures (p_{amb}) is 1.013 bar.
- In each fully opened governing valve, the steam mass flow rate is the same.
- ≈ 4% of inlet pressure is the pressure losses in fully opened governing valves.
- The speed ratios (u/cf) are supposed to be similar in every turbine phase,
- The pump's efficiency is equal to 85%.
- Terminal Temperature Difference (TTD) is 4 ˚C.
- When going into the combustor, with a temperature of T_{amb} = 25 ˚C.

2.1. Exergy analysis of the steam plants

When the system is in a dead case, exergy is mainly the maximum work that is gained from it. A clear datum that should be utilized in many of the calculations is the ambient (surrounding) states. When the system is in mechanical and thermal equilibrium, it approaches this state. The second law in thermodynamics is a generic term for a concept that identifies the maximum potential works for the systems. The energy analysis relies on the second law in thermodynamics, which relates to energy conservation. The second law analysis utilized the laws of energy conservation and mass with the entropies. The exergetic analysis merges the 1st and 2nd thermodynamics laws. Generally, the overall exergy of the systems is the totality of KE exergy, PE exergy, physical exergy, and chemical exergy.

The 2nd law of efficiency presents a correct measure of energy system performance from the thermos dynamic viewpoint [9]. Table 1 presents the apparatuses' functional exergy efficiencies [27].

Table 1. The efficiencies of functional exergy for the apparatuses.

Units # in Fig. 1	Name	η_{ex}
1 **4**	Boiler Reheater	$\frac{Ex_{out} - Ex_{in}}{Ex_{fuel}}$
2 **5**	Turbine	$\frac{P_m}{Ex_{in} - Ex_{out}}$
4 **8, 10, 11, 12, 15, 16, 20**	Condenser Flashed heater	$\frac{Ex_{w\ out} - Ex_{w\ in}}{Ex_{s\ in} - Ex_{s\ out}}$
13	Desecrator	$\frac{m_w Ex_{w\ out} - Ex_{w\ in}}{Ex_{s\ in} - m_s Ex_{s\ out}}$
7, 9, 14	Pump	$\frac{Ex_{out} - Ex_{in}}{P_m}$

Equation (1) calculates the steam cycle thermal efficiency, $\eta_{th\text{-}cycle}$ using the predicted internal exergy efficiency, η_o of the cycles.

$$\eta_{th-cycle} = \eta_o[1 - \frac{T_C}{T_H}] \tag{1}$$

All systems use the same condenser temperature, T_C. By only the value for T_H, $\eta_{th\ -\ cycle}$ is determined, the mean temperature of heat addition to the reheater and boiler, and η_o. The temperature, T_H is calculated using Eq. (2).

$$T_H = \frac{\sum(h_{out} - h_{in}) * m}{\sum(S_{out} - S_{in}) * m} \tag{2}$$

2.2. Simulation model of steam turbine

The models carry out primary stable state analysis based on user input specifications, such as power output or primary steams and condensing pressures, and many parameters concerning either boilers and turbines efficiency or power block. The conclusions are summed up by the heat and mass balances of the steam generator and power blocks. A turbine is probably operated for a remarkably long time with the changeable steam flow rate in start-up and shutdown regimes. The estimated conditions are probably confused due to salt deposition in the steam path [24].

The equation of state and semi-empirical equations has been adapted to construct the simulation model in terms of the energy and mass equation. The dynamic models for every component are uncomplicated empirical relations that connect the system's variables with restricted parameters. The model's training operation is achieved by following Cycle - Tempo and MATLAB Simulink. The power model contains a model of a steam turbine, a generator, and a control system. Changeable equations of energy and mass and conservation have been utilized to formulate model models of components. Some models were contracted in simplified and advanced versions to perform the models in Simulink and to reach the simulation time within the available time. This model improvement is addressed to the appropriate representation of these variables relevant for modelling. The model, in this case, can clarify the turbines' behaviours in the MAT LAB/SIMULINK codes. To merge this model into MATLAB/SIMULINK, it should present variables such as enthalpy drop through the turbine, pressure drop through the turbines, power outputs, pressures at the extraction lines, etc. [25]. The model components are linked by ports propagating and enabling current steam parameters, pressure, temperature, mass, and energy flow rates. Figure 3 [26] clarify the block diagram of steam turbine representation.

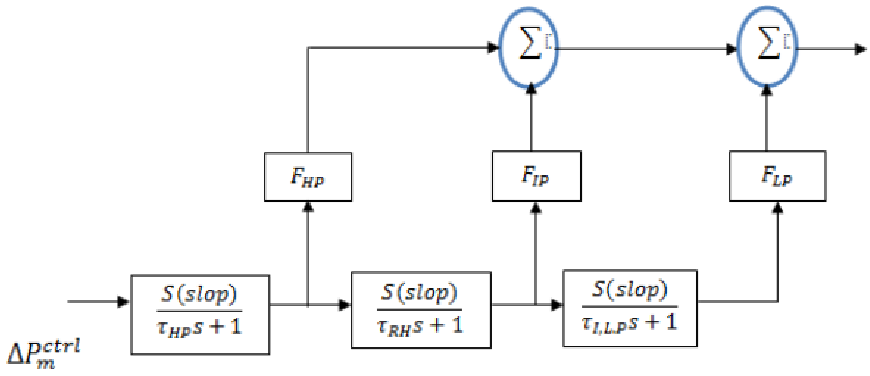

Fig. 3. The block diagram of the steam turbine of Al-Dura (K- 160-13.34-0.0068) [26].

3. Results and Discussion

Firstly, results are compared with standard data to compute the accuracy of the thermodynamic properties like entropy and enthalpy of water steams. The response of proposed functions for specified enthalpy and entropy are applied for this case, and they are applied at two extraction points (extractions no.1 and extractions no.3) with various temperatures and pressures clarified respectively in Figs. 4 and 5. The comparison reveals a high accuracy and shows that the modelling error is less than 0.01%. For a full load, these figures detail each section's thermodynamic properties, mass, and energy balances. Conventional waters - steam cycles for the station (Ks-160-s13.34-0.0068s) are described in Figs. 4 and 5. The design calculations are performed for three loads and power 100%, 160 MW, 75%, and 128 MW, respectively. These calculations are applied by utilizing Cycle-Tempo programs.

Prediction results of properties are presented in Tables 2 and 3 using Cycle-Tempo software and the developed code in MATLAB for 100% load operation of the 160 MW Al-Dura PP. There is an agreement between the calculated values of thermodynamics properties and the conclusions gained from Cycle-Tempo & MATLAB. The two mentioned tables display the conclusions gained through utilizing two programs, MATLAB and Cycle-Tempo, every station at full loads. This reveals an excellent agreement between the conclusions gained through utilizing these programs. The efficiency of internal exergy was calculated in Table 2 to understand the results from the cycle calculation.

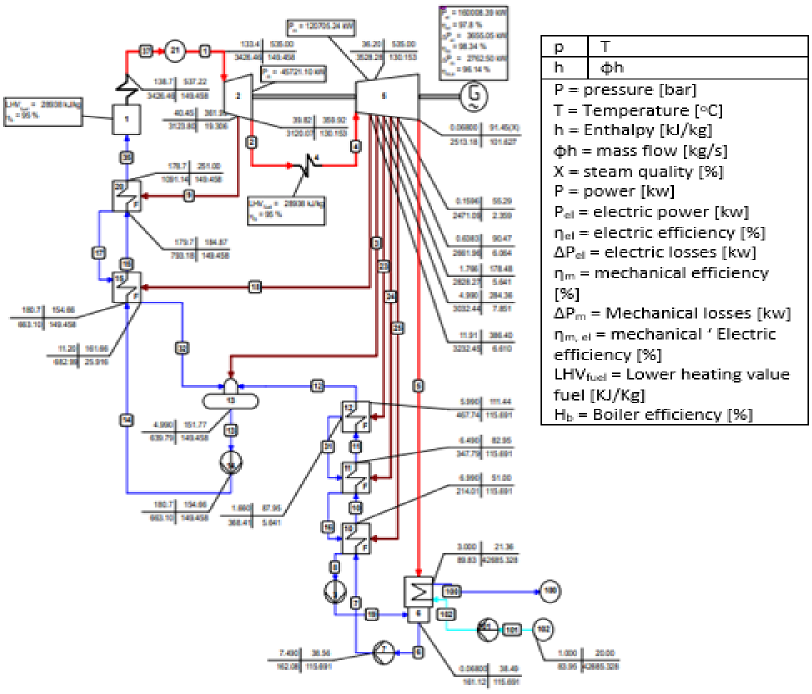

Fig. 4. Design calculation at 100% load and 160 MW power for water-steam cycle at Al-Dura power station.

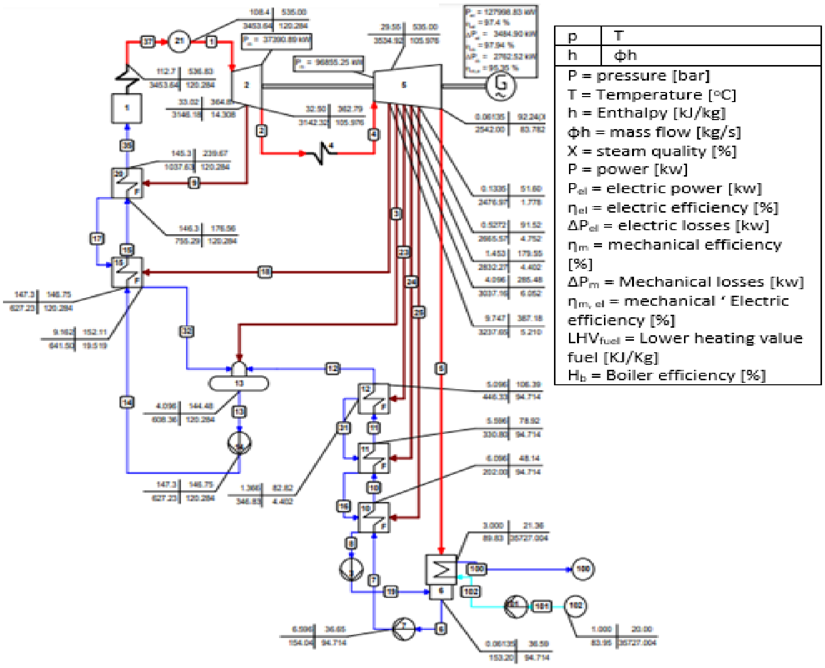

Fig. 5. Design calculation at 75% load and 128 MW power for water-steam cycle at Al-Dura power station.

Table 2. Results of 160 MW and 100% load obtained by Cycle - Tempo program (Al-Dura PP).

Parameter	P (MPa)	T (°C)	Mass (kg/s)	h (kJ/kg)	S (kJ/kg. K)
Input for the first stage of Hp turbine	13.34	535	149.46	3426.46	6.544
Extraction (1) at HPC	4.045	362	19.306	3123.80	6.628
At the reheat	3.620	535	130.15	3528.28	7.241
Extraction (2) at IPC	1.191	386.40	6.61	3232.45	7.339
Extraction (3) at IPC	0.499	284.36	7.851	3032.44	7.401
Extraction (4) at LPC	0.176	178.46	5.641	2828.27	7.473
Extraction (5) at LPC	0.063	90.47	6.064	2661.96	7.528
Extraction (6) at LPC	0.015	55.29	2.359	2471.04	7.591
Output from the LPC to condenser	0.0068	38.49	101.627	2513.18	8.098

Table 3. Results of 160 MW and 100% load for MATLAB code (Al- Dura PP).

Parameter	P (MPa)	T (°C)	Mass (kg/s)	h (kJ/kg)	S (kJ/kg. K)
Input to the first stage of Hp turbine	13.34	535	149.518	3428.4	6.5474
Extraction (1) at HPC	4.045	363.53	19.360	3144.4	6.6233
At the reheat	3.620	535	130.60	3518.5	7.2230
Extraction (2) at IPC	1.191	384.28	6.625	3217.2	7.3283
Extraction (3) at IPC	0.53	289.19	7.835	3022.4	7.3992
Extraction (4) at LPC	0.176	172.66	5.655	2818.7	7.4699
Extraction (5) at LPC	0.063	88.75	6.079	2663.7	7.5280
Extraction (6) at LPC	0.015	55.39	1.559	2481.0	7.6911
Output from the LPC to condenser	0.0068	38.50	101.8	2464.1	7. 9823

The prediction results for the Al-Dura PP with 75% loads using Cycle-Tempo program are shown in Table 4.

Table 4. Results of 128 MW and 75% load for Cycle-Tempo program (Al-Dura PP).

Parameter	P (MPa)	T (°C)	Mass (kg/s)	h (kJ/kg)	S (kJ/kg. K)
Input to HP turbine	10.84	535	120.284	3453.64	6.6650
Extraction (1) at HPC	3.302	364.87	14.308	3146.18	6.7507
At the reheat	2.955	535	105.976	3534.92	7.3409
Extraction (2) at IPC	0.9747	387.18	5.210	3237.65	7.4381
Extraction (3) at IPC	0.4096	285.48	6.052	3037.16	7.5036
Extraction (4) at LPC	0.1453	179.55	4.402	2832.27	7.5705
Extraction (5) at LPC	0.05272	91.52	4.752	2665.57	7.6250
Extraction (6) at LPC	0.01335	51.60	1.778	2476.97	7.6866
Output from the LPC to condenser	0.00614	36.59	83.782	2542.00	8.2386

However, the exergy at the nine design points is also predicted by Cycle-Temo and presented in table 5 for the 160 MW PP at 100% and 75% operation of the plant. The exergy at all identified points is lower in the case of 75% operation. The results revealed that the highest losses of exergies in the 160 MW power plant are various at different loads. They accounted for 76.97% at full load, 77.41% at 75% load of irreversibility in the boiler, 10.02% at full load, 10.22% at 75% load of irreversibility in the turbine, and 4.48% at 100% load, 4.04% at 75% of irreversibility in the 172condenser.

Table 5. Comparison of the exergy values when operating the 160 MW PP with 100% and 75% loads.

Extraction point	Exe. (kJ/kg) predicted by Cycle-Tempo	
	100% load,	75% load,
Input to the first stage of HP turbine	1542.5	1534.71
Extraction (1) at HPC	1215.5	1202.56
At the reheat	1443.35	1421.23
Extraction (2) at IPC	1119.30	1095.96
Extraction (3) at IPC	914.83	876.60
Extraction (4) at LPC	676.60	652.42
Extraction (5) at LPC	494.44	470.03
Extraction (6) at LPC	285.39	263.03
Output from the LPC to condenser	180.96	169.63

After that, the entropies and enthalpies at the outlet and inlet of the reheater and boiler should be considered as the ratios of the mass flow to reheat and boiler. The efficiency of internal exergy was calculated and presented in Table 6 and Fig. 6 to understand the results from the cycle calculation. Some necessary data for calculating these efficiencies are evaluated because of the unavailability of the original system calculations.

The cycle thermal efficiency rises with raising the temperature and pressure of steam from 0.457% at 180 bar, 530 ˚C, to 0.503% at 350 bar, 650 ˚C. Raising the inlet steam temperature from 0.54% to 0.586% raises the reversible efficiency at the same range of temperatures and pressure.

The efficiencies of internal exergy are initially identified through the steam turbine isentropic efficiencies, as illustrated in Fig. 7. Generally, as the rate of steam volume flow is higher, this isentropic efficiency is higher. In this case, the internal efficiency fully agrees with this rule. The influences on the external exergy efficiency and the thermal efficiency of the reversible cycles (the Carnot efficiency) are considered separately.

Table 6. Results of cycles calculations (singles reheat steam cycle) for (Ks-160-13.34s-0.0068) in 160 MW PP.

P_{steam}	T_{steam} (°C)	T_H (K)	T_C (K)	η_{rev}	$\eta_{th,cycle}$	$\eta_{ex,intern}$
180	530	645.56	295.52	0.5422	0.4571	0.8430
	560	650.99	295.52	0.5460	0.4652	0.8520
	580	654.71	295.52	0.5480	0.4703	0.8582
	600	658.50	295.52	0.5512	0.4750	0.8617
	620	662.38	295.52	0.5538	0.4802	0.8671
	650	668.34	295.52	0.5578	0.4843	0.8682
250	530	662.26	295.52	0.5537	0.4650	0.8398
	560	670.23	295.52	0.5590	0.4735	0.8470
	580	676.26	295.52	0.5630	0.4792	0.8511
	600	682.33	295.52	0.5668	0.4847	0.8551
	620	688.43	295.52	0.5707	0.4896	0.8578
	650	696.69	295.52	0.5758	0.4960	0.8621
300	530	669.86	295.52	0.5588	0.4676	0.8367
	560	679.41	295.52	0.5650	0.4770	0.8442
	580	688.25	295.52	0.5706	0.4848	0.8461
	600	691.07	295.52	0.5723	0.4882	0.8530
	620	699.51	295.52	0.5775	0.4933	0.8541
	650	708.12	295.52	0.5826	0.5005	0.8590
350	530	673.52	295.52	0.5612	0.4679	0.8337
	560	689.15	295.52	0.5711	0.4783	0.8375
	580	691.63	295.52	0.5727	0.4845	0.8459
	600	698.28	295.52	0.5767	0.4902	0.8500
	620	704.64	295.52	0.5806	0.4957	0.8537
	650	714.62	295.52	0.5864	0.5030	0.8577

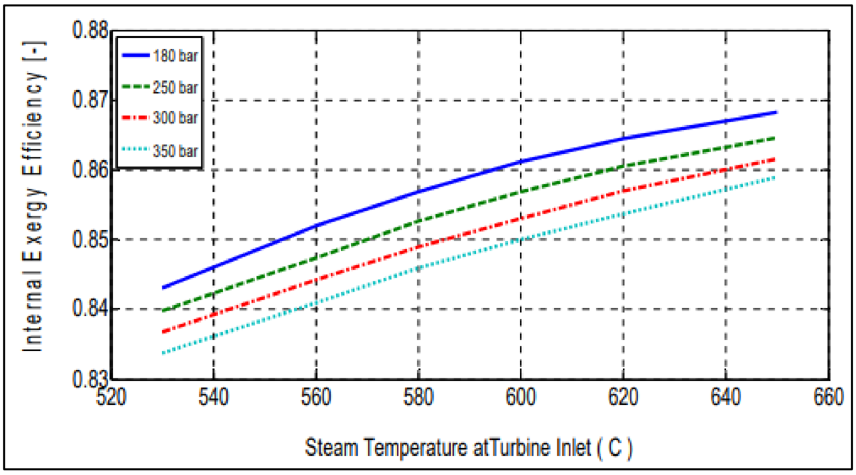

Fig. 6. The internal exergy efficiency, with different steam temperatures (Single reheat) for Al-Dura powers station.

The reversible cycle thermal efficiencies rise linearly with the temperature of steam, and this increase is per Kelvin. The change of thermal efficiency with inlet steam pressure for various temperatures is clarified in Fig. 7. This figure illustrates that for a constant's boiler pressure, 180 bar, the efficiency rises from 46.8 to 47.5%

in the case of differing the inlet turbine temperature from 560 to 600° C. Figure 7 shows that at a constant inlet, turbines, temperatures 650 ºC, the efficiency rises from 48.8 to 50.3% as the boiler pressure increases from 180 to 350 bar. The increase in the boiler pressures and turbine temperature raises the steam enthalpy at the inlet of the turbine, and condenser pressures stay constant at 0.0034 bar.

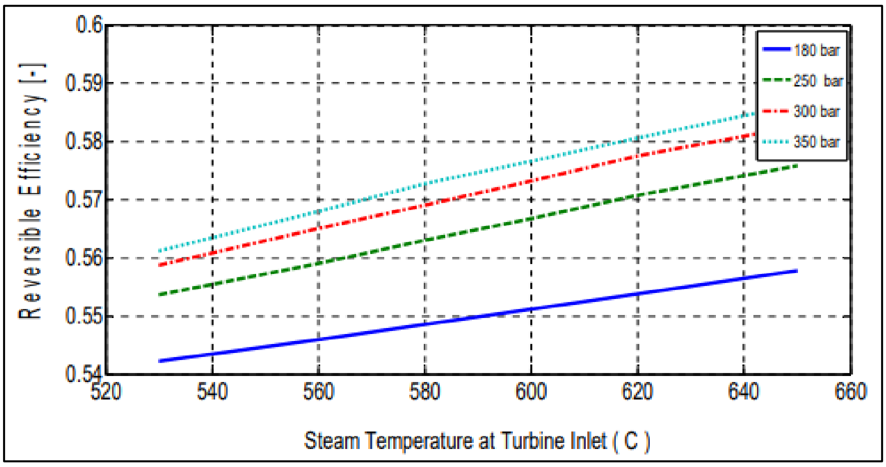

Fig. 7. The reversible efficiency with different steam temperatures at turbine inlet for Al-Dura power station.

Figure 8 shows that at a constant inlet, turbines, temperatures 650 ºC, the efficiency rises from 48.8 to 50.3% as the boiler pressure increases from 180 to 350 bar. Clearly, the increase in the boiler pressures and turbine temperature raises the steam enthalpy at the inlet of the turbine, and condenser pressures stay constant at 0.0034 bar.

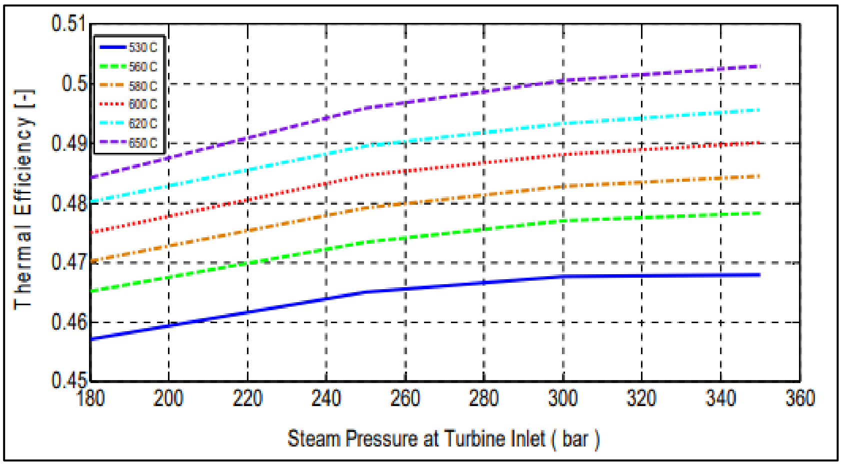

Fig. 8. Thermal efficiency with different steam pressures at turbines inlet the temperatures for Al-Dura power station.

4. Conclusions

A mathematical model is processed to simulate Al-Dura power plant in Baghdad - Iraq and programmed as MATLAB code. Results are compared with those obtained from the Cycle-Tempo software. It gives reasonable agreement. The following conclusions were included in the present works for analysis of exergy and energy and simulation modelling.

- The cycle thermal efficiency rises with raising the temperature and pressure of steam from 0.457% at 180 bar, 530 °C, to 0.503% at 350 bar, 650 °C. Raising the inlet steam temperature from 0.542% to 0.5864% raises the reversible efficiency at the same range of temperatures and pressure.
- The calculations revealed that the highest's losses of exergies in the (Ks-160s-13.34s-0.0068) power plant had been presented at different loads occurred in the boiler, which accounted for 76.97% at full load, 77.41% at 75% load of irreversibility, followed by turbine which accounted for 10.02 at full load, 10.22% at 75% load of irreversibility, then in the condenser 4.48% at 100% load, 4.04% at 75% of irreversibility.
- By exergetic analysis of the plants, a logical procedure to improve the power production of a thermal power plant is presented.

Nomenclatures

C_p	Specific heat, J/kg °C
E	Exergy, kJ/kg
Ex	Inlet mass flow rate, kg/s
G	Specific enthalpy, kJ/kg
h	Lower heating value, kJ/kg
Hv	Exergy losses, kJ/kg
I	Constant value for linear equation
m	Mass flow rate, kg/s
P	Power, MW
p	Pressure, MPa, bar
Ps	Saturation pressure, MPa, bar
S	Entropy, kJ/kg. K
S	Entropy, kJ/kg. K
T	Temperature, °C
T_s	Saturation temperature, °C

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