Optimization of Combined Thermal Power Plant and Performance Analysis using Matlab/Simulink using Real Data: Kuwait as a Case Study

Meshari F A F Alshammari[1], Siti Fauziah Toha[2*], Hazleen Anuar[3], Yose Fachmi Buys[4]

[1]*Department of Electrical Power, The Public Authority for Applied Education and Training, Higher Institute of Energy, Kuwait*

[2]*Department of Mechatronics, Faculty of Engineering, International Islamic University Malaysia*

[3]*Department of Manufacturing and Materials Engineering, Faculty of Engineering, International Islamic University Malaysia, Malaysia*

[4]*Department of Mechanical Engineering, University of Malaya, Malaysia*

*Corresponding author: *tsfauziah@iium.edu.my*

(Received: 22nd March 2021; Accepted: 18th April 2021)

Abstract— To increase the overall plant efficiency, the Combined cycle power plant (CCPP), which is a combination of the Gas turbine (Brayton cycle) and steam turbine (Rankine cycle), is a highly efficient system for electricity generation. In this paper, optimization and performance simulation analysis of Subiyah Combined Thermal Power Plant using real operating data is performed. The model is developed using MATLAB software. The main factors in the top and bottom cycles of the combined cycle are investigated and discussed. The simulation results demonstrate the exhaust of the Gas turbine reached up to 600°C. The net-power output based on the performance model using MATLAB (Simulink) is greater than the station's current real output by 20.5%. The overall thermal efficiency of the power plant is also raised from 50.5% to 55.2%.

Keywords: *electricity generation, Combined cycle power plant (CCPP), Gas turbine (Brayton cycle) and steam turbine (Rankine cycle).*

1. INTRODUCTION

The combination of the gas turbine cycle and the steam turbine cycle is one of the most promising technologies in power generation. The main concept of such cycles is based on supplying the heat to the gas cycle. Therefore, it uses the same components of the above cycles to generate more efficient power output. The heat from the gas turbine exhaust powers the steam cycle. This cycle works between the gas turbine's high temperature and the low temperature of steam turbine heat rejection. Therefore, the performance of the combined power plant is better than the performance of both plants individually. It is also suitable to run facilities like those run by the steam turbine or the gas turbine power plants. For example, it successfully provides a power output that suits the middle-sized peak facilities like a gas turbine and extensive baseload facilities like a steam turbine. Using natural gas to power combined cycle power plants im- proves its efficiency and consumes less time and costs than coal-fired power plants.

The concept of a combined cycle power plant is based on increasing the heat recovery from the same heat input to generate extra power. The combined cycles' advantage is guaranteed by using the appropriate working fluid and its physical states to attain the best heat transfer between cycles. Experimentally, the best successful configuration was proved to be between the gas turbine Brayton cycle and the steam turbine Ranking cycle. The

DOI: https://doi.org/10.69955/ajoeee.2021.v1i1.13

processes involved in this combination are illustrated thermodynamically by Fig. 1. Therefore, to enhance their efficiency and reduce energy depletion and greenhouse gas emissions, a major industry initiative and focused studies related to the gas turbine cycle have recently emerged [1–4]. Several scientists have tested the combination of regenerative cycle gas turbines [2–5]. An advanced gas turbine with a regenerator was considered by [6] to recover power and increase both combined cycle performance and electrical efficiency.

A peak power output from the steam turbines reached 100MW in the 1930s. This amount was boosted to 1000MW in the 1960s and to 1300 MW in the 1970s. In the 1960s, the gas turbine exhaust gases were used to power the steam turbine engine to generate the combined cycle power plant, which had higher performance.

The temperature of the waste exhaust gas from the gas turbine decreases as it flows into the superheater, evaporator, and economizer heat recovery steam generator (HRSG). The HRSG then provides the steam for the steam turbine to produce electricity. The steam turbine's surplus condensate will be transferred to a condenser in the steam turbine, where cooling water moves waste heat to the cooling tower. Feedwater is the supply from a condenser in the final stage, then sucked by the feedwater pump and sent to the steam generator for heat recovery and so on [7]. Compared to the gas turbine-based plant or steam turbine-based plants, these have higher thermal efficiency in isolation; the gas/steam combined cycle power plant's output depends on the topping and bottoming cycle output. If the turbine inlet temperature (TIT) can be increased, gas turbines give high specific work performance. As the efficiency of the heat recovery steam generator (HRSG) and the steam turbine improved due to the rise of TIT, that also cause the improvement of the combined cycle output [8]. The HRSG is a three-component heat exchanger, namely the economizer, the evaporator, and the superheater, and can be built with standard single-pressure or multi-pressure setups, with or without additional firing. In a study on the optimization of the Maputo power plant, it was found that a steam turbine's most critical design parameter is the steam data that includes the input pressure and temperature of the mass flow and steam turbine and the condenser pressure [9].

In this paper, a Combined cycle power plant (CCPP) is utilized for performance analysis study. This paper aims to optimize and perform simulation analysis of the Subiyah Combined Thermal Power Plant using real operating data. The model is developed using MATLAB software.

2. SYSTEM ARCHITECTURE AND MODELING

Subiyah Thermal Power Plant produces 2GW (2000MW) gas-fired power station comprises four combined-cycle power blocks. This plant was converted into combined-cycle operations with a total generating capacity of 2GW in phase two completed in July 2012.

The design and simulation in this work will be for one block out of the four available in the station. Based on the data, the output of this unit is around 270MW with 50% of efficiency. The Combined Cycle Power Plant's major components are Gas turbine, Heat recovery, steam generator, Steam turbine, and Balance of plant systems. The other components are Heat exchangers, Water pumps, Condensers, Electrical Generators.

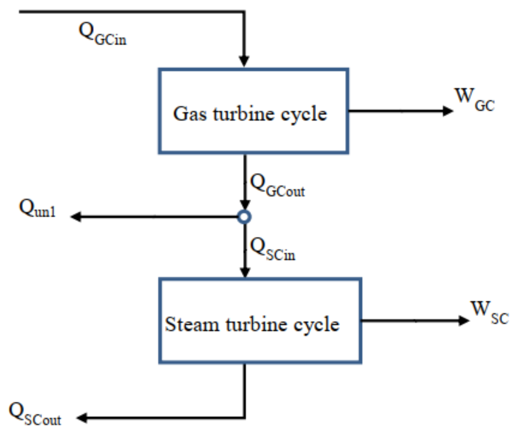

Fig 1. The combination between a gas turbine and a steam turbine cycles

Table 1. Data for Main Parameters (Combined cycled)

Parameter	Value	Unit
Inlet Temp. of the Air (Ambient temp)	34	oC
Inlet Pressure	1	Bar
Pressure ratio	10.1	-
Specific heat capacity of Air	1.005	kJ/kgK
Compressor efficiency	80% (0.8)	-
Intercooling efficiency	90% (0.9)	-
Isentropic index	1.4	-
Specific heat capacity of gas	1.15	kJ/kgK
Max. Gas Temp. for the turbine	1200	oC
Mechanical efficiency	95% (0.95)	-
Turbine isentropic efficiency	85% (0.85)	-
Boiler heat exchanger effectiveness	0.85	-
Total Power (1 unit)	500	Megawatt
Turbine efficiency	0.85	-

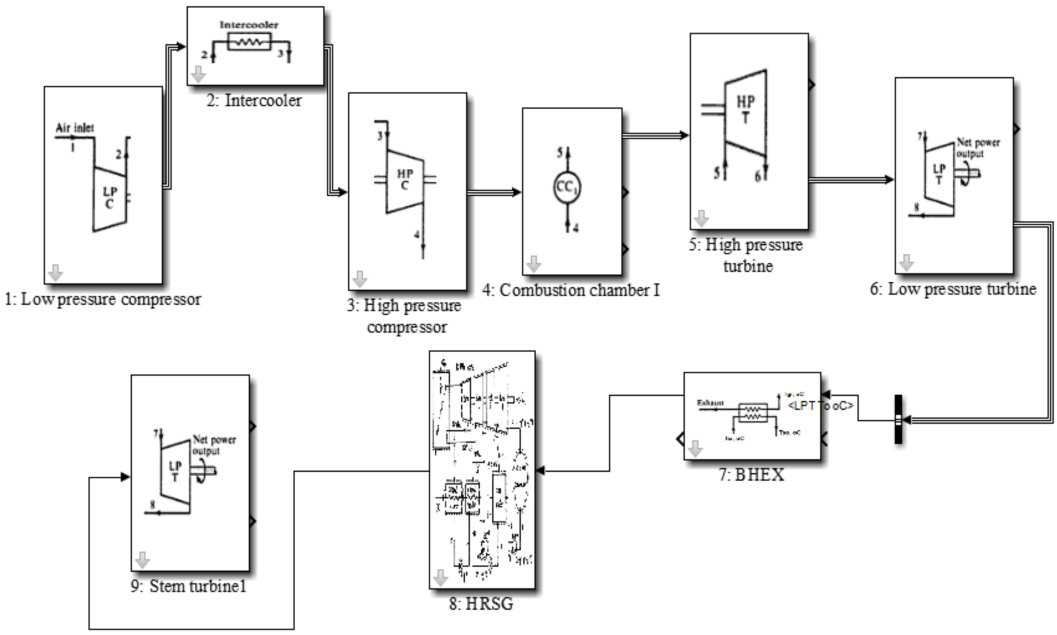

Figure 2. Full diagram (Gas-turbine with intercooling, reheat, and regeneration)

Figure 2 shows the complete diagram of the project (1 unit); a combined-cycle power plant uses both a gas and a steam turbine together to produce up to 50 percent more electricity from the same fuel than a traditional simple-cycle plant. The gas turbine's waste heat is routed to the nearby steam turbine, which generates extra power.

A hand measurement analysis of this configuration gas turbine cycle involving examining properties at ten different points is particularly tedious when compressor and turbine irreversibility and pressure losses are considered. The MATLAB software is used to design the model, run the simulations to study the performance analysis, and compare the results with the available currently in the power plants.

3. RESULTS AND DISCUSSION

In this section, the performances of the combined cycle thermal power plant are presented. The performance analysis and optimization of combined cycle thermal power plant two simulations have been done in this work.

3.1 Steady-state mode and Dynamic mode

The first part will be in a steady state. Stop time is 0. The unit with steady-state mode (Temp is 1200°C). The second part of the study is in the Dynamic state (Gas temp) is in Dynamic mode between (400°C to 1200°C): The results of main parameters such as (Heat and Heat add in each cycle, efficiency in the top and bottom cycles, mass flow rate, and temperature are analyzed. The energy in the top cycle will increase with a certain time during the increasing temperature from 400°C to 1200°C in the combustion chamber, as shown in Figure 2.

Figure 3 and Figure 4 show the gas turbine cycle's mass flow rate and efficiency, respectively. The change of the heat in the heat recovery steam generator with respect to time is shown in figure 5, which is the total heat transfer rate for boiler/superheater/ reheater.

The top cycle temperature reached up to 1200°C. However, the waste heat or the exhaust gas Temperature from the gas turbine reaches up to 634°C as shown in figure 6. which is enough to use in several applications. In this design, the exhaust temperature will be reused in the steam section to reheat the water as we mentioned earlier.

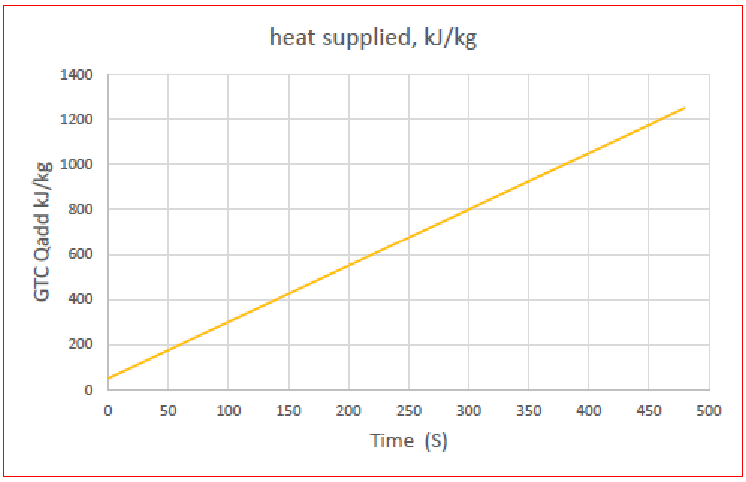

Figure 3. Energy supplied to the top cycle (Gas turbine Cycle, GTC)

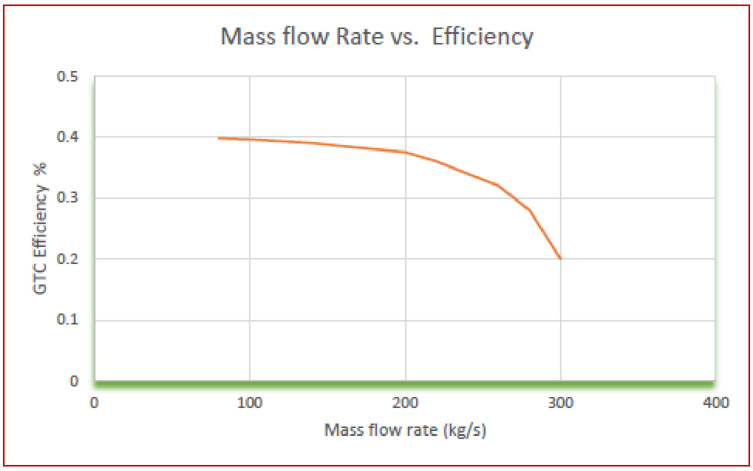

Figure 4. Cycle mass flow rate Vs. Gas turbine cycle efficiency

Table 2: Results (Steady-state mode, Temp = 1200ºC)

Parameter	Value	Unit
LPC Outlet Temp.	488.3	K
LPC Outlet Pressure	3	Bar
LPC Outlet enthalpy	490.6	kJ/kg
Outlet cooling air Temp.	470.6	K
Intercooler Outlet enthalpy	328.2	kJ/kg
HPC Outlet Temp.	519	K
HPC Outlet Pressure	15	Bar
HPC Outlet enthalpy	521.9	kJ/kg
CC Outlet Temp.	1470	K
CC Outlet Pressure	15	Bar
CC Outlet enthalpy	1696	kJ/kg
Q_{add} (Heat supplied to the cycle)	1556.9	kJ/kg
HPT Outlet Temp.	1113	ºC
HPT Outlet Pressure	4.3	Bar
HPT Outlet enthalpy	1310	kJ/kg
Gas turbine cycle efficiency	0.37	49%
Top steam Temp.	841.1	ºC
Exhaust Gas turbine Temp.	634.3	ºC
Steam Turbine stages energy	1276	kJ/kg
Net steam turbine Energy	1255	kJ/kg
Pump Energy	20.98	kJ/kg
Total Mass flow rate	664.8	Kg/s
Thermal efficiency	0.446	44.6%

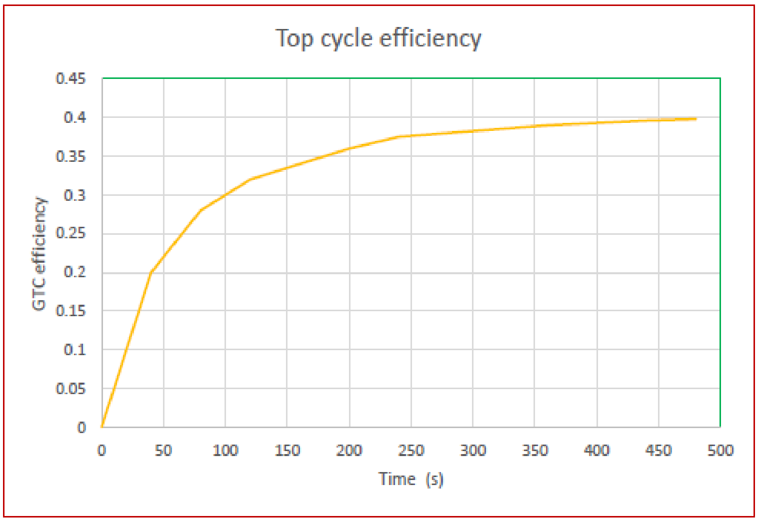

Figure 5. Top cycle efficiency (GTC efficiency %)

Turbine components will withstand certain temperatures otherwise will damage if we increase the temperature more than the limit. The efficiency reaches up to 39.80% in the top cycle while the temperature was around 1200°C. However, the overall efficiency shown in figure 7, the graph reaches up to 55.20%, when the

TIT is around 1200°C with a pressure ratio of 15. The figure shows the relationship between Gas turbine efficiency and the overall thermal efficiency of the power plant. Table 3 shows the comparison between the current output and efficiency of the Subiyah station and the results from the simulations.

Using MATLAB (Simulink) based on real operating data from the station is shown in table 1. Based on these results, there are some losses due to less gas turbine maintenance or lifetime.

Table 3. Comparison between the actual and real output

Parameters	Real Data	Simulations (MATLAB)
GT Efficiency %	34%	39.80%
Overall thermal Efficiency %	50.50%	55.2%
GT output power (MW)	160	200
ST output power (MW)	110	140
Net Power output (MW)	270	340

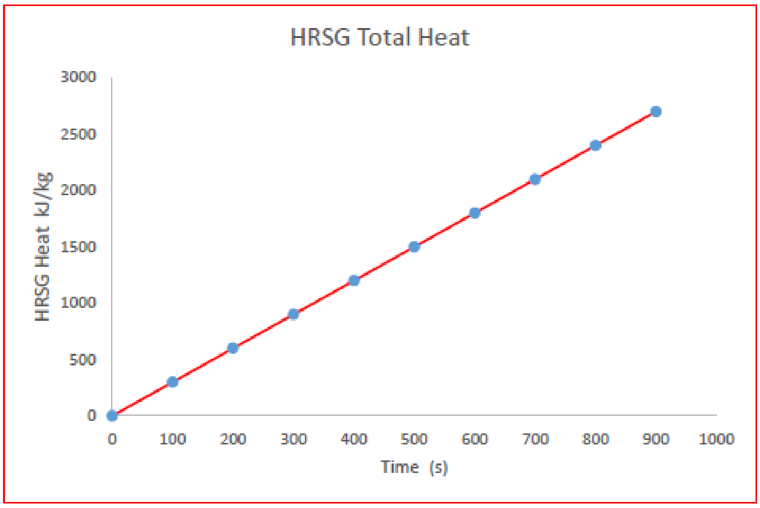

Figure 6. HRSG Total Heat

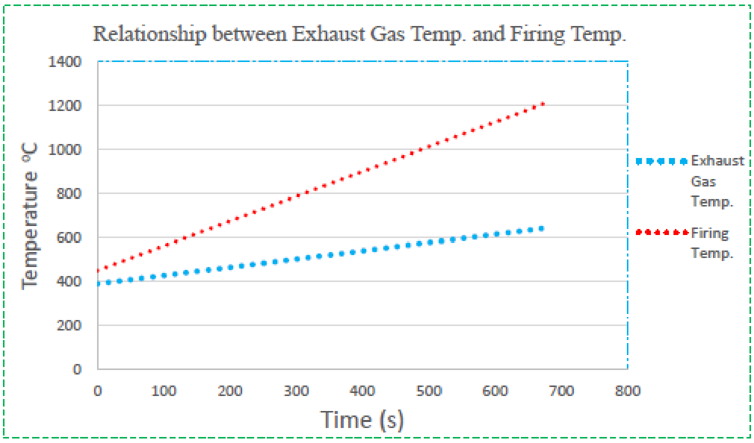

Figure 7. Exhaust Gas Temp vs. Firing Temp

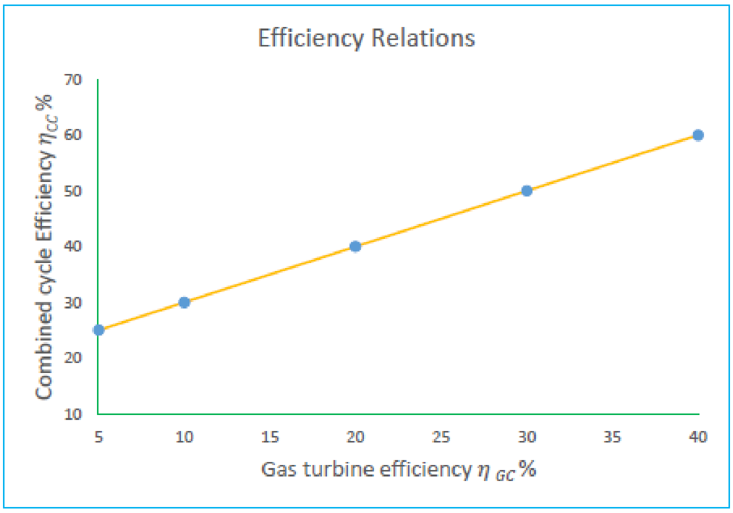

Figure 8. Overall efficiency vs. Pressure ratio in Combine cycle

Several factors increase the power output, such as increasing the turbine inlet temperature and supporting the station with the reheated system. To increase the temperature in the heat recovery steam generator (HRSG), or implementing the gas turbine's reheated configuration, is to increase both the output power and the exhaust temperature.

4. CONCLUSION

The performance modeling and analysis and optimizations of single and combined cycled in Sabiyah Thermal Power Plant are studied. Meanwhile, the climate policy and air pollution need to be taken into consideration. To optimize them and to get closer to the limit of what the material can withstand. It is required to improve the cycle's performance and reduce both the natural gas used for driving the cycle and the CO2 emissions.

ACKNOWLEDGEMENT

The author would like to thank the financial support from the International Islamic University Malaysia under research grant IRF19-026-002: Highly Efficient Lithium-Ion Battery Recycling with Capacity-Sorted Optimization for Secondary Energy Storage System.

REFERENCES

[1]. Al-Qawasmi, A. R., & Tlili, I. (2018), "Energy efficiency audit based on wireless sensor and actor networks: air-conditioning investigation". *Journal of Engineering*, *2018*, https://doi.org/10.1155/2018/3640821

[2]. Khan, Z., Rasheed, H.U., Tlili, I., Khan, I. and Abbas, T., "Runge-Kutta 4th-order method analysis for viscoelastic Oldroyd 8-constant fluid used as coating material for wire with temperature dependent viscosity". *Scientific reports*, vol. *8*(1), pp.1-13.,2018, https://doi.org/10.1038/s41598-018-32068-z

[3]. Tlili, I, "Finite time thermodynamic evaluation of endoreversible Stirling heat engine at maximum power conditions". *Renewable and Sustainable Energy Reviews*, vol. *16*(4), pp.2234-2241, 2012, https://doi.org/10.1016/j.rser.2012.01.022

[4]. Tlili, I.A., "Numerical investigation of an Alpha Stirling engine using the Ross Yoke linkage", *Heat Technol*, vol. *30*, pp.23-36,2012, https://doi.org/10.18280/ijht.300104

[5]. Tlili, I., Khan, W.A. and Khan, I., " Multiple slips effects on MHD SA-Al2O3 and SA-Cu non-Newtonian nanofluids flow over a stretching cylinder in porous medium with radiation and chemical reaction", *Results in physics*, vol. *8*, pp.213-222, 2018, https://doi.org/10.1016/j.rinp.2017.12.013

[6]. Xue, Lichao, Wei Wang, and Zhongyue Huang. "Investigation on Performance of Cycle Combined Brayton and Ambient Pressure Gas Turbine." In *Challenges of Power Engineering and Environment*, pp. 69-72. Springer, Berlin, Heidelberg, 2007. https://doi.org/10.1007/978-3-540-76694-0_12

[7]. Ibrahim, Thamir K., and M. M. Rahman. "Effective Parameters on Performance of Multipressure Combined Cycle Power Plants.", *Advances in Mechanical Engineering (Hindawi Publishing Corporation)*, 2014, http://dx.doi.org/10.1155/2014/78150

[8] Yadav, J.P. and Singh, O., "Thermodynamic Analysis of Air Cooled Simple Gas/ Steam Combined Cycle Plant", *Journal of the Institution of Engineers(India), Part MC, Mechanical Engineering Division*, vol. *86*, pp.217-222,2006.

[9] Armando, A, "Optimization of Maputo Power Plant", M.S Thesis, KTH, School of Industrial Engineering and Management (ITM), Energy Technology, Heat and Power Technology, Stockholm, Sweden, 2013.

[10] Han, W., Chen, Q., Lin, R.M. and Jin, H.G., "Assessment of off-design performance of a small-scale combined cooling and power system using an alternative operating strategy for gas turbine", *Applied Energy*, vol. *138*, pp.160-168, 2015, https://doi.org/10.1016/j.apenergy.2014.10.054