Thermodynamics Optimization of GARRI (1) Combined Cycle Power Plant by Using ASPEN HYSYS Simulation

AbdAllah Mokhtar.M[b] ,Mohammed Elayeb.M[a], Tawfiag Ahmed .J[b],Ala'a eldin[b],Abdalrahim[b],Hamdnalla[b]

[a]*Mechanical Engineering Department,Collage of Engineering,Karry University SUDAN*

[b] *Department of Power Engineering, School of Mechanical Engineering, Collage of Engineering, Sudan University of Science and Technology, SUDAN.*

Abstract: - The study aims to simulate GARRI (1) combined cycle power plant by using ASPEN HYSYS. It aims to conduct a detailed thermodynamic analysis for combined cycle power plant and optimization to attend maximum efficiency by dissertating different scenarios of operating parameters. The study examined the operational side by passing through all the components of the combined cycle power plant and the mechanism of the system. Block 1 in GARRI (1) combined cycle power plant is used. The results efficiency obtained from ASPEN HYSYS simulator is **31.89%**, while that of GARRI (1) is **27.4%.** The effect of each operating parameter on the efficiency and power output was extracted by using Microsoft excel in form of graphical charts resulted from the thermodynamic analysis done by using ASPEN HYSYS simulator. The maximum efficiency in the optimum operating parameters is about **33.88%** by using different scenarios

Keyword:-*Energy, efficiency, Pressure,Gas cycle,Garri(1), Steam cycle, Air inlet temperature ,compressor pressure ratio ,steam temperature ,steam pressure ,efficiency curve.*

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I. Introduction:

The generation of electric power has become even important over recent years. Due to the rising consumption and growing environmental awareness, new requirements have to be met. The power supply has to be constantly adapted to the stochastic requirements of the consumers. Differences between generation and consumption result in deviations from the adjusted target values of the network frequency and power delivered to customers.

The continued quest for higher thermal efficiencies has resulted in rather innovative modifications to conventional power plants, which is called the combined gas–vapor cycle, or just the combined cycle. Efficiencies ranging depending on the lay-out and size of the installation and vary from about 40-66% for large new natural gas-fired stations. Developments needed for this type of energy conversion is only for the gas turbine. Both waste heat boilers and steam turbines are in common use and well-developed, without specific needs for further improvement.

II. Objectives:

The purpose of this study is to develop a model as a part of the general combined cycle power plant by:

1. Simulation of combined cycle power plant with ASPEN HYSYS simulator.
2. Detailed thermodynamics analysis for plant will be conduct.
3. Different scenarios will be considered for optimum power plant efficiency.

III. ASPEN HYSYS Simulation Software:

HYSYS is powerful engineering simulation tool, has been uniquely created with respect to/w.r.t the program architecture, interface design, engineering capabilities, and interactive operation. The integrated steady state and dynamic modeling capabilities, where the same model can be evaluated from either perspective with full sharing of process information, represent significant advancement in the engineering software industry. The various components that comprise HYSYS provide an extremely approach to steady state modeling. The comprehensive selection of operations and property methods allow modeling a wide range of processes with confidence. Perhaps even more important how the HYSYS approach modeling maximizes your return on simulation time through increased process understanding.

3.1Assumptions:

The fowling assumptions are purposed:

- Camera of combustion of the process from GARRI (1) station as a conversion100% reactor in the HYSYS.
- Compressor and turbines the efficiencies are adiabatic.
- Components of the natural gas are: methane, ethane and nitrogen.
- The natural gas in the feed comes directly at the pressure of 23 bars.
- Neglect mechanical losses and losses in each unit (turbine, compressor, boiler and HRSG adiabatic).

3.2 Constraints:

The constraints of the process are

Temperature combustion < 1500° C

Temperature steam turbine < 600° C

Pressure cycle steam < 170 bars

3.4 Fluid Packages:

In HYSYS, all necessary information pertaining to pure component flash and physical property calculations are defines inside a single entity with the following advantages as below:

- Associated information is defined in a single location, allowing for easy creation and modification of the information.
- Fluid packages can be exported and imported as completely defined packages for use in any simulation. This simplifies the task of making small changes to a complex Fluid package.
- Multiple Fluid Packages can be used in the same simulation; however; they are all defined inside the common Simulation Basis Manager.

Table (3.1): Temperature and Pressure data for each fluid package tested.

Properties	**SRK(Soave- Redlich- Kwong)**	**GARRI(1)**
T(^{O}C) exit compressor	384.5	**364**
KW compressor	$2.88x10^4$	**$2,66x10^4$**
T(^{O}C) combustion	1271	**1280**
MW net gas turbine	95.83	**60**
T(^{O}C) exit gas turbine	913	**913**
T(^{O}C) exit gases HRSG	594.7	**571**
T(^{O}C) exit steam turbine	109.3	**150**
MW steam turbine	21.33	**30**
T(^{O}C) exit pump HP	104	**100**

According to the results of temperatures, pressures and works, thermodynamic model SRK is chosen. HYSYS in stationary state mode, problems appear, since none of the thermodynamic models resembled the results of the process of GARRI (1) station, as obtaining liquid in the exit of the reactor, leading to discarded the thermodynamic package.

3.5 Fluid Package:

The components of the package are shown composition of the Fuel (LPG) in (table 3.2) below

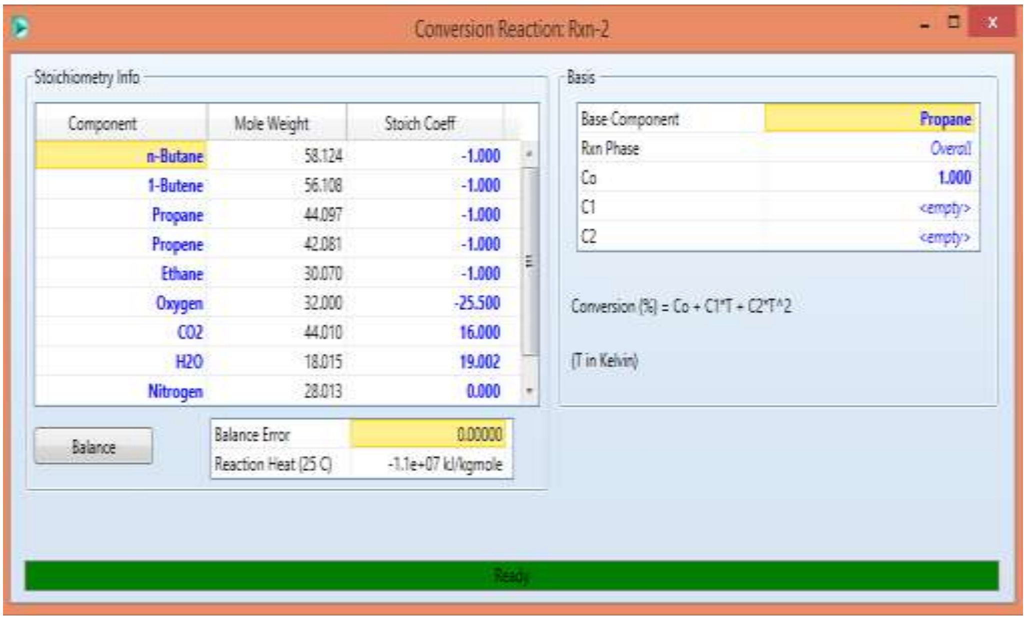
Component	% (Mass)
Butane	**0.265**
Butene	**0.1885**
Propane	**0.3456**
Propene	**0.1798**
Ethane	**0.0027**
Nitrogen	**0.0184**

3.6 Combustion Reaction:

The reaction takes place in the combustion, where it mixes the natural gas with the air:

$$(C_4H_{10} + C_4H_8 + C_3H_8 + C_3H_6 + C_2H_6 + N_2) + 25.5(O2 + 3.76\ N_2) \rightarrow 16\ CO_2 + 19\ H_2O + 96.88\ N_2$$

Compare to that In the HYSYS software



Component	Mole Weight	Stoich Coeff
n-Butane	58.124	-1.000
1-Butene	56.108	-1.000
Propane	44.097	-1.000
Propene	42.081	-1.000
Ethane	30.070	-1.000
Oxygen	32.000	-25.500
CO2	44.010	16.000
H2O	18.015	19.002
Nitrogen	28.013	0.000

Balance Error	0.00000
Reaction Heat (25 C)	-1.1e+07 kJ/kgmole

Base Component	Propane
Rxn Phase	Overall
Co	1.000
C1	<empty>
C2	<empty>

Conversion (%) = Co + C1*T + C2*T^2

(T in Kelvin)

Figure (3.1): Definition of the combustion reaction in HYSYS

3.7 Results of the Steady-State simulation with HYSYS:

Calculation of efficiency of the combined cycle, the net work corresponds to the one generated by the turbines is less than that consumed by the pump and compressor.

The results of the simulated cycle, the global efficiency of the plant is obtained as table (3.3-3.5)

Table (3.3): Energy Streams result

	Unit	GT	HP ST	LP ST	COMP	Q add
Heat Flow	**MW**	**132.8346**	**17.06678**	**13.44931**	**68.55338**	**296.5855**
	Unit	**Q rej**	**Q Dearator**	**W HPP**	**W FP**	
Heat Flow	**MW**	**70.16702**	**1.177066**	**0.187663**	**0.015327**	

Table (3.4): Efficiencies of turbines, compressors and the pump

Efficiency	Works(MW)	Efficiency (%)
Compressor	**68.55338**	**83 %**
Gas Turbine	**132.8346**	**83 %**
HP Steam Turbine	**17.06678**	**83 %**
LP Steam Turbine	**13.44931**	**83 %**
Pumps	**0.20299**	**75 %**

3.8 Comparison results of the simulated plants:

Table (3.5) represents HYSYS simulation analysis, analysis and the real data of GARRI (1) power plant.

Table (3.5): comparison between simulation results and GARRI (1) data

	GARRI(1) plant	HYSYS simulated plant
Net Work (MW)	**58.220**	**94.59432**
Heat (combustion) (MW)	**212.482**	**296.5855**
Combined Cycle efficiency	**27.4 %**	**31.89 %**

Result shown that HYSYS simulated plant efficiency is near to the actual efficiency of GARRI (1) plant which calculated. HYSYS simulator used as an optimize technique of combined cycle by making different scenario to calculate the optimum value of parameters to give maximum efficiency of combined cycle power plant.

IV. Optimization 0f Combined Cycle Power Plant:

Thermodynamic analysis and optimization of combined cycle power plant depending on the operating parameters as takes

1. Air inlet temperature (ambient temperature)
2. Air mass flow rate
3. Fuel mass flow rate
4. Air/fuel ratio
5. Compressor pressure ratio
6. Gas turbine inlet temperature
7. Live steam pressure
8. Live steam temperature
9. Condenser pressure
10. Mass flow rate of steam
11. Extraction mass flow rate
12. Pinch point temperature difference

Hyses simulation with Microsoft excel are used for optimization the efficiency and the result are shown below:

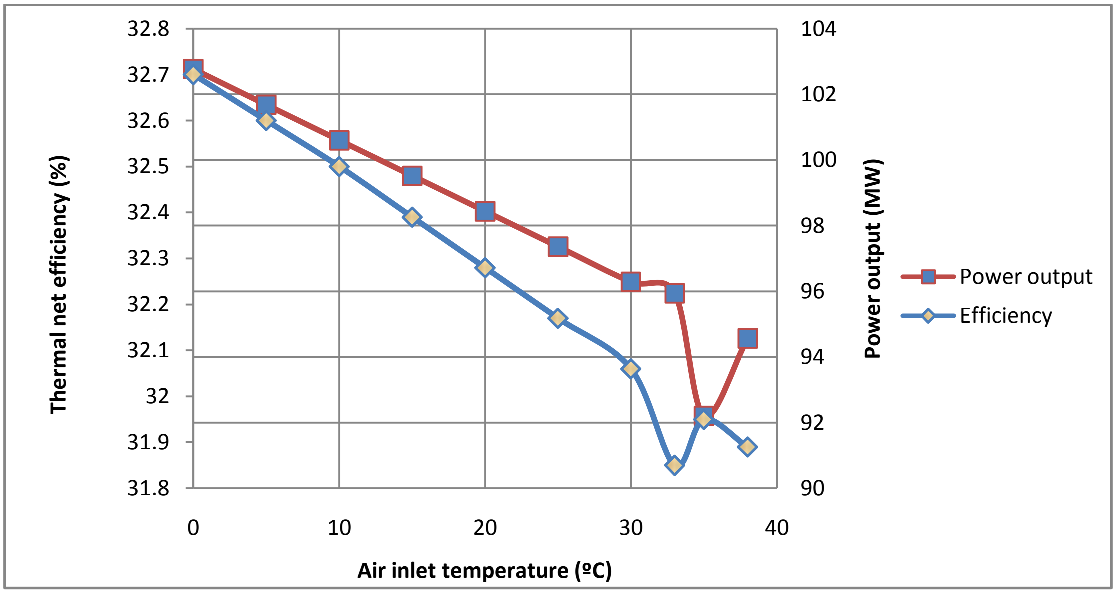


Figure (4.1): Effect of Air inlet temperature on plant efficiency and output power

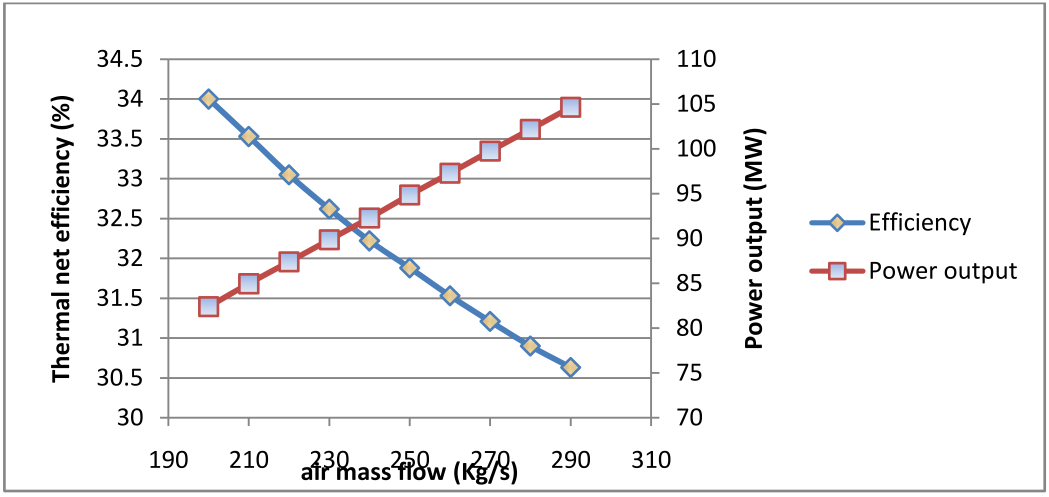


Figure (4.2): Effect of air mass flow on plant efficiency and output power

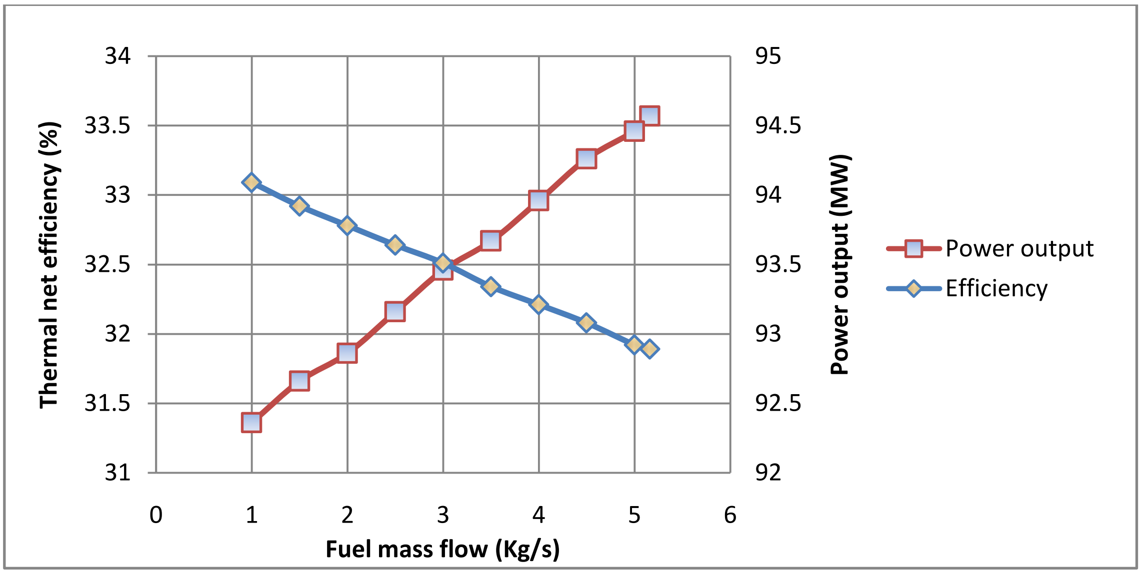


Figure (4.3): Effect of Fuel mass flow on plant efficiency and output power

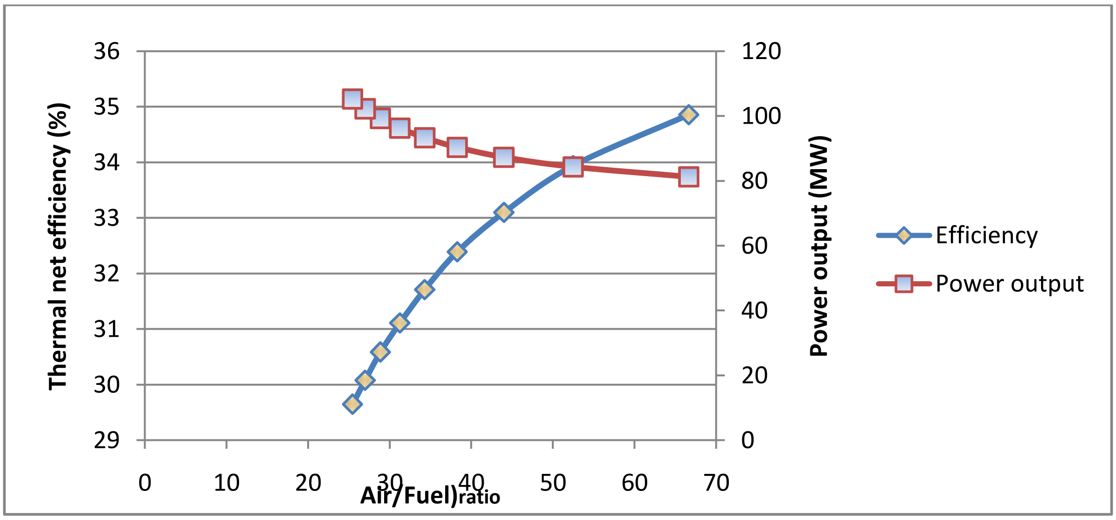


Figure (4.4): Effect of Air/ Fuel ratio on plant efficiency and output power

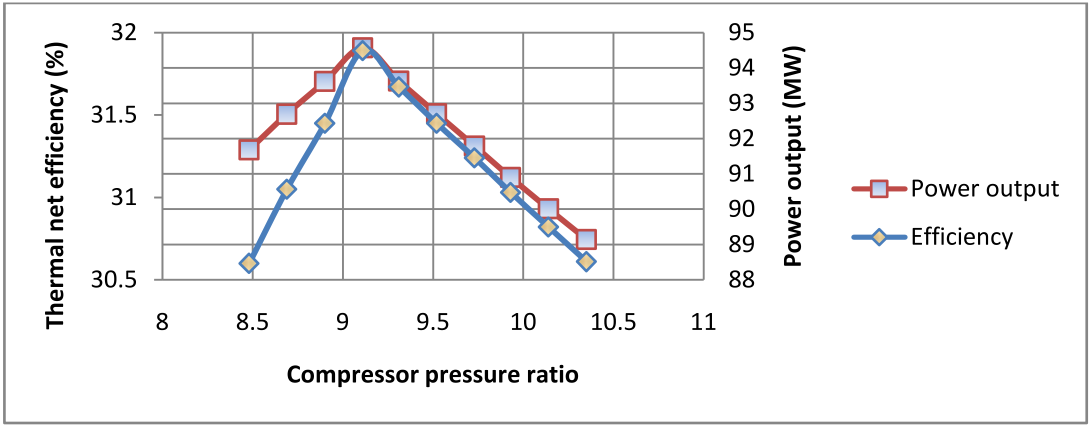


Figure (4.5): Effect of compressor pressure ratio on plant efficiency and output power

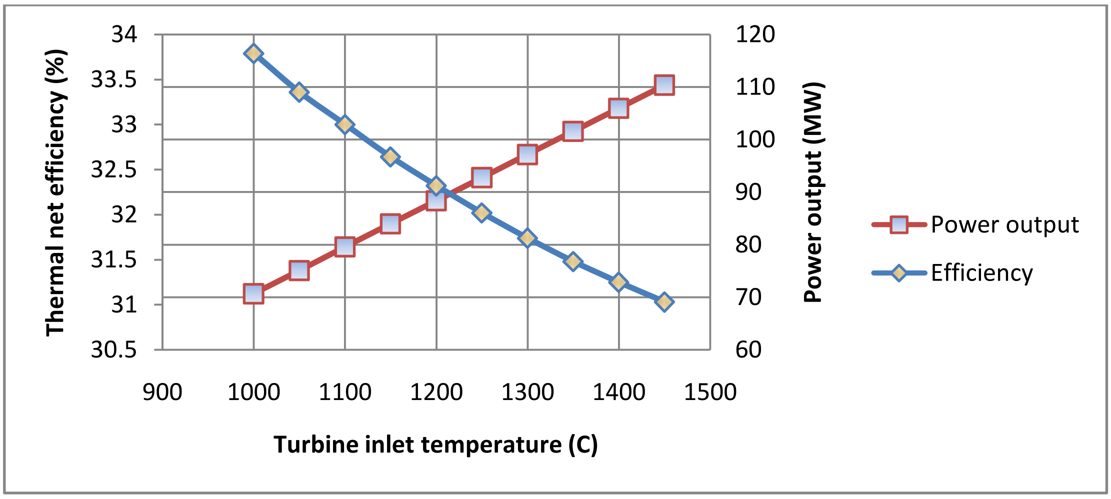


Figure (4.6): Effect of turbine inlet temperature on plant efficiency and output power

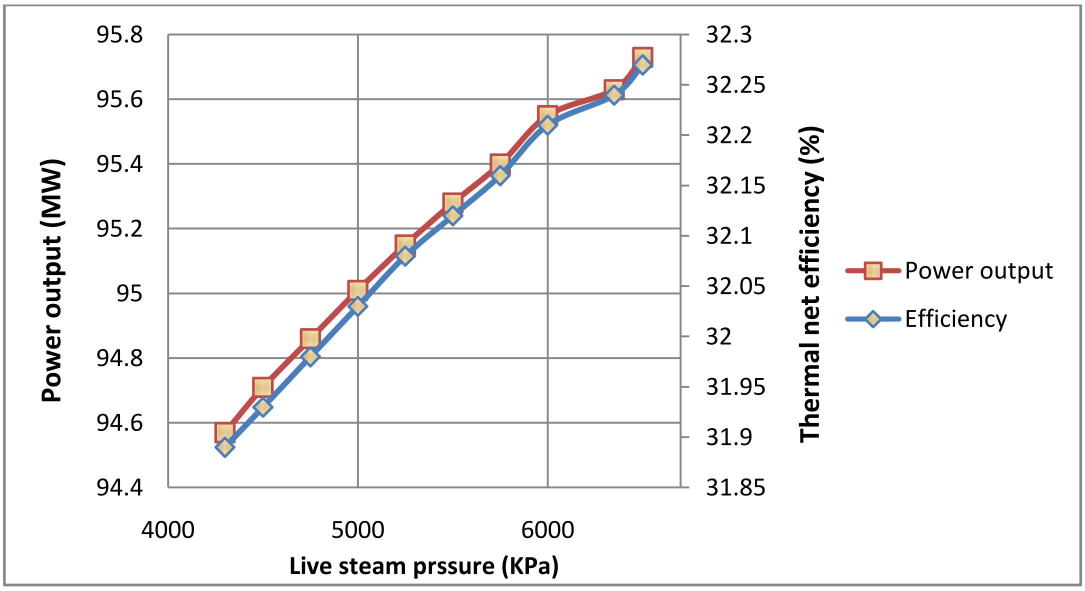


Figure (4.7): Effect of Live steam pressure on plant efficiency and output power

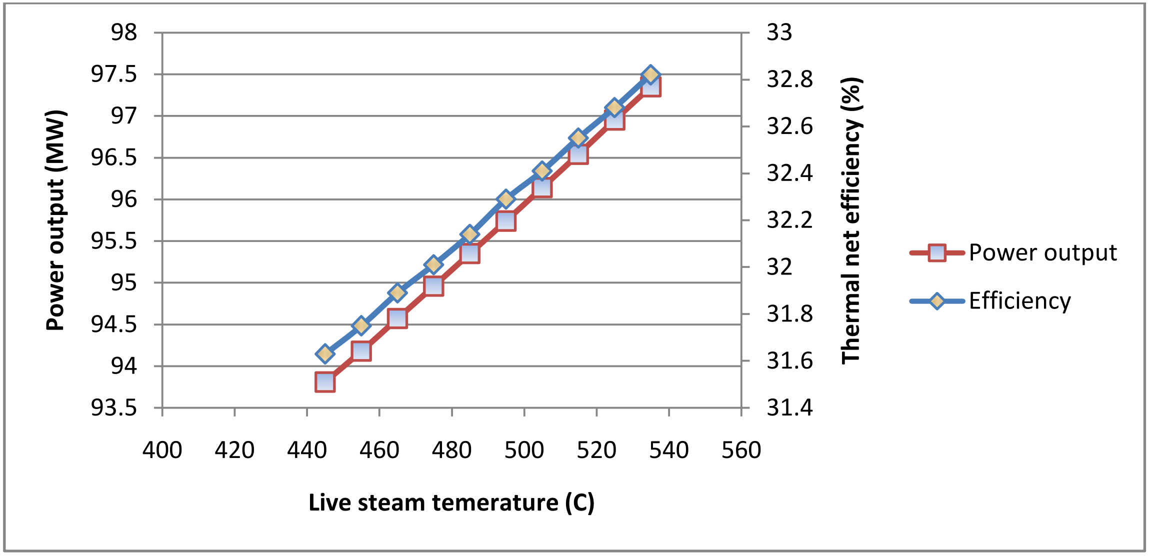


Figure (4.8): Effect of Live steam temperature on plant efficiency and output power

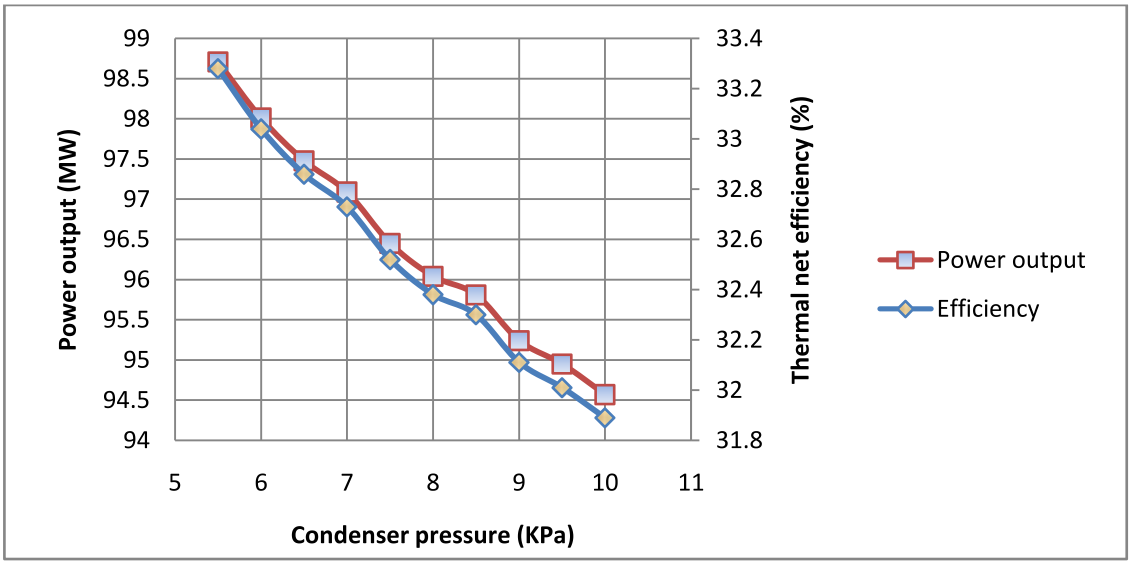


Figure (4.9): Effect of Condenser pressure on plant efficiency and output power

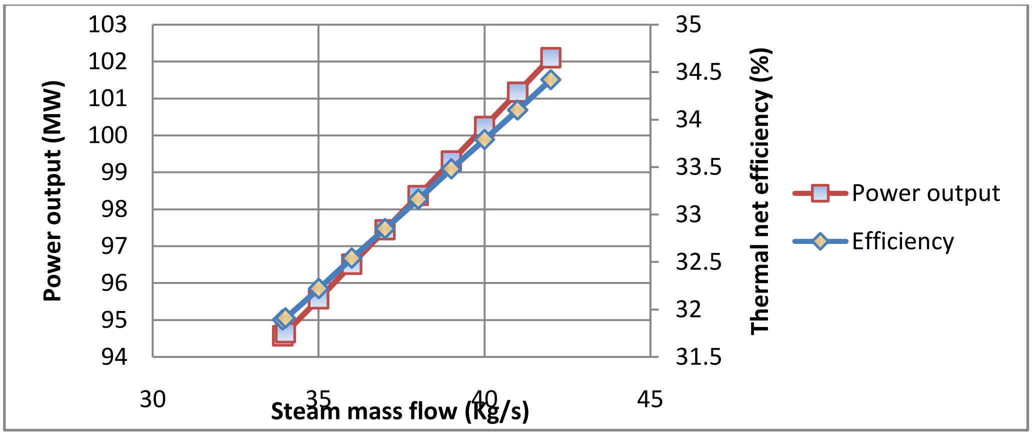


Figure (4.10): Effect of Steam mass flow on plant efficiency and output power

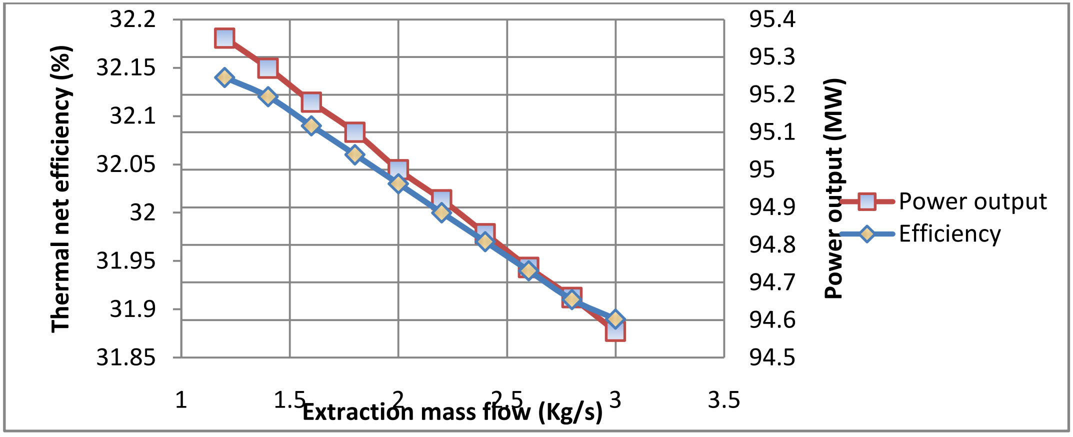


Figure (4.11): Effect of Extraction steam mass flow on plant efficiency and output power

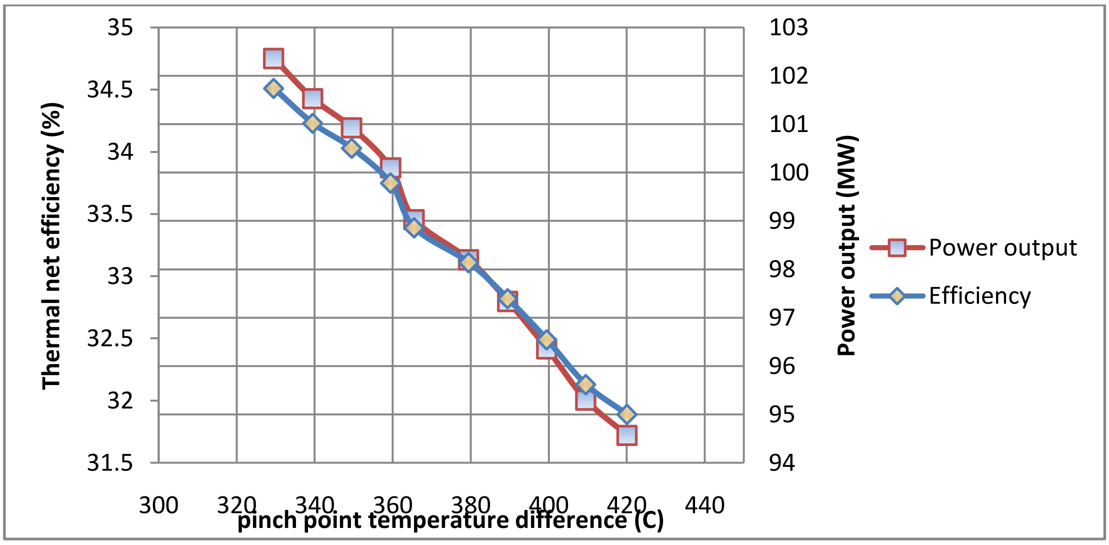


Fig (4.12): Effect of pinch point temperature difference on efficiency and output power

4.2 Optimization process:

For optimization we make different scenario of working plant that we change in different parameters and focus on its effect on efficiency. Different scenarios represented in table that shown below.

4.3 Result of optimization:

The figure below explains the curve between scenarios and efficiency which explain the maximum efficiency is equal 33.88%.

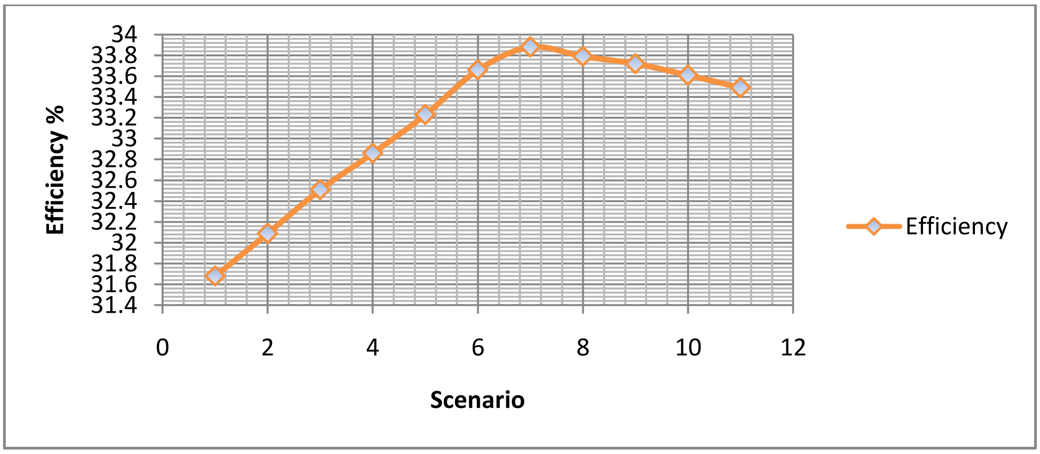


Figure (4.13): efficiency curve with numbers of scenario

Table (4.2): Comparison of optimized solution to the study

Parameters	Project work	Optimized solution	Absolute difference	Relative difference
Air inlet temperature) (C)	**38**	**28**	**-10**	**-26.31%**
Fuel mass flow rate (Kg/s)	**5.16**	**5.5**	**+0.35**	**+6.78%**
Air mass flow rate (Kg/s)	**249.2**	**260**	**+10.8**	**+4.33%**
Gas turbine inlet temperature (C)	**1271**	**1300**	**+29**	**+2.28%**
steam pressure (KPa)	**4300**	**5500**	**+1200**	**+27.9%**
steam temperature (C)	**465**	**520**	**+55**	**+11.83%**
Condenser pressure (KPa)	**10**	**11**	**+1**	**+0.1%**
Mass flow rate of steam (Kg/s)	**33.917**	**32**	**-1.917**	**-5.65%**
Extraction mass flow rate (Kg/s)	**3**	**2.8**	**-0.2**	**-6.66%**
Compressor pressure ratio	**9.11**	**9.52**	**+0.41**	**+4.5%**

V. Conclusion:

A simulation of the operating system in GARRI1 combined cycle station was done by ASPEN HYSYS simulator which show the simulation, is close to the actual efficiency for GARRI(1). The comparison between the designed cycles based on the thermal net efficiency produced and the thermal net efficiencies calculated were shown in table (501) below:

Table (5.1) efficiency values

GARRI (1) combined cycle station efficiency	**27.4%**
efficiency obtained from ASPEN HYSYS simulator	**31.89%**
Optimum efficiency obtained ASPEN HYSYS simulator	**33.88%**

The effects of major operating parameters can be summarized as follows:

1. The decrease in air inlet temperature (ambient temperature) will make an increase in efficiency and power output.
2. The decrease in fuel mass flow rate will make a decrease in efficiency and increase in power output.
3. The compressor pressure ratio should be optimum for maximum performance of combined cycle.
4. The turbine inlet temperature should be kept on higher side for maximizing power output, but in other side it minimizes the thermal net efficiency.
5. The increase in live steam pressure will make an increase in efficiency and power output.
6. The increase in live steam temperature will make an increase in efficiency and power output.
7. The decrease in condenser pressure will make an increase in efficiency and power output.
8. The increase in steam mass flow will make an increase in efficiency and power output.
9. The decrease in extraction steam mass flow will make an increase in efficiency and power output.
10. The decrease in pinch point temperature improves the combined cycle performance by increasing the efficiency and power output.

The maximum efficiency of GARRI (1) was calculated. And by changing those operating parameters, the efficiencies through assuming different scenario's under different operating parameters was calculated. As maximum efficiency equals **33.88%**. From calculating the maximum efficiency, the optimum operating parameters were derived, which are as table below:

Table (5.2) optimum operation parameters

Parameter	value
Air inlet temperature (ambient temperature)	**28 ºC**
Mass flow rate of fuel (LPG)	**5.5 Kg/s.**
Air mass flow rate	**260 Kg/s**
Compressor pressure is	**920 KPa**
Turbine inlet temperature	**1300 ºC**
Live steam pressure	**5500 KPa**
Live steam temperature	**520º C**
Mass flow rate of steam	**32 Kg/s**
Extraction mass flow rate	**2.8 Kg/s**
Condenser pressure	**11 KPa**

VI. Recommendation:

1. Designing simulation software by using a specific programming language for studying thermal power plants.
2. Applying simulation by using MATLAB program for its precise numerical analysis.
3. Applying different operation research methods for calculating the optimum operating parameters due to its accuracy in extracting the optimum values for the

operating parameters which leads to the highest efficiency.

4. Extending the research domain to include all GARRI (1) combined cycle power plant blocks.
5. Possibility of redesigning GARRI (1) combined cycle power plant to appropriate the different results of this study to increase its efficiency.

VII. Referncess:

[1] Mohagheghi M, Shayegan J. Thermodynamic optimization of design variables and heat exchangers layout in HRSGs for CCGT, using genetic algorithm. Appl Therm Eng 2009.
[2] Aspen hysys plus simulation program.
[3] . R. Yokoyada, S. Takeuchi, K. Ito, “Thermoeconomic Analysis and Optimization of a Gas Turbine Cogeneration Unit by a Systems Approach”, Proceedings of ASME Turbo Expo 2005, Power of Land, Sea, and Air, June 6-9, 2005, Reno, Nevada, USA.
[4] E.T. Bonataki, A.P. Giotis and K.C. Giannakoglou, Multi–Objective Design of Optimal Combined Cycle Gas Turbine Power Plants with Supplementary Firing, EUROGEN 2003, Barcelona, Spain, 2005.
[5] E.T. Bonataki, L.S. Georgoulis, H. Georgopoulou and K.C. Giannakoglou, Optimal Design of Combined Cycle Gas Turbine Power Plants based on Gas Turbine Performance Data,ERCOFTAC Design Optimization: Methods & Applications, Athens,Greece, March 2004.
[6] E.T. Bonataki and K.C. Giannakoglou, An Automated Tool for Single– and Multi–Objective Optimization for Redesigning Combined Cycle Gas Turbine Power Plants, Proceedings of the Fourth GRACM Conference on Computational Mechanics, Patras,Greece, June 2002.