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PERFORMANCE ENHANCEMENT AND PARAMETRIC OPTIMIZATION OF AL-MANSURIYA GAS POWER PLANT VIA COMBINED CYCLE SIMULATION USING DWSIM

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Abstract:

Power plants form the backbone of modern infrastructure by providing the electricity essential for residential, industrial, and commercial applications. Their primary function is to convert various forms of energy—whether fossil fuels, nuclear energy, or renewable sources—into electrical energy that can be distributed through the power grid.

Power plants can be broadly categorized based on the type of energy source they utilize, including:

1. Fossil fuel-based power plants (natural gas, coal, diesel ,e.g.,)
2. Renewable energy power plants (solar, wind, hydroelectric, e.g.,)
3. Nuclear power plants
4. Combined Cycle Power Plants (CCPP), which integrate gas and steam turbines to enhance efficiency

A key challenge facing conventional power plants is achieving a balance between thermal efficiency, environmental sustainability, and economic viability. As global energy demand continues to grow, there is an increasing emphasis on improving the performance of power generation systems through advanced technologies, emissions reduction, and integration of cleaner energy sources.

Thus, conducting technical evaluations and performance analyses of power plants is critical for identifying optimal configurations, minimizing fuel consumption, reducing greenhouse gas emissions, and supporting the transition toward sustainable energy systems.

Indicating a performance gap that can be improved. At present, the plant operates under a simple gas turbine cycle, a system known for its reliability .But considered low in thermal efficiency compared to modern technologies (IEA, 2021, p. 112) [1]..

Due to increasing energy demand, rising fuel costs, and the global trend toward improving energy efficiency and reducing emissions, it has become essential to upgrade the plant. One of the most effective solutions is to convert the system to a combined cycle configuration, by integrating a steam cycle that utilizes the exhaust heat from the gas turbine to generate additional electricity without extra fuel (Horlock, 2003, pp. 45–50; Kehlhofer et al., 2009, pp. 88–92) [2].

As part of this study, four different models have been designed to convert the AL-Mansuriya Gas Power Plant into a combined cycle facility. These models aim to evaluate and analyze the influence of key variables such as steam pressure, inlet temperature, fuel mass flow rate, steam mass flow rate, and pressure ratio (rp) on overall efficiency and power output. The models have been assessed using dynamic simulation tools and thermodynamic analysis to identify the optimal design in terms of performance, efficiency, and sustainability. It is expected that this conversion could increase the plant's overall thermal efficiency to approximately 50–60%, reduce fuel consumption, and lower carbon emissions (Breeze, 2014, p. 136) [3]. This aligns with the strategic plans of Iraq's Ministry of Electricity to modernize the energy infrastructure and achieve sustainability in the power sector (Ministry of Electricity – Iraq, 2020, p. 21) [4].Iraq, despite being

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Keywords: Gas Power Plant, Simulation, Dwsim, Electric Power, Thermal Efficiency.

1.INTRODUCTION

The AL-Mansuriya Gas Power Plant, located in Diyala Governorate – Iraq, is one of the key facilities contributing to the national electric grid. It relies primarily on natural gas as its fuel source. The plant comprises four gas turbine units, each with a design capacity of 181 MW, while the actual output per unit is 151 MW. Accordingly, the total design capacity of the plant is 724 MW, and the current total actual output is 604 MW, rich in oil and gas, suffers from chronic electricity shortages. The national grid is comprised of three key segments: generation, transmission, and distribution, all of which face structural, administrative, and technical obstacles. Reports from the (Ministry of Electricity, 2022) [5] . reveal that although installed capacity should theoretically meet demand, actual generation often falls short—especially in the summer months when demand exceeds 34,000 MW, yet production hovers around 20,000 MW (IEA, 2021, p. 10) [6] .As part of this study, four different models have been designed to convert the AL-Mansuriya Gas Power Plant into a combined cycle facility. These models aim to evaluate and analyze the influence of key variables

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Such as steam pressure, inlet temperature, fuel mass flow rate, steam mass flow rate, and pressure ratio (rp) on overall efficiency and power output. The models have been assessed using dynamic simulation tools and

1.1. Fundamental Concepts in Gas and Steam Cycles:

1.1.1. General Introduction to Power Conversion Cycles

Modern power generation plants rely on thermal cycles to convert the chemical energy in fuel into electrical energy. The two most prominent cycles are:

- The Gas Cycle (Brayton Cycle)

- The Steam Cycle (Rankine Cycle)

Understanding these cycles is essential for designing and operating power plants. It forms the theoretical basis for the development of combined cycle systems, such as those proposed for the AL-Mansuriya Power Plant.

1.1.2. The Gas Cycle (Brayton Cycle)

The gas cycle consists of three main components: a compressor, a combustion chamber, and a turbine. Air is drawn into the compressor where it is pressurized, then mixed with fuel and combusted in the chamber. The resulting high-temperature gases are expanded through the turbine to generate mechanical work. • The thermal efficiency of this cycle typically ranges between 30–40% (El-Wakil, 1984, p. 331) [7] . • It is commonly used in peaking power plants due to its fast response time.

1.1.3. The Steam Cycle (Rankine Cycle)

This cycle involves heating water to produce high-pressure steam, which drives a steam turbine. The steam is then condensed and pumped back into the boiler. • Widely used in base load stations. • The typical

Table [2-1] Comparison of Gas Cycle and Steam Cycle Characteristics

Aspect	Gas Cycle	Steam Cycle
Working Fluid	Air + Combustion Products	Water / Steam
Operating Temperature	Very High (>1200°C)	Lower (300–600°C)
Thermal Efficiency	Higher but variable	Lower but more stable
Start-up Time	Fast – suitable for emergencies	Slower – suitable for base load
Typical Application	Peaking power stations	Base load power stations

This comparison is based on multiple sources, primarily El-Wakil (1984), Moran & Shapiro (2010)

1.1.5. The Combined Cycle

The combined cycle system maximizes the use of exhaust heat from the gas turbine by passing it through a Heat Recovery Steam Generator (HRSG) to produce steam for an additional steam turbine stage.

- The overall efficiency can exceed 55% (Horlock, 1992, p. 37) [9].

1.1.6. Importance of These Concepts for the Mansuriya Plant Study

Since the Mansuriya Power Plant currently operates on a simple cycle, a clear understanding of both gas and steam cycles is crucial to evaluate improvement opportunities through conversion to a combined cycle. This knowledge also supports the development of a

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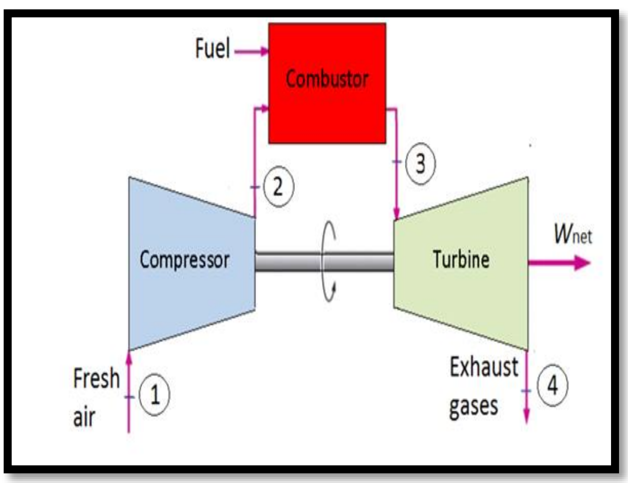
thermal efficiency ranges between 30–38% (Moran & Shapiro, 2010, p. 443) [8] .

1.1.4. Comparison between Gas and Steam Cycles

Table [2-1] presents a comparison between the key operational characteristics of the gas cycle and the steam cycle. It outlines differences in working fluid, operating temperature, thermal efficiency, start-up time, and typical applications. This comparison helps illustrate the strengths and limitations of each cycle, supporting optimal system selection based on power generation requirements.

simulation model using DWSIM to estimate the plants expected performance after optimization.

Create a model of the gas power plant using simulation software or analytical methods to understand the system dynamics and efficiencies. The system configuration chosen simple cycle gas turbine power plant as shown in Figure [1-1] .



Figure[1-1] .Schematic diagram of a simple gas turbine

The configuration was created at Dwsim using the system blocks that have been provided as shown in Figure [1-2] .

The input data was obtained based on conditions that exist in the field and the data required as shown Table [1-1].

Table [1-1]. The Main Input Data of The Simulation

Parameters	Value
Main Temperature inlet compressor T_1	**316 [k]**
Pressure inlet compressor P_1	**0.988 [bar]**
Main compressor pressure ratio r_p	**13.6**
pressure outlet compressor P_2	**13.5[bar]**
Mass flow rate air inlet compressor $\dot{m}_a$	**575 [kg/s]**
Main Mass fuel gas [N.G] $\dot{m}_f$	**9.1 [kg/s]**

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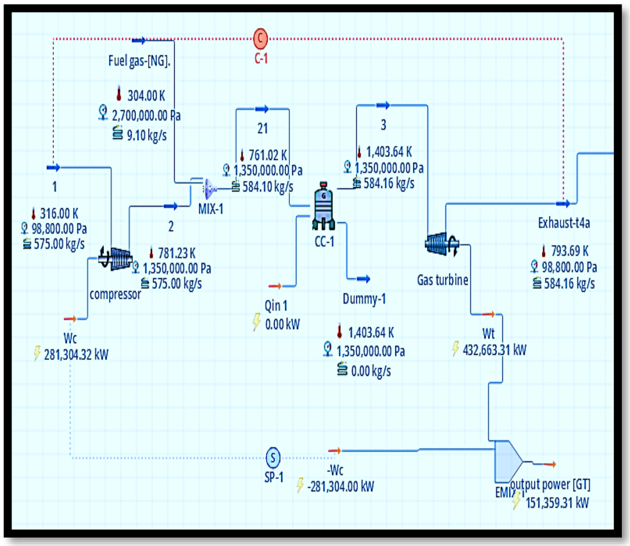

Figure[1-2] .The configuration of a gas power plant on Dwsim

Thermal efficiency compressor η_c	**72 [%]**
Thermal efficiency gas turbine η_t	**92.8 [%]**
specific heats gas C_{pg}	**1.19[kJ/kg.k]**
specific heats air C_{pa}	**1.005[KJ/kg.k]**
specific heats fuel C_{pf}	**1.8 [kJ/kg·K]**
ratio of specific heats air γ_a	**1.4**
ratio of specific heats air γ_g	**1.3**

2. Calculations Using the Brayton and Rankine Cycle Equations:

First: Brayton Cycle Equations (Gas Cycle)

Pressure Ratio (r_p):

$$r_p = \frac{p_2}{p_1} \qquad (1-1)$$

Where:

- p_2: Compressor outlet pressure [bar]
- p_1: Compressor inlet pressure [bar]

Compressor Outlet Temperature (isentropic):

$$T_2 = T_1 . (r_p)^{\frac{\gamma-1}{\gamma}} \qquad (1-2)$$

Compressor Outlet Temperature (Adiabatic): T_{2a} [k]

$$T_{2a} = T_1 \left[1 + \frac{1}{\eta_c} \left(r_p^{\frac{\gamma-1}{\gamma}} - 1 \right) \right] \qquad (1-3)$$

$$W_{GT} = m_g^{\cdot} . c_{pg} \; . (T_3 - T_{4a}) \qquad (1-9)$$

Where:

- $m_a^{\cdot}$: Air mass flow rate [kg/s]
- c_{pg} : Specific heat gas at constant pressure [kJ/kg·K] (typically ≈ 1.1)
- T_3 : Turbine inlet temperature [K]
- T_{4a}: Turbine exhaust temperature [K]

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Where:

- T_1: Temperature before compressor [K]
- η_c : Compressor efficiency (typically = 0.72)
- γ: Specific heat ratio

$$\gamma = \frac{C_p}{C_v} \approx 1.4$$

Compressor Work Input:

$$W_C = \dot{m_a} . c_{pa} . (T_{2a} - T_1) \quad (1-4)$$

Where:

- $\dot{m_a}$: Air mass flow rate [kg/s]
- c_{pa} : Specific heat air at constant pressure [kJ/kg·K] (typically ≈ 1.005)

Heat Input to the Cycle (from fuel):

$$Q_{in} = \dot{m}_f \times LHV \quad (1-5)$$

Where:

- $\dot{m_f}$: Fuel mass flow rate [kg/s]
- LHV : Lower heating value of fuel [kJ/kg]

Turbine inlet temperature:

$$T_3 = T_1 . \left(r_p^{\frac{2(\gamma g-1)}{\gamma g}} \right) \quad (1-6)$$

The exhaust stagnation temperature (T_{4a}) in the expansion process was calculated by using Eqn.

$$T_4 = T_3 . \left[\frac{1}{\left(\frac{p3}{p4}\right)} \right]^{\wedge\left[\gamma_{g-1}/\gamma_g\right]} \quad (1-7)$$

$$T_{4a} = T_3 - \eta_{gt} T_3 \left[1 - \left(\frac{p_4}{p_3}\right) ^\wedge \left[\gamma_{g-1}/\gamma g\right] \right] \quad (1-8)$$

Where:

- P_3 : Turbine inlet pressure [bar]
- P_4: Turbine exhaust pressure [bar]
- η_{gt} : gas Turbine Efficiency (%) = 0.928
- T_{4a} : Turbine Exit Temperature (Adiabatic) [k]

Work Output from the Gas Turbine:

Waste Heat Energy in the Exhaust:

$$Q_{exh} = \dot{m_g} \times c_{pg} \times (T_{exh} - T_1) \quad (1-10)$$

Where:

- Mass flow rate exhaust $\dot{m_g}$ Kg/s
- Specific heat of gasses $c_{pg} = 1.1$ kJ/kg. k
- Exhaust Gas Temperature $T_{exh} = T_{4a}$[k]
- Inlet Air TemperatureT_1[k]

Useful Thermal Energy(Q_{use}):

$$Q_{use} = Q_{in} - Q_{exh} \quad (1-11)$$

Net Work of the Gas Cycle:

$$W_{net,GT} = W_{GT} - W_C \quad (1-12)$$

Power output gas turbine station:

$$p_{owr}[GT] = W_{net,GT} . \dot{m_g} \quad (1-13)$$

Thermal efficiency of the gas turbine station(η_{gts}):

$$\eta_{gts} = \frac{Q_{use}}{Q_{in}} \quad (1-14)$$

Second: Rankine Cycle Equations (Steam Cycle)

Power Output from the Steam Turbine:

$$W_{ST} = \dot{m_s} . (h_7 - h_8) \quad (1-15)$$

Where:

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- h_7: Enthalpy at the turbine inlet.
- h_8: Enthalpy at the turbine outlet.
- $\dot{m_s}$: Steam mass flow rate [kg/s]

Work Consumed by the Pump:

$$W_p = \dot{m_w} . (h_6 - h_9) \quad (1-16)$$

Where:

- h_9: Enthalpy at the pump inlet.
- h_6: Enthalpy at the pump outlet.
- $\dot{m_w}$: water mass flow rate [kg/s]

Net Work of the Steam Cycle:

$$W_{net,ST} = W_{ST} - W_P \quad (1-17)$$

Power output gas turbine station:

$$p_{owr} [ST] = W_{net,ST} . \dot{m_s} \quad (1-18)$$

Thermal Efficiency of the Steam Cycle:

To calculate the heat input from the exhaust gases:

$$Q_{HRSG} = \dot{m_g} \times c_{pg} \times (\mathrm{T_{exh}} - \mathrm{T_5}) \quad (1-19)$$

Where:
- $\mathrm{T_{exh}}$: Heat recovery steam generator inlet temperature [k]
- $\mathrm{T_5}$: Heat recovery steam generator outlet temperature [k]

$$\eta_{STS} = \frac{p_{owr} [ST]}{Q_{HRSG}} \quad (1-20)$$

3.1. Overview of Simulation Outputs

Simulation of the four proposed combined cycle models using DWSIM produced detailed predictions of power output, fuel consumption, exhaust heat recovery, and overall thermal efficiency. Each model represents a different configuration strategy for retrofitting the existing AL-Mansuriya Gas Power Plant, with variations in turbine count, fuel input, HRSG design, and auxiliary firing.

These results provide a quantitative basis for comparing the trade-offs in efficiency gains, capital complexity, and operational challenges across alternative designs.

3.2. Model 1: Single Gas Turbine with Single HRSG and Steam Turbine

3.2.1. Introduction:

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Third. Total Power Output of the Plant

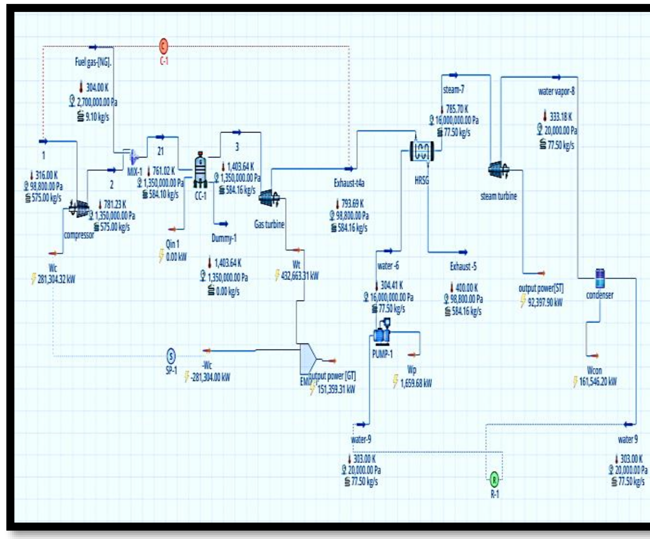
$$p_{Total} = p_{owr}\,[GT] + p_{owr}\,[ST] \qquad (1-21)$$

Fourth: Actual Thermal Efficiency of the Combined Cycle power plant (η_{CCPP}):

$$\eta_{CCPP} = \frac{p_{Total}}{Q_{in}} \qquad (1-22)$$

3. Detailed Results of the Proposed Combined Cycle Models:

This appendix presents the first simulation model developed using DWSIM for the Mansuriya gas power plant in Iraq, following the integration of a Combined Cycle system. The model represents a fully integrated thermal configuration that includes a gas turbine, a Heat Recovery Steam Generator (HRSG), and a steam turbine as shown in Figure [3-1]. It aims to analyze the plant's performance



and enhance its thermal efficiency (Al-Hadith & Kareem; 2020 Zhang et al., 2023) [10].

Fig [3-1] Schematic diagram of a combined cycle gas turbine power plant [CCGT], model [1]

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3.2.2. Model Components:

Component	Description
Gas Turbine (GT)	Power Output: 151.359 MW, Exhaust Temperature: 793.69 K
Fuel Used	Natural Gas, Flow Rate: 9.1 kg/s
HRSG	Recovers exhaust heat to produce high-pressure steam
Steam Turbine (ST)	Power Output: 92.398 MW, Steam Pressure: 160 bar
Condenser + Pump	Condenses steam and recycles water

3.2.3. Operating Conditions:

Item	Value
Inlet Air Temperature	316 K
Compressor Inlet Pressure	0.988 bar
Exhaust Temperature after Turbine	793.69 K
Steam Temperature from HRSG	785.7 K
Steam Flow Rate to ST	77.5[kg/s]

3.2.4. Computational Results:

Item	Value
Thermal energy input (Qin)	436.8 MW
Power output from the gas turbine(W_{GT})	151.36 MW
Power output from the steam turbine(W_{ST})	92.40 MW
Total net power output	243.75 MW
Gas cycle efficiency(η_{gts})	29.84%
Steam cycle efficiency (η_{STS})	36. 51%

3.3. Model 2: Single Gas Turbine with Auxiliary Firing As Shown In Figure [3-2].

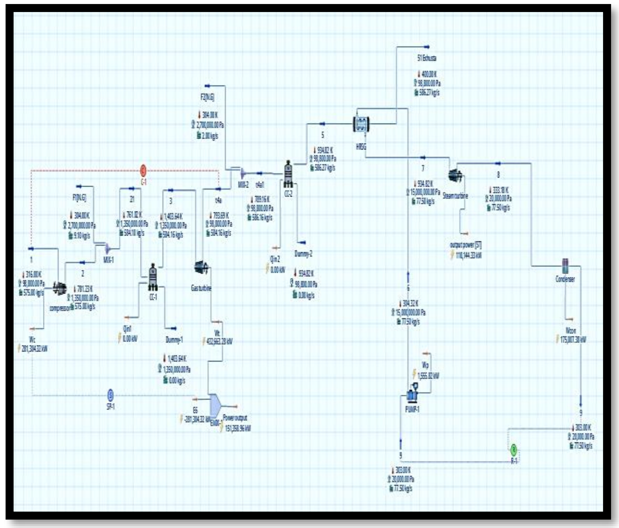

Fig [3-2] Schematic diagram of a combined cycle gas turbine power plant [CCGT], model [2]

3.3.1. Introduction:

This appendix outlines the second simulation model constructed using DWSIM to represent the Al-Mansuriya Gas Power Plant after its upgrade to a combined cycle system. The model integrates a gas turbine, a Heat Recovery Steam Generator (HRSG), and a steam turbine, and introduces an additional fuel feed to simulate auxiliary combustion. The objective is to evaluate performance enhancement and efficiency gains.

3.3.2 Model Components:

Component	Description
Gas Turbine (GT)	Power Output: 151.36 MW, Exhaust Temp: 793.69 K
Additional Fuel Input	2.0 kg/s added to main fuel stream (Total: 11.1 kg/s)
HRSG	Utilizes exhaust gases (~520°C) to produce high-pressure steam

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Overall combined cycle efficiency(η_{CCPP})	55.40%

Steam Turbine (ST)	Power Output: 110.14 MW, Steam pressure: 150 bar
Condenser + Pump	Facilitates water recirculation

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3.3.3. Operating Conditions:

Parameter	**Value**
Main fuel flow	9.1 kg/s
Auxiliary fuel flow	2.0 kg/s
Total fuel input	11.1 kg/s
Gas turbine exhaust temp	793.69 K
HRSG steam output temp	934.82 K
Steam pressure (ST inlet)	150 bar
Steam flow rate	77.5 kg/s

3.3.4. Computational Results:

Item	**Value**
Thermal energy input (Qin)	532.8 MW
Power output from the gas turbine(W_{GT})	151.36 MW
Power output from the steam turbine(W_{ST})	110.14MW
Total net power output	261.50 MW
Gas cycle efficiency(η_{gts})	25.2%
Steam cycle efficiency (η_{STS})	31. 9%
Overall combined cycle efficiency(η_{CCPP})	59.9%

3.4.2. Model Components:

Component	**Description**
Gas Turbines (GT1 & GT2)	Combined output: 302.72 MW, Exhaust Temp: ~793.7 K
HRSG	Processes exhaust from both turbines to produce steam
Steam Turbine (ST)	Output: 183.39 MW, Steam pressure: 160 bar
Condenser + Pump	Manages water recovery and circulation

3.4.3. Operating Conditions:

Parameter	**Value**
Fuel flow per turbine	9.1 kg/s
Total fuel flow	18.2 kg/s
GT exhaust temp	793.7 K
HRSG steam outlet temp	785.7 K
Steam pressure (ST inlet)	160 bar
Steam mass flow rate	155.0 kg/s

3.4.4. Computational Results:

Item	**Value**
Thermal energy input (Qin)	873.6 MW
Power output from the gas turbine(W_{GT})	302.72 MW
Power output from the steam turbine(W_{ST})	183.39MW
Total net power output	486.11 MW
Gas cycle efficiency(η_{gts})	29.84%

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3.4. Model 3: Dual Gas Turbine Configuration As Shown In Figure [3-3]

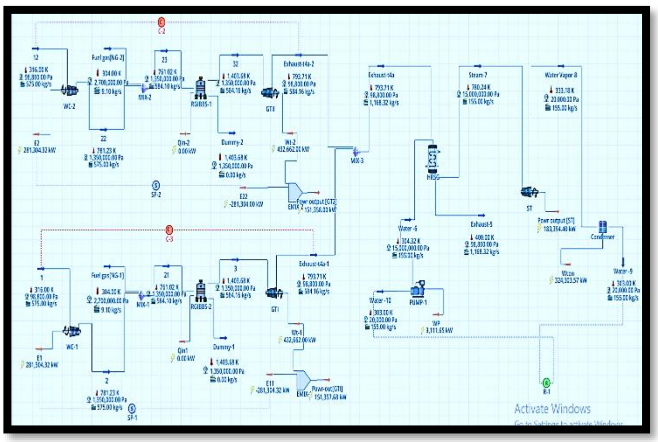

Fig [3-3] Schematic diagram of a combined cycle gas turbine power plant [CCGT], model [3]

3.4.1. Introduction:

This appendix presents the third simulation model developed using DWSIM for the Al-Mansuriya Gas Power Plant, incorporating two gas turbines connected to a common HRSG and a steam turbine. This dual-turbine configuration aims to maximize power output and improve overall efficiency, serving as a high-capacity layout for future deployment (Kadima & Hasan; 2023Youssef et al., 2022) [11,12].

Steam cycle efficiency (η_{STS})	36. 31%
Overall combined cycle efficiency(η_{CCPP})	55.64%

3.5. Model 4: Dual Gas Turbines with Dual HRSGs and Advanced Steam System As Shown In Figure [3-4].

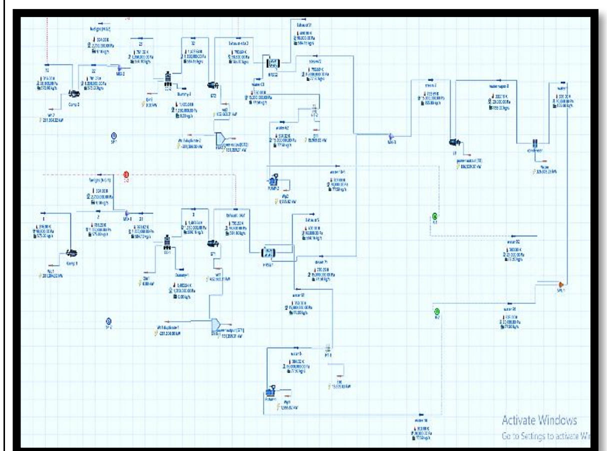

Fig [3-4]

Schematic diagram of a combined cycle gas turbine power plant [CCGT], model [4]

3.5.1. Introduction:

This appendix presents the fourth simulation model developed using DWSIM for the AL-Mansuriya gas power plant, following the proposed conversion from a simple cycle to a Combined Cycle Gas Turbine (CCGT) system. The model represents an advanced thermal configuration that integrates a gas turbine (GT), heat recovery steam generator (HRSG), and a

3.6. Comparative Analysis of Model Results

Table [3-1] presents a consolidated comparison of the four proposed combined cycle models based on key performance indicators. The data include fuel input, gas turbine output, steam turbine output, total power output, and overall efficiency. Model 2 demonstrates the highest overall efficiency at 59.9%, while Model 4 achieves the highest total output of approximately 491 MW. These results highlight the

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steam turbine (ST). The goal is to analyze performance enhancement and estimate thermodynamic efficiency gains (Rizwan & Tariq, 2022; Chen et al., 2023) [13,14].

3.5.2. Model Components:

Component	Description
Gas Turbines (GT1 & GT2)	Two gas turbines (GT13E2) operating in parallel, each producing approximately 151.36 MW. Air is compressed, fuel is combusted, and hot gases expand in the turbine (El-Wakil, 2021, p. 402) [15].
HRSG	Two Heat Recovery Steam Generators, each recovering exhaust heat from the gas turbines to produce high-pressure steam. Each HRSG includes three sections: Economizer, Evaporator, and Super heater (Yousef et al., 2022, pp. 67–69) [16].
Steam Turbine (ST)	A high-efficiency steam turbine utilizing the steam produced by the HRSG units. Output: ~188.16 MW. Designed for multi-pressure operation to maximize heat recovery (Jasim & Hameed, 2023) [17].
Condenser + Pump	The condenser converts exhaust steam back to water, which is recirculated by high-pressure pumps to the HRSGs. The system maintains thermal balance and cycle continuity (Rahim et al., 2021) [18].

3.5.3. Operating Conditions:

Parameter	Value
Inlet air temperature	316 K

trade-offs between fuel input and performance across different system configurations.

Table [3-1]: Consolidated Performance Comparison of the Four Proposed Combined Cycle Models:

Model	Fuel Input (kg/s)	Gas Output (MW)	Steam Output (MW)	Total Output (MW)	Overall Efficiency (%)
1	9.1	151.36	92.40	243.75	55.40
2	11.1	151.36	110.14	261.50	59. 9
3	18.2	302.72	183.39	486.11	55.64
4	18.2	302.72	188.16	490.88	56.72

4. Methodology and Simulation Environment

For this study, the DWSIM simulation environment was chosen for its flexibility, transparent thermodynamic modeling, and suitability for power plant component integration. The Al-Mansuriya retrofit scenario was modeled as a combined cycle system with:

- One or more gas turbines (GT13E2-type as installed at AL-Mansuriya)
- Single- or multi-pressure HRSG
- Steam turbine
- Condenser
- Auxiliary systems such as pumps and heat exchangers

Each component was parametrized with design and off-design data sourced from manufacturer specifications and literature (Gas Turbine World, 2022). The overall system was validated against known performance data for the current simple cycle operation of AL-Mansuriya to ensure credible baseline conditions.

Parametric sensitivity analysis was performed using a one-at-a-time (OAT) approach for transparency and ease of interpretation. Each parameter was varied across a defined realistic range while holding others constant. Simulation results were recorded for:

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Compressor inlet pressure	0.988 bar
Fuel flow rate	18.2 kg/s
GT exhaust temperature	793.69 K
HRSG steam temperature	785.7 K
Steam mass flow rate	35.0 kg/s
GT power output	302.72 MW
ST power output	188.16 MW
Total power output	490.88 MW

3.5.4. Computational Results:

Item	Value
Thermal energy input (Qin)	880.8 MW
Power output from the gas turbine(W_{GT})	302.72 MW
Power output from the steam turbine(W_{ST})	188.16MW
Total net power output	490.88 MW
Gas cycle efficiency(η_{gts})	29.84%
Steam cycle efficiency (η_{STS})	36. 49%
Overall combined cycle efficiency(η_{CCPP})	56.72%

- Net electrical power output (MW)
- Overall thermal efficiency (%)
- Fuel consumption (kg/s)
- Exhaust gas temperatures (K)
- Steam generation rates (kg/s)

By systematically exploring the design space in this way, the analysis aimed to capture first-order sensitivities and identify parameters with the greatest leverage over performance improvements.

4.1. Selection of Parameters for Analysis

The selection of parameters for sensitivity analysis in the AL-Mansuriya Gas Power Plant retrofit study is driven by both engineering intuition and evidence from previous literature. A combined cycle system's

6. Condenser Pressure (P_8): Affects the steam turbine's exhaust conditions. Lower condenser pressures
7. Improve steam turbine efficiency but may increase cooling water demands and costs.

Each of these parameters is both critical and realistically adjustable in a retrofit scenario. Their selection is consistent with best practice in CCGT design optimization literature (Silva et al., 2022).

5. Parametric Sensitivity Study: Impact of Key Operational Factors on Model 1 Performance

5.1. Introduction:

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performance depends on a complex interplay between gas turbine operating conditions, HRSG heat recovery effectiveness, steam cycle pressures, and condenser performance. However, not all variables have equal impact or are equally controllable in practice.

For this study, six primary parameters were chosen based on their demonstrated influence in similar CCGT conversions:

1. Compressor Inlet Temperature (T_1): A critical driver of gas turbine performance. Higher inlet temperatures (typical in Iraq's summer) reduce air density, lowering mass flow rate and efficiency. Sensitivity analysis helps identify the performance penalty associated with ambient conditions and the potential value of inlet cooling technologies.
2. Pressure Ratio (r_p): The ratio of compressor outlet to inlet pressure strongly influences turbine work output and efficiency. An optimal pressure ratio balances compressor work against turbine expansion benefits while avoiding surge margins.
3. Fuel Mass Flow Rate ($\dot{m}f$): Directly controls the energy input to the gas turbine. While increasing fuel flow increases power output, it may reduce efficiency due to higher exhaust temperatures exceeding HRSG design limits.
4. Steam Mass Flow Rate ($\dot{m}s$): Defines the amount of heat recovered and converted in the steam cycle. A higher steam flow can increase steam turbine power but may face limits due to HRSG surface area and pinch point constraints.
5. Steam Pressure (P_7): Determines the thermodynamic potential of the Rankine cycle. Higher steam pressures increase cycle efficiency but require stronger materials, higher capital costs, and more complex control.

This section presents the detailed results of the parametric sensitivity study for Model 1 of the AL-Mansuriya Gas Power Plant retrofit simulation. Using DWSIM modeling, key operational parameters were systematically varied to evaluate their impact on the performance of the integrated combined cycle system.

The analysis focuses on six critical parameters: compressor inlet temperature (T_1), compressor pressure ratio (r_p), fuel mass flow rate ($\dot{m}f$), steam mass flow rate ($\dot{m}s$), steam pressure (P_7), and condenser pressure (P_8). For each parameter, simulations were conducted over realistic ranges to reflect operational conditions typical of the Iraqi climate and infrastructure.

Results in Table **[5-1]** summarize the simulated outputs for the gas turbine cycle, steam turbine cycle, and the overall combined cycle power plant. These outputs include net power output (kW) and calculated thermal efficiencies (%) for each subsystem and for the plant as a whole.

This sensitivity analysis provides valuable insight into how adjusting operating parameters can optimize performance, increase net power output, and improve thermal efficiency. Such understanding is essential for the effective design and implementation of the proposed combined cycle retrofit, helping to ensure that future operations achieve both technical and economic goals as shown Figure [5-1][5-2][5-3][5-4][5-5][5-6].

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Table[5-1]: Model[1] Simulation						
Parameters	GAS TURBINE CYCLE		STEAM TURBINE CYCLE		COMBINED CYCLE POWER PLANT	
Main Temperature inlet compressor T1 [k]	p_{owr} $[GT]$ [kw]	η_{gts} [%]	p_{owr} $[ST]$ [kw]	η_{sts} [%]	p_{owr} $[tot]$ [kw]	η_{ccpp} [%]
298	155821	0.3033	83835	0.3511	239372	0.515
313	152053	0.2984	90347	0.3606	242400	0.5549
316	151358	0.2984	91692	0.3631	243051	0.5564
320	150349	0.2969	93531	0.3658	243925	0.5584
325	149232	0.2968	94558	0.3659	243790	0.5591
Main compressor pressure ratio r_p [bar]						
12.2469	147673	0.2895	93748	0.3657	241421	0.5527
13.2591	150351	0.2954	92251	0.3635	242602	0.5554
13.6639	151358	0.2984	91692	0.3631	243051	0.5564
14.6761	164594	0.3028	90452	0.361	255046	0.5839
15.2834	172150	0.3057	89765	0.360	261915	0.5996
Main Mass fuel gas $\dot{m}_f$ [N.G] [k g/s]						
5	60536	0.1786	39412	0.2746	99948	0.4165
7	105348	0.2531	63533	0.3222	168881	0.5026
9.1	151358	0.2984	91692	0.3631	243051	0.5564
10	170799	0.312	97460	0.353	268259	0.5589
10.2	175096	0.315	98390	0.3498	281315	0.5699
Main Mass flow rate steam $\dot{m}_s$ [kg/s]						
50	151358	0.2984	60173	0.238	211531	0.4843
65	151358	0.2984	78225	0.3098	229583	0.5256
77.5	151358	0.2984	91692	0.3631	243051	0.5564
85	151358	0.2984	87782	0.3476	239140	0.5475
95	151358	0.2984	84388	0.3342	235746	0.5397
Main steam Pressure P_7 [bar]						
140	151358	0.2984	91692	0.3631	243050	0.5564
145	151358	0.2984	91421	0.3621	242679	0.5558
150	151358	0.2984	91692	0.3631	243051	0.5564
155	151358	0.2984	92050	0.3645	243408	0.5573
160	151358	0.2984	92397	0.3659	243737	0.558
Main condenser Pressure P_8 [bar]						
0.1	151358	0.2984	97788	0.3873	249146	0.5704
0.15	151358	0.2984	94271	0.3733	245629	0.5623
0.2	151358	0.2984	91692	0.3631	243051	0.5564

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0.3	151358	0.2984	87930	0.3482	239288	0.5478
0.5	151358	0.2984	82967	0.3286	234325	0.5365

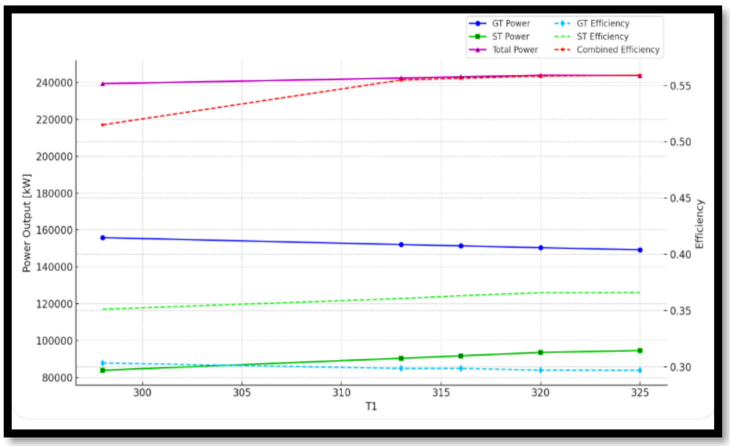
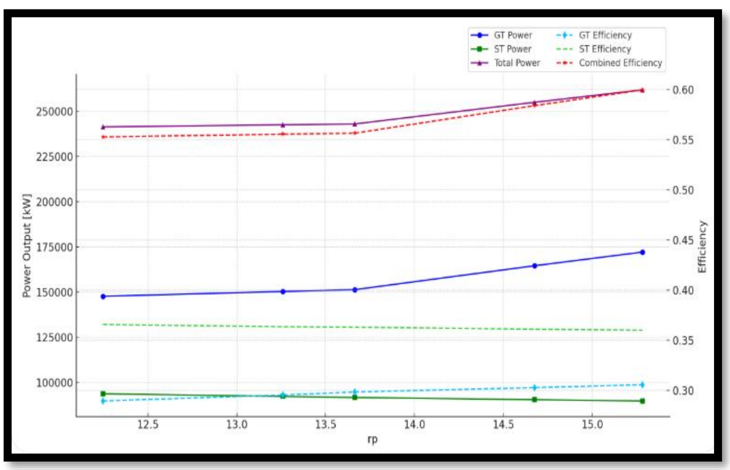


Fig [5-1] Effect of Compressor Inlet Temperature on Overall Efficiency and Total Power Output, and on Gas and



Steam Cycle Efficiencies and Power Output

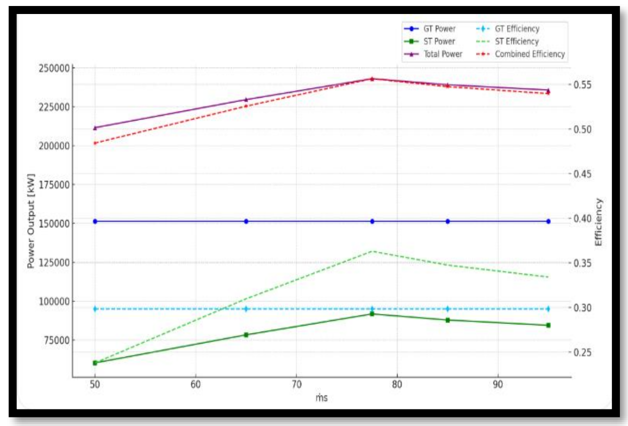


Fig [5-4] Effect of Steam Mass Flow Rate on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

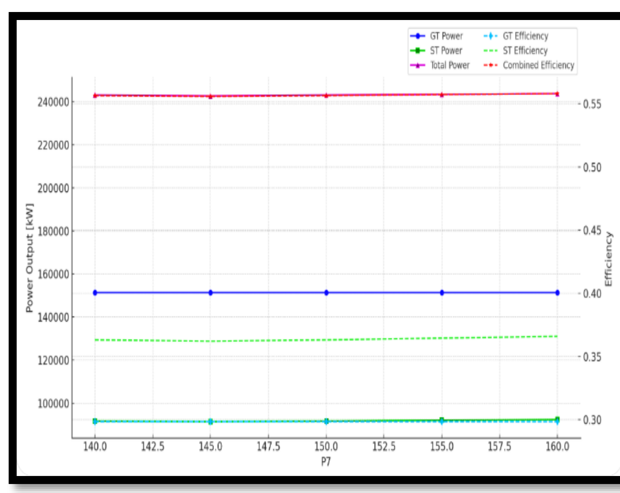


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Fig [5-2] Effect of Pressure Ratio on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

Fig [5-3] Effect of Fuel Mass Flow Rate on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

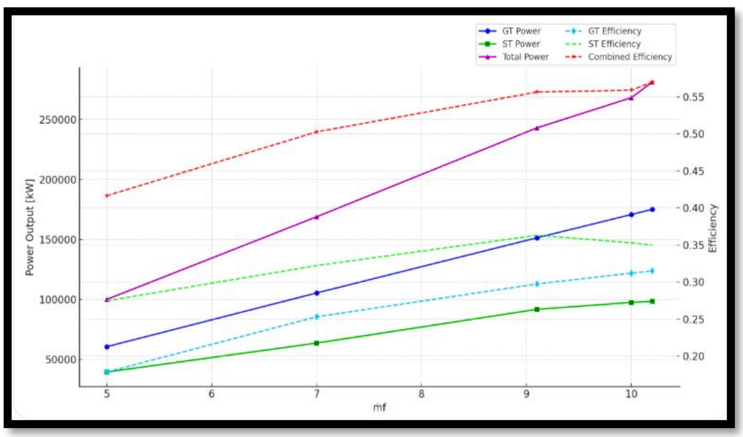
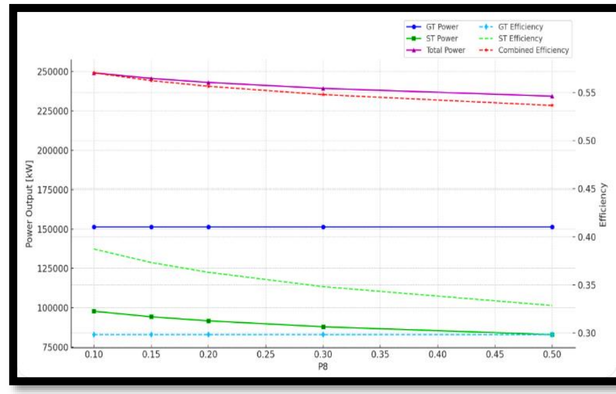


Fig [5-5] Effect of Steam Pressure on Overall



Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

Fig [5-6] Effect of Condenser Pressure on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

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5.2. Resulting Performance at This Point – Model 1

Table [5-2]: Optimal Power Output and Efficiency of Gas and Steam Turbines

Performance Metric	Value	Notes
Gas Turbine Power Output	175,096 kW	At optimal fuel flow ṁf = 10.2 kg/s
Gas Turbine Efficiency (η_{gts})	31.5 %	

6. Parametric Sensitivity Study: Impact of Key Operational Factors on Model 2 Performance

6.1. Introduction

Table [6-1] presents the results of a detailed parametric sensitivity analysis for Model 2, which represents an enhanced combined cycle configuration of the AL-Mansuriya Gas Power Plant. In this model, the system integrates a gas turbine, Heat Recovery Steam Generator (HRSG), and steam turbine with provisions for additional fuel injection (auxiliary firing). This design aims

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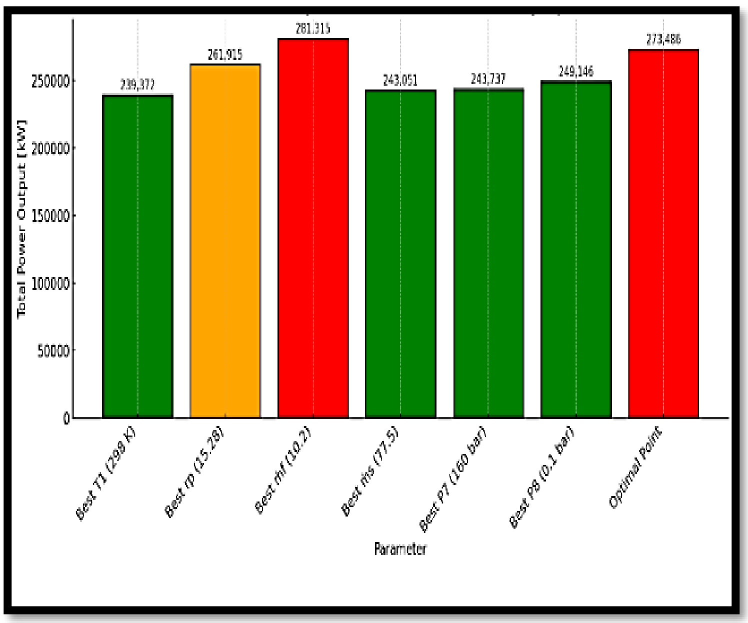
Steam Turbine Power Output	98,390 kW	At optimal steam flow ṁs = 77.5 kg/s
Steam Turbine Efficiency (η_{STS})	34.98 %	
Combined Cycle Power Output	281,315 kW	Total GT + ST output
Combined Cycle Efficiency (η_{CCPP})	56.99 %	Highest overall efficiency at this point

The bar chart illustrates the total power output (in kW) of the combined cycle system under different optimized parameters. Among the tested variables, the highest output (281,315 kW) is achieved when the fuel flow rate (ṁf = 10.2 kg/s) is optimized. The second-highest output



(273,486 kW) is obtained at the overall optimal point where all parameters are balanced. Other parameters such as pressure ratio, steam mass flow, and condenser pressure show moderate influence on power output. This analysis highlights the strong sensitivity of total system output to fuel flow and confirms the importance of integrated optimization for peak performance as shown in Figure [5-7].

to boost overall capacity and operational flexibility while maintaining high thermal efficiency.

The analysis systematically examines how key operational parameters influence the performance of the gas turbine cycle, steam turbine cycle, and the overall combined cycle power plant. Specifically, the parameters studied include:

- Compressor inlet temperature (T_1)
- Compressor pressure ratio (r_p)
- Fuel mass flow rate (ṁf)
- Steam mass flow rate (ṁs)
- Steam pressure (P_7)
- Condenser pressure (P_8)

Each parameter was varied within realistic engineering ranges to capture its impact on critical performance indicators such as power output (kW) and thermal efficiency (%) for both the gas and steam cycles, as well as the combined cycle plant as a whole.

The goal of this sensitivity analysis is to identify optimal operating ranges, reveal performance trade-offs, and support informed decision-making in the design and operation of the retrofit project. The results demonstrate how even modest adjustments to these variables can significantly affect the overall plant output and efficiency—insights that are crucial for achieving a reliable, efficient, and economically viable upgrade of Iraq's power generation infrastructure as shown Figure[6-1][6-2][6-3][6-4][6-5][6-6].

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Fig [5-7] Bar Chart of Total Power Output at Best Operating Conditions for Each Parameter and Overall Optimal Point – Model 1	

Table[6-1]: Model[2] Simulation

Parameters	GAS TURBINE CYCLE		STEAM TURBINE CYCLE		COMBINED CYCLE POWER PLANT	
Main Temperature inlet compressor T1 [k]	p_{owr} $[gt]$ [kw]	η_{gt} [%]	p_{owr} $[ST]$ [kw]	η_{sts} [%]	p_{owr} $[tot]$ [kw]	η_{ccpp} [%]
298	155574	0.2558	107557	0.3252	263131	0.6024
313	152053	0.2522	109713	0.3205	261766	0.5993
316	151358	0.2522	110144	0.3199	261502	0.5987
320	150394	0.251	110726	0.3187	261120	0.5978
325	149232	0.2498	111447	0.3172	260679	0.5968
Main compressor pressure ratio r_p [bar]						
12.2469	147674	0.2449	110439	0.3172	258113	0.5909
13.2591	150351	0.2498	109971	0.3182	260322	0.596
13.6639	151358	0.2522	110144	03199	261502	0.5987
14.6761	153610	0.2558	109402	0.3196	263012	0.6021
15.2834	154868	0.2582	109182	0.3201	264050	0.6045
Main Mass fuel gas $\dot{m}_f$ [N.G] [k g/s]						
5	60536	0.1216	83709	0.3468	144245	0.601
7	105348	0.1985	100251	0.343	205599	0.6119
9.1	151358	0.2522	110144	03199	261502	0.5987
10	170799	0.2691	113929	0.3106	284728	0.5932
10.2	175096	0.2731	114852	0.3092	289948	0.5922
Main Mass flow rate steam $\dot{m}_s$ [kg/s]						
50	151358	0.2522	70835	0.2058	222193	0.5087
65	151358	0.2522	92086	0.2675	243444	0.5573
77.5	151358	0.2522	110144	0.3199	261502	0.5987
85	151358	0.2522	120420	0.3498	271778	0.6222
95	151358	0.2522	134587	0.3909	285945	0.6546
Main steam Pressure P_7 [bar]						
140	151358	0.2522	109795	0.3189	261153	0.5979
145	151358	0.2522	109976	0.3194	261334	0.5983
150	151358	0.2522	110144	0.3199	261502	0.5987
155	151358	0.2522	110299	0.3204	261657	0.599
160	151358	0.2522	110442	0.3208	261800	0.5994

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Main condenser Pressure P_8 [bar]						
0.1	151358	0.2522	116738	0.3391	268096	0.6138
0.15	151358	0.2522	112936	0.328	264294	0.6051
0.2	151358	0.2522	110144	0.3199	261502	0.5987
0.3	151358	0.2522	106067	0.3081	257425	0.5893
0.5	151358	0.2522	100678	0.2924	252036	0.577

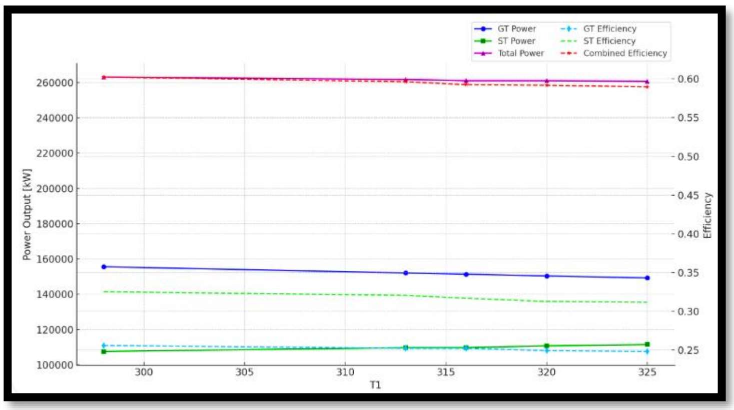
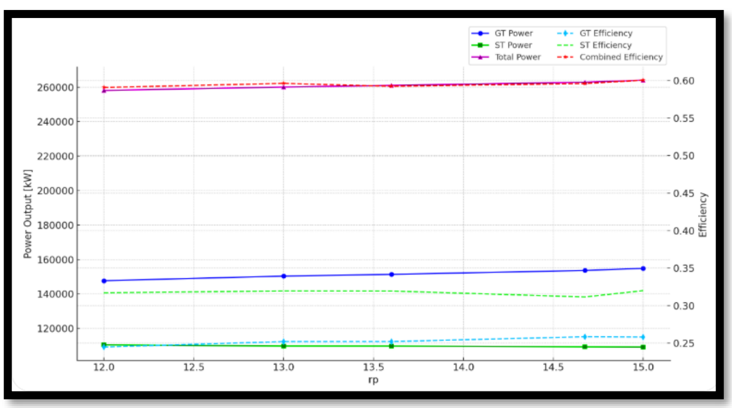


Fig [6-1] Effect of Compressor Inlet Temperature on



Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

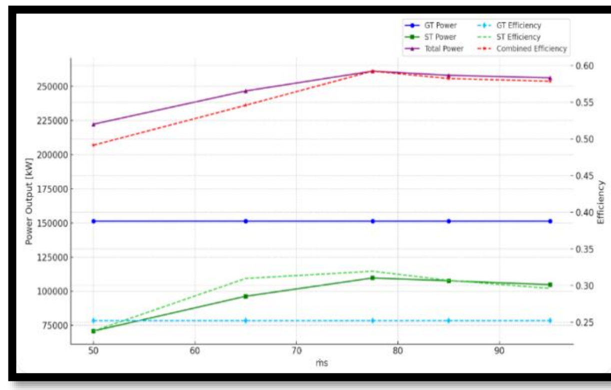


Fig [6-4] Effect of Steam Mass Flow Rate on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

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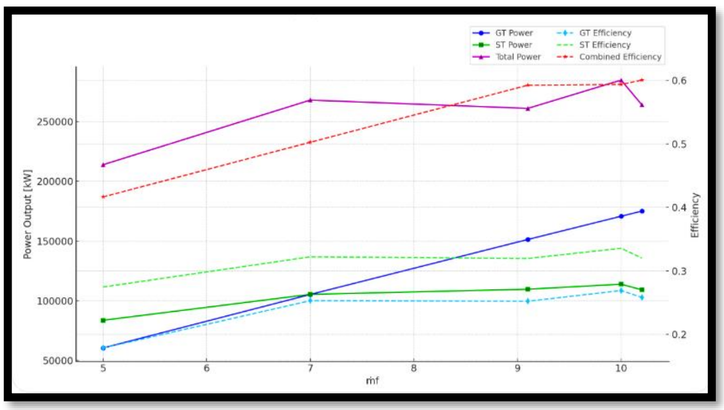
Fig [6-2] Effect of Pressure Ratio on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

Fig [6-3] Effect of Fuel Mass Flow Rate on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output



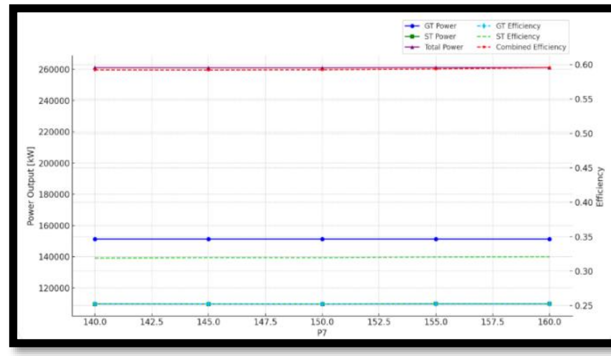
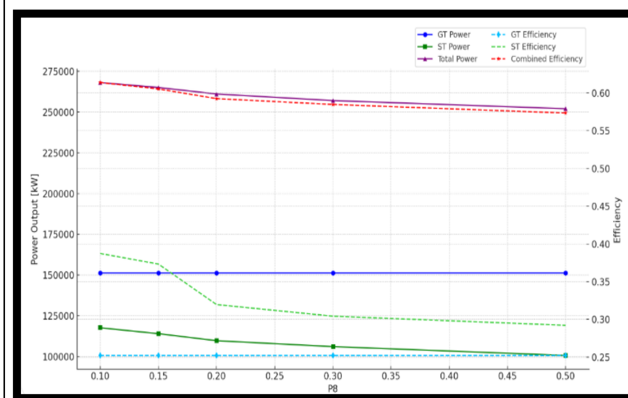


Fig [6-5] Effect of Steam Pressure on Overall Efficiency and Total Power Output, and on Gas and



Steam Cycle Efficiencies and Power Output

Fig [6-6] Effect of Condenser Pressure on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

6.2. Resulting Performance at This Point – Model 2

This Table [6-2] presents the optimal performance metrics for Model 2 of the combined cycle system. The gas turbine (GT) achieved a power output of 175,096 kW with an efficiency of approximately 27.32%, indicating robust performance. The steam turbine (ST) delivered 113,429 kW of power with a high efficiency nearing 33.66%, attributed to optimized vacuum pressure and steam mass flow conditions.
The total combined power output reached 288,525 kW, the highest recorded across all tested scenarios, confirming the

7. Parametric Sensitivity Study: Impact of Key Operational Factors on Model 3 Performance.

7.1. Introduction

The Table [7-1] Understanding the effect of critical operational parameters is essential for optimizing the performance of any power generation system. In this section, a detailed parametric sensitivity study is conducted to

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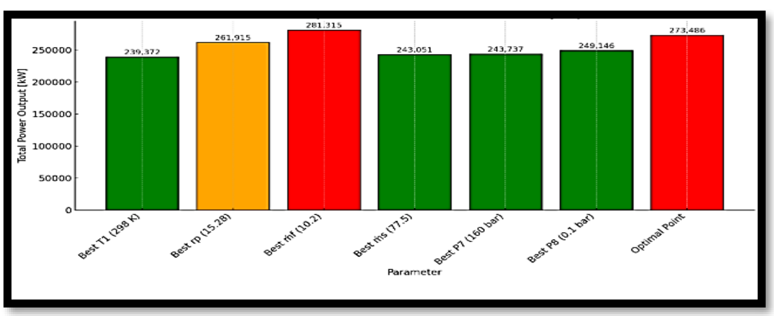
superior performance of this configuration. The overall combined cycle efficiency stood at around 60.36%, placing this point among the best-performing setups in the analysis.

Table [6-2]: Optimal Power Output and Efficiency of Gas and Steam Turbines

Metric	Value	Note
GT Power	175,096 kW	Strong GT output
ST Power	113,429 kW	Enhanced due to vacuum + mass flow
Total Power	288,525 kW	🔝 Highest across all tested scenarios
GT Efficiency	~0.2732	Excellent considering high power
ST Efficiency	~0.3366	Close to upper realistic limit
Combined Efficiency	~0.6036	Among highest recorded

This Figure [6-7] illustrates the impact of various key parameters on the total power output of Model 2 in the combined cycle system. Among all tested variables, the fuel flow rate ($\dot{m}f$ = 10.2 kg/s) resulted in the highest total power output of 281,315 kW, highlighted in red. The optimal point, derived from the best combination of all parameter values, achieved a slightly lower but still significant output of 273,486 kW. Other parameters such as pressure ratio (r_p = 15.28), inlet temperature (T_1 = 298 K), and steam turbine conditions ($\dot{m}s$, P_7, P_8) yielded varying outputs between 239,000 kW and 262,000 kW, with color coding reflecting their performance impact. This comparison highlights how parameter optimization directly influences power generation efficiency and plant performance.



evaluate how variations in key operational factors influence the overall performance of Model 3 of the combined cycle power plant. The analysis aims to identify the most influential parameters that affect power output, thermal efficiency, and system stability.

By systematically varying parameters such as inlet air temperature (T_1), compressor

Pressure ratio (r_p), fuel mass flow rate ($\dot{m}f$), steam mass flow rate ($\dot{m}s$), steam pressure (P_7), and condenser pressure (P_8), the study reveals the relative sensitivity of Model 3's performance metrics to each factor. This approach provides valuable insights for operators and engineers seeking to fine-tune operational settings to achieve maximum efficiency and reliability.

The results of this sensitivity analysis will inform decision-making regarding process optimization, control strategy design, and potential retrofitting needs for Model 3. Ultimately, the goal is to enhance the plant's economic and environmental performance by targeting the parameters with the highest impact on efficiency and power generation as shown figure [7-1] [7-2] [7-3] [7-4] [7-5] [7-6].

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Fig [5-20] Bar Chart of Total Power Output at Best Operating Conditions for Each Parameter and Overall Optimal Point – Model 2	

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Table: [7-1] Model[3] Simulation

Parameters	GAS TURBINE CYCLE			STEAM TURBINE CYCLE		COMBINED CYCLE POWER PLANT	
Main Temperature inlet compressor T1 [k]	p_{owr} $[GT1]$ [kw]	p_{owr} $[GT2]$ [kw]	$\eta_{gts\ 1-2}$ [%]	p_{owr} $[ST]$ [kw]	η_{sts} [%]	p_{owr} $[tot]$ [kw]	η_{ccpp} [%]
298	155821	155821	0.3033	167680	0.3511	479322	0.515
313	152053	152053	0.2984	180705	0.3606	484811	0.5549
316	151358	151358	0.2984	183394	0.3631	486110	0.5564
320	150349	150349	0.2969	187073	0.3658	487771	0.5584
325	149232	149232	0.2968	189121	0.3659	487585	0.5591
Main compressor pressure ratio r_p [bar]							
12.2469	147673	147673	0.2895	187496	0.3657	482642	0.518
13.2591	150351	150351	0.2954	184502	0.3635	485204	0.549
13.6639	151358	151358	0.2984	183394	0.3631	486110	0.5564
14.6761	164594	164594	0.3028	180904	0.361	510092	0.5839
15.2834	172150	172150	0.3057	179530	0.360	523830	0.5996
Main Mass fuel gas $\dot{m}_f$ [N.G] [k g/s]							
5	60536	60536	0.1786	78828	0.2746	199900	0.4165
7	105348	105348	0.2531	127072	0.3222	337768	0.5026
9.1	151358	151358	0.2984	183394	0.3631	486110	0.5564
10	170799	170799	0.312	194926	0.353	536524	0.5589
10.5	175096	175096	0.315	196780	0.3498	546972	0.5699
Main Mass flow rate steam $\dot{m}_s$ [kg/s]							
100	151358	151358	0.2984	120350	0.238	423066	0.4843
130	151358	151358	0.2984	156450	0.3098	459166	0.5256
155	151358	151358	0.2984	183394	0.3631	486110	0.5564
170	151358	151358	0.2984	175564	0.3476	478280	0.5475
190	151358	151358	0.2984	168776	0.3342	471492	0.5397
Main steam Pressure P_7 [bar]							
140	151358	151358	0.2984	183348	0.3631	486100	0.5564
145	151358	151358	0.2984	182842	0.3621	485558	0.558
150	151358	151358	0.2984	183394	0.3631	486110	0.5564
155	151358	151358	0.2984	184100	0.3645	486816	0.5573
160	151358	151358	0.2984	186794	0.3659	489510	0.558

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Main condenser Pressure P_8 [bar]							
0.1	151358	151358	0.2984	195587	0.3873	498303	0.5704
0.15	151358	151358	0.2984	188553	0.3733	491269	0.5623
0.2	151358	151358	0.2984	183394	0.3631	486110	0.5564
0.3	151358	151358	0.2984	175871	0.3482	478587	0.5478
0.5	151358	151358	0.2984	165944	0.3286	468660	0.5365

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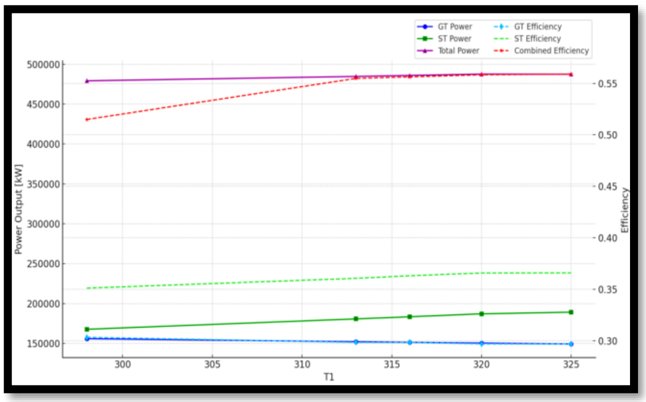
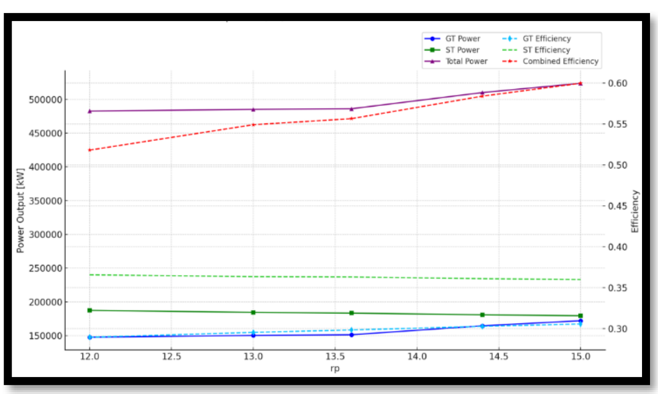


Fig [7-1] Effect of Compressor Inlet Temperature on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output



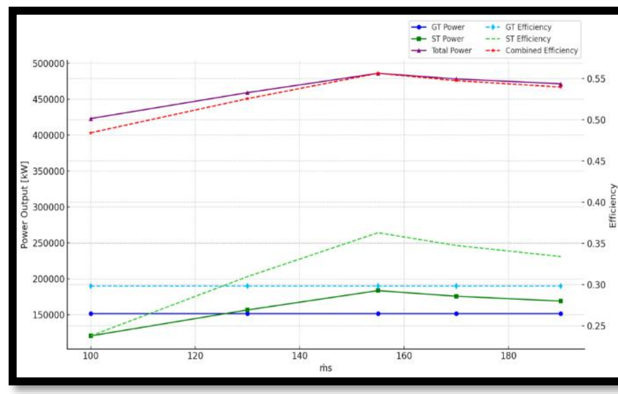


Fig [7-4] Effect of Steam Mass Flow Rate on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

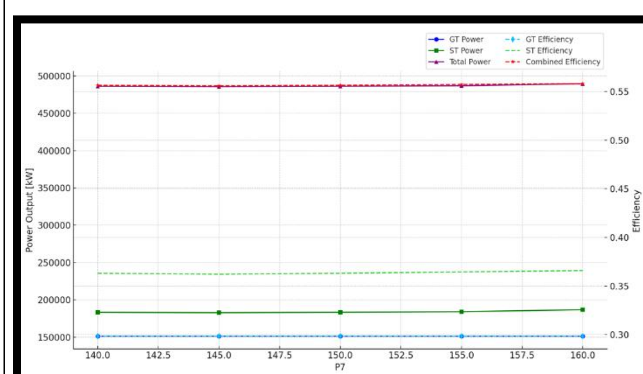


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Fig [7-2] Effect of Pressure Ratio on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

Fig [7-3] Effect of Fuel Mass Flow Rate on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

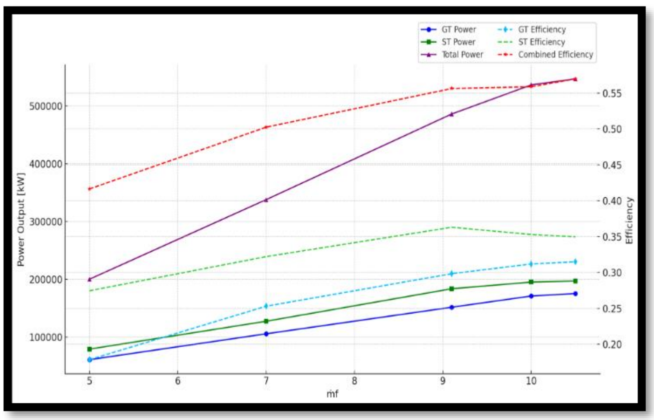
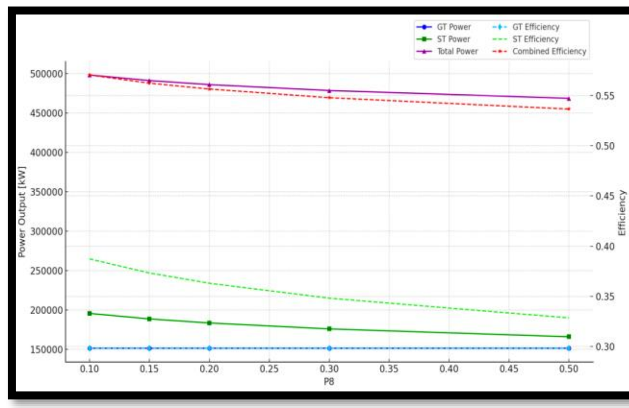


Fig [7-5] Effect of Steam Pressure on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

Fig [7-6] Effect of Condenser Pressure on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output



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7.2. Resulting Performance at This Point – Model 3

This Table [7-2] presents the key performance metrics of the combined cycle power plant under optimized operating conditions for Model 3. The gas turbine (GT) produced a stable output of 151,358 kW, supported by a balanced efficiency of 0.2984. The steam turbine (ST) achieved a remarkable output of 195,587 kW, primarily due to the low condenser pressure, resulting in a record-high steam cycle efficiency of 0.3873.

The total power output reached 498,303 kW, one of the highest among all scenarios analyzed. Most notably, the combined cycle efficiency (η_{CCPP}) was

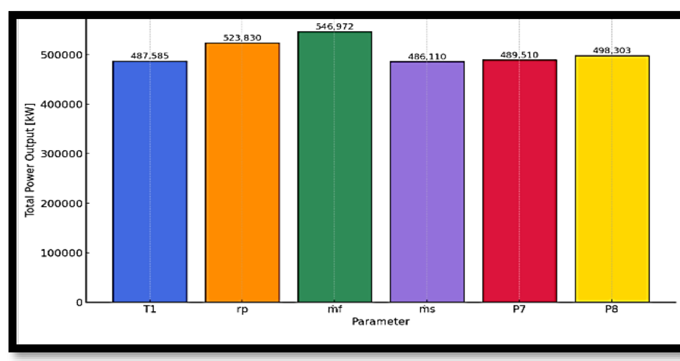

Fig [7-7] Bar Chart of Total Power Output at Best Operating Conditions for Each Parameter and Overall Optimal Point – Model 3

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maximized at 0.5704, indicating the most effective performance configuration for this model.

Table [7-2]: Optimal Power Output and Efficiency of Gas and Steam Turbines

Metric	Value	Remarks
GT Power	151,358 kW	Stable performance with high fuel flow ṁf
ST Power	195,587 kW	Elevated due to low condenser pressure
Total Power	498,303 kW	🔝 Very high total power output
GT Efficiency	0.2984	Balanced performance
ST Efficiency	0.3873	🔝 **Highest recorded steam cycle efficiency**
Combined Efficiency η_{CCPP}	**0.5704**	**Highest overall efficiency in Model 3**

This Figure [7-7] illustrates the impact of various operational parameters on the total power output in Combined Cycle Model 3. The highest total power output was achieved at the optimal fuel mass flow rate (ṁf = 10.5 kg/s), reaching 546,972 kW, indicating the strong influence of fuel flow on overall plant performance.

The pressure ratio (rp = 15.28) also contributed significantly to power output, achieving 523,830 kW, followed by the low condenser pressure (P_8 = 0.1 bar), which enhanced steam turbine performance and yielded 498,303 kW .In contrast, changes in compressor inlet temperature (T_1), steam flow rate (ṁs), and steam inlet pressure (P_7) had a relatively smaller effect, with outputs ranging between 486,000 and 489,500 kW**.** This analysis highlights the critical role of optimizing fuel flow rate and pressure ratio in maximizing combined cycle performance, providing a solid foundation for design and operational improvements in advanced gas-steam power systems.

8. Parametric Sensitivity Study: Impact of Key Operational Factors on Model 4 Performance

8.1 Introduction

The Table [8-1] Conducting a parametric sensitivity study is essential to understand how variations in critical operational parameters affect the performance of complex power generation systems. In this section, the focus is on Model 4 of the combined cycle power plant configuration, analyzing its response to changes in key factors such as compressor inlet temperature (T_1), pressure ratio (r_p), fuel mass flow rate (ṁf), steam mass flow rate (ṁs), steam pressure (P_7), and condenser pressure (P_8).

This analysis aims to identify which parameters have the most significant influence on the combined cycle efficiency (η_{CCPP}) and overall power output. By systematically varying each parameter within a realistic operational range, the study reveals the sensitivity of Model 4's performance metrics, providing insight into the optimization potential of the system.

Understanding these relationships is crucial for plant operators and engineers who seek to maximize efficiency, improve fuel utilization, and reduce operational costs. The findings from this sensitivity analysis can inform control strategies, maintenance planning, and potential retrofitting or upgrading decisions for Model 4, ensuring reliable and cost-effective power generation as shown in Figure [8-1] [8-2] [8-3] [8-4][8-5][8-6].

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Table [8-1] Model[4] Simulation

Parameters	GAS TURBINE CYCLE			STEAM TURBINE CYCLE		COMBINED CYCLE POWER PLANT	
Main Temperature inlet compressor T1 [k]	p_{owr} $[GT1]$ [kw]	p_{owr} $[GT2]$ [kw]	η_{gts1-2} [%]	p_{owr} $[ST]$ [kw]	η_{sts} [%]	p_{owr} $[tot]$ [kw]	η_{ccpp} [%]
298	155821	155821	0.303	181392	0.3592	493034	0.5542
313	152053	152053	0.2984	185685	0.3677	489791	0.5591
316	151358	151358	0.2984	186539	0.3649	489255	0.56
320	150349	150349	0.2969	187691	0.3717	488389	0.5614
325	149232	149232	0.2968	189116	0.3745	487580	0.563
Main compressor pressure ratio r_p [bar]							
12.2469	147673	1147673	0.2895	187826	0.3719	483172	0.5615
13.2591	150351	150351	0.2954	186891	0.3701	487593	0.5604
13.6639	151358	151358	0.2984	186539	0.3649	489255	0.56
14.6761	164594	164594	0.3028	185752	0.3678	514940	0.5591
15.2834	172150	172150	0.3057	185313	0.3669	529613	0.5586
Main Mass fuel gas $\dot{m}_f$ [N.G] [k g/s]							
5	60536	60536	0.1786	92845	0.194	213917	0.2449
7	105348	105348	0.2531	141089	0.2794	351785	0.4027
9.1	151358	151358	0.2984	186539	0.3649	489255	0.56
10	170799	170799	0.312	196780	0.386	538378	0.6161
10.2	175096	175096	0.315	199571	0.3952	549763	0.6293
Main Mass flow rate steam $\dot{m}_s$ [kg/s]							
100	151358	151358	0.2984	128622	0.2547	431338	0.4937
130	151358	151358	0.2984	142537	0.2822	445253	0.5097
155	151358	151358	0.2984	186539	0.3649	489255	0.56
170	151358	151358	0.2984	192982	0.3821	495698	0.5674
190	151358	151358	0.2984	186469	0.3692	489185	0.56
Main steam Pressure P_7 [bar]							
140	151358	151358	0.2984	186267	0.361	488983	0.5597
145	151358	151358	0.2984	186418	0.362	489134	0.5599
150	151358	151358	0.2984	186539	0.3649	489255	0.56
155	151358	151358	0.2984	186623	0.3659	489339	0.5601
160	151358	151358	0.2984	186699	0.3697	489415	0.5602
Main condenser Pressure P_8 [bar]							
0.1	151358	151358	0.2984	198828	0.3937	501544	0.5741
0.15	151358	151358	0.2984	191739	0.3797	494455	0.566
0.2	151358	151358	0.2984	186539	0.3649	489255	0.56
0.3	151358	151358	0.2984	178954	0.3543	481670	0.5514

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0.5	151358	151358	0.2984	168944	0.3345	471660	0.5399

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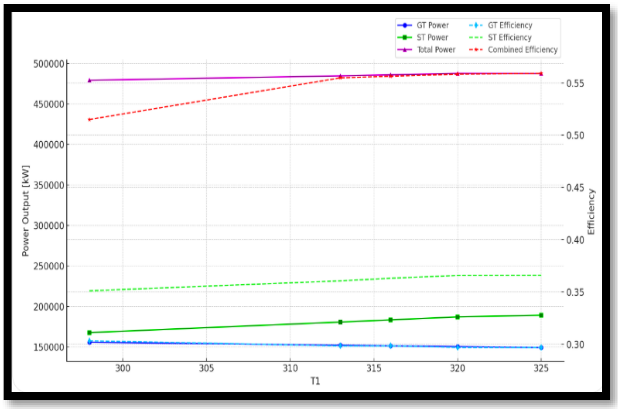
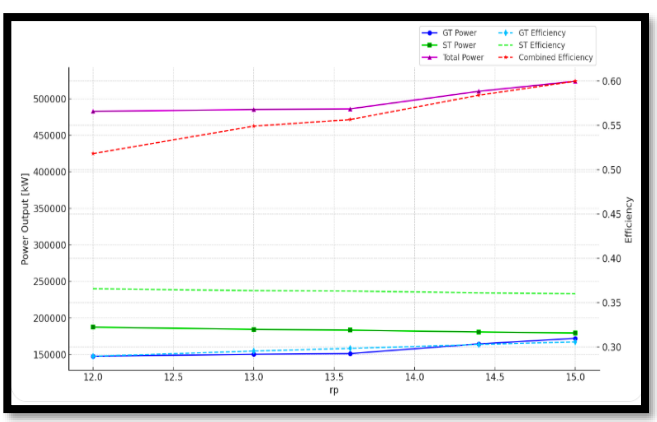


Fig [8-1] Effect of Compressor Inlet Temperature on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output



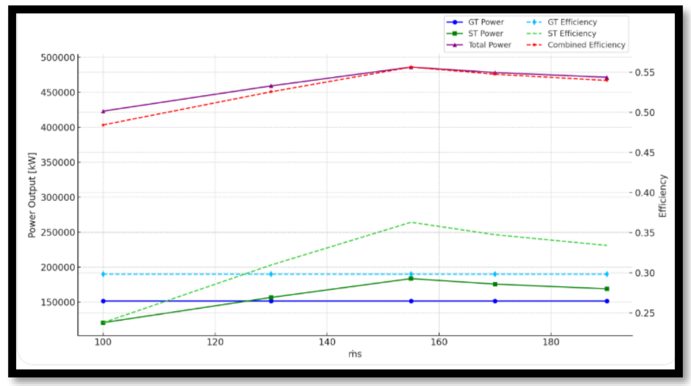


Fig [8-4] Effect of Steam Mass Flow Rate on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

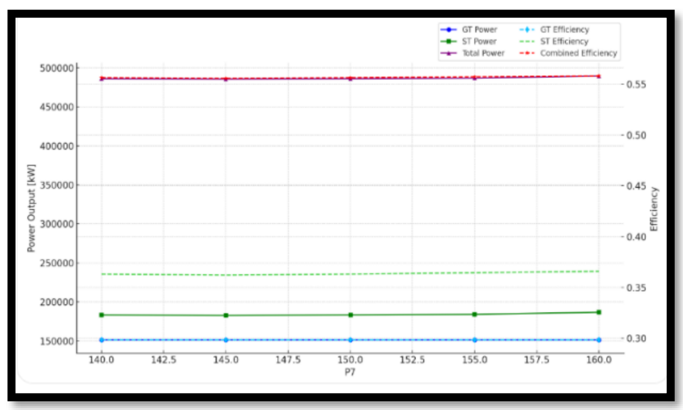


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Fig [8-2] Effect of Pressure Ratio on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

Fig [8-3] Effect of Fuel Mass Flow Rate on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

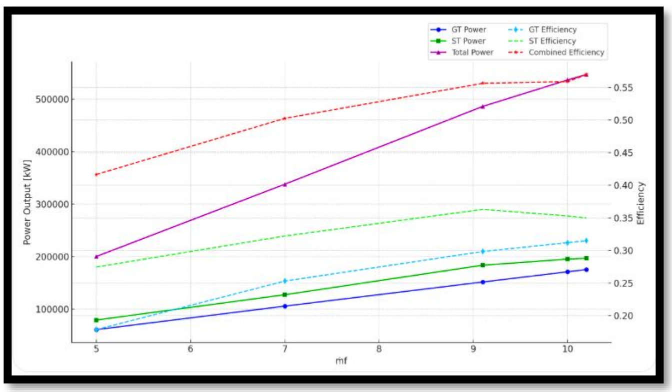
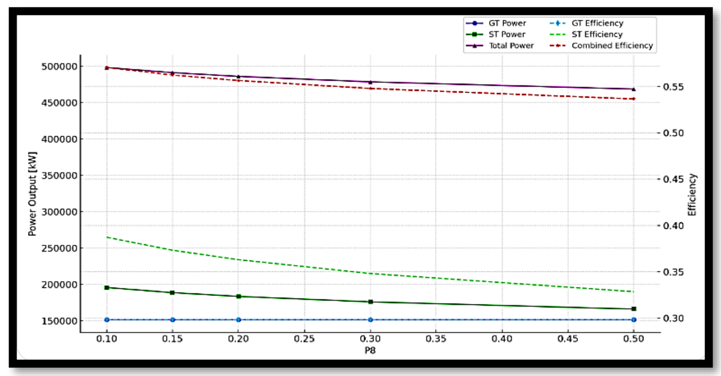


Fig [8-5] Effect of Steam Pressure on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output

Fig [8-6] Effect of Condenser Pressure on Overall Efficiency and Total Power Output, and on Gas and Steam Cycle Efficiencies and Power Output



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8.2. Resulting Performance at This Point – Model 4

This Table [8-2] presents the optimal values of key operational parameters and their impact on the total power output and combined cycle efficiency (η_{CCPP}). Lower inlet air temperature (T_1) slightly improves gas turbine performance, while increasing the pressure ratio (rp) significantly boosts gas turbine power. The highest total power and efficiency are achieved at a fuel flow rate ($\dot{m}f$) of 10.2 kg/s. Steam mass flow ($\dot{m}s$) of 155 kg/s provides optimal steam turbine performance before saturation. The steam pressure (P_7) has minimal effect near 150 bar, whereas reducing condenser pressure (P_8) to 0.1 bar significantly enhances steam turbine efficiency and overall cycle efficiency.

Table [8-2] Effect of Optimal Operating Parameters on Total Power Output and Combined Cycle Efficiency

Parameter	Optimal Value	Total Power [kW]	η_{CCPP}	Remarks
T_1 ↓	325 K	500,382	0.5634	🔻 Lower T_1 improves GT efficiency slightly
rp ↑	15	529,613	0.5586	🔺 Higher rp → higher GT power
$\dot{m}f$ ↑	**10.2 kg/s**	**549,763**	**0.6293**	✅ **Highest power & efficiency overall**
$\dot{m}s$ ↗	155 kg/s	498,953	0.5600	🔼 Optimal ST flow before saturation

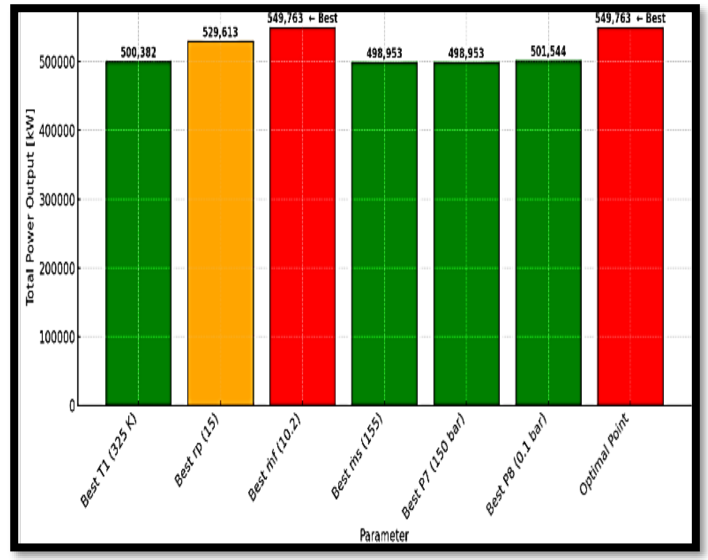

Fig [8-7] Bar Chart of Total Power Output at Best Operating Conditions for Each Parameter and Overall Optimal Point – Model 4

9. Final Ranking of the Models:

This Table [9-1] provides a comparative ranking of the four proposed combined cycle models based on their overall performance. **Model [4]** ranks first due to its superior total power output and strong efficiency. **Model [2]** follows in second place with the highest recorded combined thermal efficiency. **Model [3]** takes third place, offering a balanced performance between power generation and efficiency. **Model [1]** ranks fourth, showing good but comparatively lower performance in both metrics. This evaluation supports selecting Model [4] as the most favorable design.

Table: [9-1] Comparative Ranking of Combined Cycle Models Based on Performance Evaluation

Rank	Model	Overall Evaluation
First	Model [4]	Highest total power output and excellent efficiency
Second	Model [2]	Highest combined thermal efficiency
Third	Model [3]	Well-balanced performance in power and efficiency
Fourth	Model [1]	Good efficiency and performance but lower than others

This Figure [9-2] illustrates the peak thermal efficiency achieved by each combined cycle model. Model [2]

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P_7 ↔	150 bar	498,953	0.5600	← → Minor effect near this value
P_8 ↓	0.1 bar	501,544	0.5741	▼ Lower condenser pressure boosts ST efficiency

This Figure [8-7] illustrates the variation in total power output for different operating parameters in Model 4 of the combined cycle power plant. The highest output (549,763 kW) is achieved at the optimal fuel mass flow rate ($\dot{m}f$ = 10.2 kg/s), which is also marked as the optimal operating point. Other parameters such as pressure ratio (r_p = 15) and condenser pressure (P_8 = 0.1 bar) also contribute significantly, but do not exceed the output obtained at the optimal fuel flow. This analysis highlights the critical impact of fuel input optimization on maximizing overall power generation.

records the highest combined cycle efficiency, followed closely by Model [4], then Model [3]. Model [1] ranks last in terms of efficiency, indicating relatively lower performance compared to the other configurations. This Figure [9-3] displays the maximum total power output (in kW) achieved by each model. Model [4] leads significantly, generating over 540,000 kW, making it the most powerful design. The other models—[1], [2], and [3]—deliver similar power levels, but far below the output of Model [4], highlighting its superior generation capacity.

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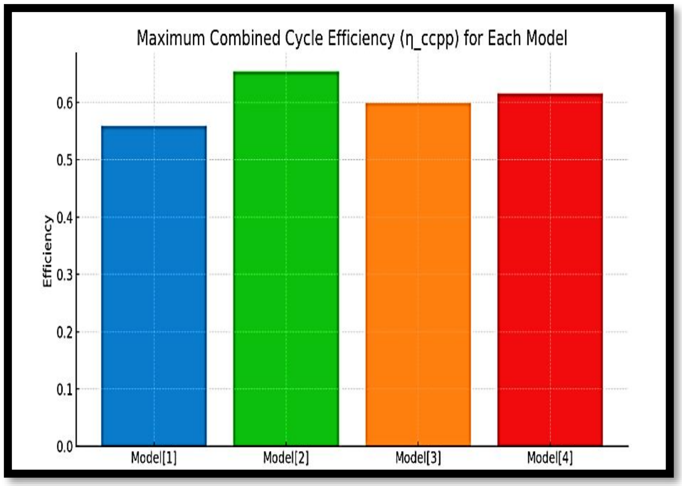
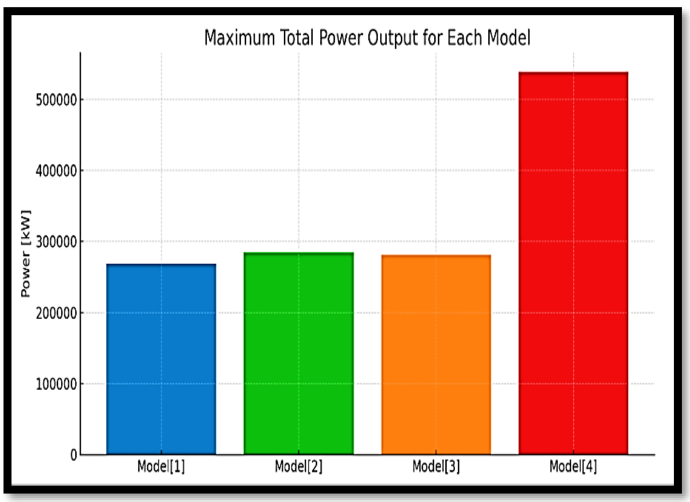


Fig [9-2] Bar Chart of Maximum (η_{CCPP}) Values for



Models 1 to 4

Fig [9-3] Comparison of Maximum Total Power Output across Models 1–4

10. Results Analysis:

Highest Combined Cycle Thermal Efficiency (η_{CCPP}):
Model [2] achieved the highest efficiency (≈ 0.6546), indicating excellent thermal energy utilization. It is followed by Model [4] with an efficiency of ≈ 0.6161, which is also very high.

Highest Total Power Output:
Model [4] delivered the highest total power output (≈

10. Discussion of the Simulation Results

The simulation of four retrofit combined cycle models for the Al-Mansuriya Gas Power Plant has shown significant thermal and performance improvements over the baseline simple cycle operation. Each model was evaluated based on its thermal efficiency, total power output, fuel consumption, and key operational parameters (compressor, gas turbine, HRSG, and steam turbine).

- Model [4] delivered the highest total output (~490.88 MW) and a combined cycle efficiency close to 59.96%, making it the top-performing configuration overall.
- Model [2] achieved the highest combined thermal efficiency (57.04%), though it ranks second overall due to lower power output.
- Model [3] offered a balanced performance and is suitable where both efficiency and output are moderately prioritized.
- Model [1] showed acceptable results but had the lowest overall performance, suggesting limited benefit compared to other configurations.

The parametric analysis revealed that:

- Lowering condenser pressure and increasing pressure ratio significantly enhance system performance.
- Fuel mass flow rate increases power output, but efficiency begins to drop beyond optimal ranges (~10.0 kg/s).

11. Key Conclusions

1. Retrofitting Al-Mansuriya to a CCGT plant can raise efficiency from ~33% to nearly 60%, supporting national energy efficiency goals.

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538,785 kW), significantly surpassing the other models. Model [2] and Model [3] showed similar power performance, both around ≈ 280,000 kW.	2. Model [4] is the optimal design in terms of total power, system efficiency, and investment return. 3. DWSIM proved effective in simulating complex thermal systems using real-world operational data. 4. Key thermal parameters (T_1, r_p, ṁf) significantly influence performance, underscoring the need for inlet air cooling and optimal turbine configurations. 5. These findings can be generalized to other Iraqi or regional gas plants facing similar climatic and operational challenges.

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Nomenclature Table				
Symbol	**Definition**	**Unit**	**Subscript**	**Description**
T	Temperature	K (Kelvin)	a	Air
P	Pressure	bar	amb	Ambient conditions
h	Specific enthalpy	kJ/kg	c	Compressor
s	Specific entropy	kJ/kg·K	cc	Combustion chamber
m˙	Mass flow rate	kg/s	e	Exit
Wc	Compressor work input	kW	evap	Evaporator
Wt	Turbine work output	kW	gg	Gas
ηgt	Efficiency of gas turbine	%	gen	Generator
ηst	Efficiency of steam turbine	%	HRSG	Heat Recovery Steam Generator
ηcc	Overall combined cycle efficiency	%	i	Inlet
Qin	Heat input to the system	kJ or kJ/kg	max	Maximum
Qexh	Heat in exhaust gases (waste heat)	kJ or kJ/kg	min	Minimum
Q˙	Heat transfer rate	kW	out	Outlet
HRSG	Heat Recovery Steam Generator	—	p	Pump
ST	Steam Turbine	—	st	Steam turbine
GT	Gas Turbine	—	t	Turbine
NG	Natural Gas	—	tot	Total

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