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A Power Station (Brayton Cycle) Equipped with Solar Energy: A Numerical Study

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ABSTRACT

The combination of renewable sources of energy with classical power generation systems is the future of sustainable energy generation. The feasibility and performance of integrating solar energy into a Brayton cycle power plant are investigated in this study through numerical simulations. A good opportunity for this integration is represented by the Brayton cycle, which is characterized by high efficiency and the proper use of several heat sources. The present work focuses on the possibility and efficiency of incorporating solar energy into the power plant based on the scheme of Brayton cycle to increase the efficiency and reduce the cost according to numerical modelling. The up to date technique concerns the feasibility of using CH_4 gas in the Brayton cycle that has a gas turbine combustion chamber and an air blower. Main observations include increased efficiency of the turbines by 32 percent and the fact that over the years, the general expenses have also reduced from \$5.2 USD per MWh of electricity without solar panel to approximately \$4.3 USD per MWH with the use of solar panels. About the exhaust temperature, the results stated that the temperatures rose by twenty- nine percent due to the use of solar panels. The presented outcomes prove the potential and the benefits of the integrated use of renewable solar energy and the conventional power generation systems to promote the formation of more efficient energy sources.

1. INTRODUCTION

To obtain a sustainable energy solution, renewable sources should be integrated with conventional power generation systems and it has become a key area of research and development. One such successful framework is the Brayton cycle which is a very efficient and flexible power production system that can capture heat sources of different origins to produce electricity. The recent solar energy integration in the Brayton cycle has received a lot of attention because of the possibility of the further increase in system efficiency and reduction of environmental impacts. The abundant and thermally inexhaustible solar energy represents a good opportunity to supplement the conventional manners of power generation, especially in the regions which enjoy a lot of sun. Utilizing the energy of the sun with photovoltaic or concentrated solar power systems, power stations can diversify their sources of energy, reduce greenhouse gases and facilitate the shift to a sustainable energy future.

Yu et al. [1] attained such information as was relevant with regard to the supercritical CO_2 (S-CO_2) Brayton cycle, which is characterized by its efficiency and quite small size, being applied in different heat sources. The research team examined 724 studies between the years 2000 and 2019 to determine the common authors, research institutes, and countries where different researchers are located. The S-CO_2 data information was based on countries. The United States is the most pioneering countries followed by China and South Korea. An overview of the present work from five aspects including the application, layered structure, modeling, S-CO_2 based blends, system components and execution processes was investigated. Finally, S-CO_2 power technology development must be promoted to give the commercialization of S- CO_2 power systems a boost. Wu et al. [2] investigated S-CO_2 Brayton cycle is a prospective candidate for utilization in the nuclear energy construction due to high conversion efficiency, small size, simplicity, and efficiency retention of dry cooling method. This can be used in distinct nuclear power systems with wide usage – from small modular reactors and generation IV reactors to fusion reactors. The S-CO_2 power cycle can also increase the safety of the commercial nuclear power plants by operating as the self- driven technology and the self-sustaining machine to divert the decay heat from the power plants through the cycle. This article looks at the literature on the S-CO_2 power cycle as a nuclear application, to examine its features, carry out experimental studies and take analyze from different research fields. The study concludes that the S-CO_2 Brayton cycle can, thus, be regarded a suitable alternative for broadening the field of utilized nuclear energy power plants. Yang et al. [3] examined the part-load performance of four typical S-CO_2 Brayton cycles: cycle of recuperation simple, simple cycle, the intercooling cycle, the reheating cycle, the recompression cycle. The second law result shows that the reheating process has higher efficiency than the simple recuperative cycle. The recompression world and the intercooling cycle are superior to the reheating cycle under part load. Meanwhile, power losses can be minimized by the application of the intercooling method with a high combustion percentage exceeding 60% as there the most effective load adjustment takes place. There is going to be better performance in recompression cycle when the difference between effective power generation (total electricity formation) and maximum potential power generation is less than 62.5%. On the other hand, the intercooling cycle has better performance when this difference is greater than 68.3%.

Chen et al. [4] researched a heat cycle recovery-cycle technology inside the electrical Machines is good for enhancing thermodynamic efficiency and reducing the pollution in a Brayton cycle. The paper presents an enlarged Maisotsenko-Brayton plant model technique viewed from the guidelines of finite time thermodynamics when taking into account limitations in plant size. The model contains pressure drop losses during intake, compression, expansion, and discharge processes as well as heat transfer loss hot the ambience and irreversible compression and expansion loss in the compressor and the turbine, and irreversible combustion loss in the combustor. Adjusting the working fluid energy circulation rate and waste energy distribution of pressure loss, peak power and efficiency can be driven. Moreover, the tests conclude the ideal pressure ratio of the compressor, the highest power output, and the consumed society shall increase the usage of public transport and encourage carpooling to reduce climate change risks associated with private car use. The workability of a two-loop open cycle is compared with the other classical open regenerate cycle, the results show the power, and efficiency performance of the second is higher. Liu et al. [5] studied the supercritical carbon dioxide Brayton cycle (SCBC) and found it as a novel technology which is efficient and cost effective in power plant generation. These include high efficiency and small equipment size in the range of 450-750℃. However, they also have material-related issues because they work at high pressure and temperature. SCBC can work with sunlight, nuclear power, high-temperature fuel cells, or waste heat. The study considers the SCBC's structural forms, applications, thermodynamics, optimization, and design studies. It posits enhancing the efficiency of turbomachinery, constructing miniature heat exchangers, building huge wind tunnels, fine-tuning SCBC designs, and improving control procedures. Additional studies on commercialization are essential. Mecheri and Le Moullec [6] demonstrated the application of supercritical CO_2 cycles in coal power plants in a thermodynamic context and using industrial modeling as a tool. It recommends that one power cycle be the first phase of technology adoption. The major findings are that there is need to do a reheat cycle in this application, and even if the temperature is lower, there is an efficiency difference of more than 4.5% pt. Single reheat, an easy to operate option, will deliver 1.5% pt gains in efficiency. Double reheat and recompression cycles together with innovative flue gas economizer design lead to increase in efficiency by at least 0.3 to 0.5% pt. Ho et al. [7] contrasted various S-CO_2 closed loop Brayton cycle cycles with a concentrating solar heater source concerning cost, maintenance and performance. Base, singular, multi-pass, as well as partially recovered heat exchanger systems are presented. The core property allows for differentials in temperature and to have the lowest price in components of blocks with lowest power. The reduced temperature differences cycles lead to more efficient systems and to cheaper solar collector and receiver prices. Every part of the life cycle that has a higher efficiency leads to a lowest price for the solar and power-block part over the entire range of lifespan. As reported by Padilla et al. [8], concentrated solar power (CSP) becomes an attractive option due to the favorable environment it offers in terms of high temperatures and low cost. Researchers place their focus on solar field, solar receiver, energy storage and power block in order to increase the efficiency and make this technology commercially viable. Compared to conventional cycles, supercritical CO_2 Brayton cycles are more preferable for plant blocks connected to central receiver tower systems provided their thermal efficiency and compactness are superior. The current research work explored four various supercritical carbon dioxide Brayton cycle configurations, i.e., simple Brayton, recompression Brayton cycle, partial cooling with recompression, and recompression with main compression intercooling. The research team established that the thermal efficiency of the supercritical CO_2 Brayton cycle not only increased with the cycle temperature linearly, but the maximum amount of thermal efficiency could be obtained with the recompression cycle and main compression intercooling. The exergy should reach its performance limit that slightly depends on the cycle configuration to be 700℃-750℃.

Al-Sulaiman and Atif [9] compared five supercritical carbon dioxide Brayton cycles combined with a solar power tower. The analysis used a mathematical code and the differential evolution approach to construct and refine a heliostat field pattern. The optical performance of the heliostat field was improved before merging with the supercritical CO_2 Brayton cycles. The recompression Brayton cycle achieved the best thermal efficiency, with a maximum of 52%. The regenerative Brayton cycle performed similarly, despite having a simpler setup. The study was conducted in Dhahran, Saudi Arabia. Ahn and Lee [10] studied the steam Rankine cycle was previously used in SFRs, but concerns about sodium water reactions have led to the development of closed Brayton cycles like supercritical CO_2 cycle, helium cycle, and nitrogen cycle. This gas Brayton cycles are compared based on their physical sizes and performance for small modular SFR applications, considering turbomachinery architecture and system volume. Le Roux et al. [11] studied on Brayton cycle and solar thermal Brayton cycle has revealed their applicability to sunny area power plants. On the other side, there is a trade-off between maximizing heat transfer and reducing pressure losses. Working at high temperatures, the radiator is exposed to the risk of heat loss. The authors suggest the use of Gouy-Stodola theorem, turbine modeling, total entropy generation minimization method, and multiple modeling perspectives as optimization tools for solar thermal power. The aim of the article is to offer guidance to other researchers on how to improve the model of the solar thermal Brayton cycle. This, in turn, would help the development of solar thermal technology. Iverson et al. [12] examined the supercritical CO_2 Brayton cycles are a quite promising technique for the improvement of the efficiency in solar – thermal power plants, though very high investment costs. They become more and more favorable with the growth of operating temperature of the devices and have activity beyond the production of solar power. This study shows how the Brayton turbomachine adapts to variations in heat load, the heat load seen in short-term bursts associated with solar energy. Though the cycling process is somehow different from each other, the energy stored in the thermal mass would sustain a temporary running of the cycle by the fuel until the input gets back. With storage in the system, the interaction between long- and short-duration options gets mitigated, and this is followed by a comparison of different storage components' system efficiency. However, for purposes of benchmarking computer modeling, barely critical point supercritical CO_2 Brayton cycle operation data are collected and effects of cycle enhancements on loss mechanisms are studied. Garg et al. [13] compared three types of carbon dioxide-based Brayton cycles for concentrated solar power applications. The supercritical cycle has the highest thermal efficiency at 85 bar, with a linear growth with low side pressure. It can generate power with over 30% thermal efficiency even at lower source temperatures, despite higher turbine inlet pressure. Compressor, regenerator, turbine, and gas cooler irreversibility analyses reveal lower efficiency than ideal cycles. The supercritical cycle's low source temperature sensitivity and low volumetric flow rates can overcome high-pressure disadvantages.

Conboy et al. [14] studied supercritical CO_2 power cycles among S-CO2 power cycles are promising as they offer higher isothermal processes, small size and the possibility to use standard building materials instead of highly engineered ones. The undertaking of such project by Sandia National Lab and the U.S. Department of Energy signifies the largest supercritical CO_2 split-flow supercritical fluid, which is the first and almost the only megawatt-scale S-CO_2 cycle in the world. The Sandia-DOE loop, already improved by adding more heaters, a second recuperating printed circuit heat exchanger, greater waste heat removal capacity, yield load banks with more power, higher and better temperature piping, and scavenging pumps with less windage within the turbomachinery, has now been improved even further. The reheat has broken through previous records and goes beyond the maximum values projected in the temperature of turbine intake, shaft course, pressure ratio, flow rate and the power generation. The experiment scenery will include behavior of the main power cycle parts at the limit of their operational speeds and temperatures caused by supersonic flight. Sarkar [15] examined the impact of operational parameters on ideal pressure ratio, energetic efficiency, and component irreversibility's in an S-CO_2 recompression cycle. It finds that minimum operating temperature has a more significant impact on optimum pressure ratio and cycle efficiencies than maximum operating temperature. The study also highlights that heat exchangers have higher irreversibility's than turbomachinery's, and recuperations' operating characteristics have a greater impact on irreversibility. The turbine's isentropic efficiency is more significant than compressors, and the high temperature recuperation's effectiveness is twice as significant as the low temperature recuperate. The reactor's pressure drop has a more significant effect on the second law efficiency reduction. Moisseytsev and Sienicki [16] examined the recompression supercritical cycle, also known as the Feher cycle, is commonly used for analyzing S-CO_2 Brayton cycle performance. However, it may not be the best configuration for SFRs operating at low core outlet temperatures. Researchers have investigated alternative cycle layouts for an S-CO_2 Brayton cycle coupled to the advanced burner test reactor SFR preconception design. No advantages were found, so focus was on improving the recompression supercritical cycle. The study found that an optimal combination of minimum cycle temperature and pressure could achieve improvements in cycle efficiency of at least 1% compared to previous analyses that fixed the minimum temperature and pressure arbitrarily. However, larger coolers may be needed for heat rejection, and lower heat sink temperatures may be needed at minimum temperatures below essential temperatures, depending on the plant site's climate. Zhang et al. [17] utilized closed form thermodynamics to develop a thermodynamic model for a combined Brayton and reverse Brayton cycles, taking into account pressure drops and power plant size restrictions. The flows meet with 11 flow resistances of which 4 belong to the isentropic efficiency. The remaining resistance of the flow is due to the change of the flow section at different points which affect the airflow rate and net power output also. Compressor inlet relative pressure drop is employed for calculating pressure drops due to flow exposure to various cross-sectional areas. Analytical formulas are derived therefore for power output, thermal conversion efficiency, and compressor pressure ratio of the top cycle. Through adjusting the inlet pressure of the compressor, air mass flow rate and pressure losses along the channel the model cycle's efficiency is optimized. Power is maximized in line with the bottom inlet pressure of the bottom cycle compressor, the input air flow rate, and / or the pressure drop, while the extra maximum is achieved in line with the top cycle compressor pressure ratio.

Pra et al. [18] studied on high temperature, direct cycle gas cooled reactors gained interest due to their potential for greater efficiency than standard steam cycles. The helium/helium recuperate used in the Brayton cycle must operate under challenging conditions like temperature, pressure, and pressure differential. The research focused on promising technologies for small recuperates, including the Heatric Printed Circuit Heat Exchanger and the Norman plate fin idea. A mock-up of the Heatric Printed Circuit Heat Exchanger was created and tested at CEA's Claire loop, exposed to thermal shocks typical of recuperates. Computational Fluid Dynamic and Finite Element calculations were conducted to understand the thermal and mechanical behavior of the mock-ups. The experimental and numerical findings were compared, and recommendations for full-size recuperates using the chosen technologies were made. Other works [19-21] studied enhancement the performance of compression refrigeration cycle, enhancement of energy transfer efficiency for photovoltaic systems and economic and technical feasibility analysis of hybrid renewable energy (PV/Wind) grid-connected.

Power generation of solarized supercritical CO_2 (S-CO_2) Brayton cycle configurations was techno-economically evaluated by Ho et al. [22]. Drawing on such configurations among others as base, single-pass, multi pass and partially recovered heat exchanger systems, the study compared analysis on performance, cost and lifecycle of these configurations in CSP plant. Firm specific evidence suggested that system designs with lower differentials in the temperature levels registered better thermal efficacies, and simultaneously holding down costs of solar receivers and collectors. However, high-performance heat exchangers which are optimised for these cycles lowered life-cycle costs and provided superior heat exchange compared to Rankine cycles.

Ohara and Lee [23] have done the performance analysis of both Brayton and inverse Brayton cycles incorporated with a solar thermal power plant. The objective of their work was to assess the thermodynamic efficiency and practicability of these configurations in increasing the performance of solar power systems. By integrating the Brayton cycle and inverse Brayton cycle, it was able to take advantage of high thermal efficiency of the Brayton cycle as well as energy recovery capability of the inverse Brayton cycle resulting in better system efficiency.

Conventional techniques of electricity production like the coal and natural gas systems are comparatively less efficient and have worse environmental effects than renewable energies. Solar integration into such systems can help lessen some of these problems. However, most of what is currently in use as hybrid systems is a combination of the solar conversion to steam Rankine cycles commonly used in CSP. Several advantages can be given to the Brayton cycle compared to the Rankin Cycle with its high efficiency at high temperatures, and fast start/stop characteristics that allow it to be better suited to work in conjunction with the fluctuating sources of Renewable Energy Sources such as solar energy.

2. METHODOLOGY

The model interpretation developed to explore the favorable scenario of the cycle of natural gas CH_4 cycle is as give below. It is the gas turbine (GT), combustion chamber (CC), and air blower (AC) as the structure diagram plotted in Figure 1. Instruction of easy to follow for assembled frame will be prepared in the following manner. The air gets highly condensed upon entering the AC blower. Moreover, it has to work a lot before cooling down again. The air is then recruited to the control space being in connection with gaseous gasoline fuel where after giving high-pressure - high temperature exhaust gas. While the burnout gases gradually change the machine in use. Airflow agent is equipped with solar panels.

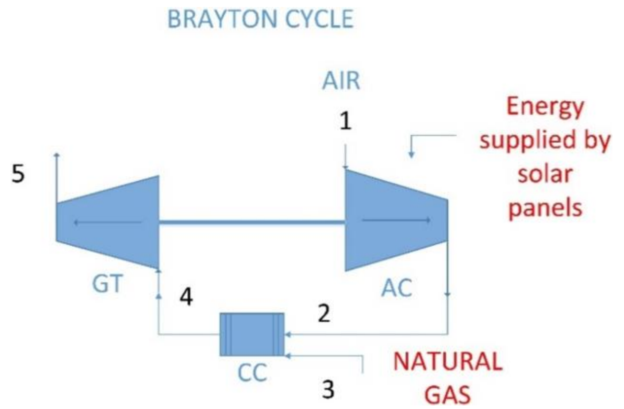

Figure 1. Schematic diagram of Brayton cycle

2.1 General mass and energy equations

The Natural Gas Cycle are separate thermodynamic power-generation technologies. It is necessary to use fundamental thermodynamic principles, which are stated through generic mass, energy, and exergy equations.

The conservation of mass equation for SSSF open system [24]:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{1}$$

where, $\sum \dot{m}_{in}$: the total mass flow entering per unit time, $\sum \dot{m}_{out}$: the total mass flow exiting per unit time. The energy balance for every part depends on the primary law of thermodynamics for SSSF open framework [23]:

$$\dot{Q} + \dot{W} = \sum \dot{m}_{out} h_{out} - \sum \dot{m}_{in} h_{\text{in}} \tag{2}$$

2.2 Thermodynamic analysis for BC model

2.2.1 Compressor model

Air blowers, machines that utilization ability to make dynamic energy, pack and compress air and may deliver it in short explodes. Rotating blowers are expected because of the huge stream paces of turbines and their relatively low-pressure proportions. Fiery connection for the blower model is changed as follow [25]:

Energy balance:

$$\dot{W}_{AC} = \dot{m}_{\text{air}} (h_2 - h_1) \tag{3}$$

Isentropic efficiency:

$$\eta_{AC} = \frac{\dot{W}_{AC,s}}{\dot{W}_{AC}} \tag{4}$$

2.2.2 Combustion chamber model

Exergetic connection for the ignition chamber model is altered as follow:

Energy balance:

$$\dot{m}_2 h_2 + \eta_{CC} \dot{m}_3 \text{LHV} = \dot{m}_4 h_4 \tag{5}$$

2.2.3 Gas turbine model

Exergetic connection for the gas turbine model is altered as follow:

Energy balance:

$$\dot{W}_{GT} = \dot{m}_{gas} (h_4 - h_5) \tag{6}$$

Isentropic efficiency:

$$\eta_{GT} = \frac{\dot{W}_{GT,s}}{\dot{W}_{GT}} \tag{7}$$

2.3 Economic analysis

The chief expenses of a warm framework are the capital venture, the activity and upkeep, and the fuel costs. In light of the capital recuperation factor (CRF) an improved on financial model can be applied. The Total Capital Investment (TCI) in a plant is given by the amount of all the Purchased Equipment Costs (PEC) duplicated by a steady component. The all out capital interest in a plant is in this way given by [25]:

$$\dot{Z}_k = \frac{Z_k \times CRF \times \phi}{N \times 3600} \tag{8}$$

where, *PEC*: the equipment's purchase cost in US dollar. φ: the maintenance factor 1.06. CRF: the capital recovery factor, which can be calculated as:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{9}$$

where, *i*: the interest rate (consider to be 10%). *n*: lifetime of the system (consider to be 20 years). The PEC for the NGCC parts are as per the following:

Brayton cycle gear buy costs [25]:

Air compressor

$$ZAC = (71.1m40.9 - \eta AC)(P5P4)Ln\,(P5P4) \tag{10}$$

Combustion chamber

$$ZCC = (46.08m40.995 - P7P5)\,(1 + exp - (0.018T7 - 26.4)) \tag{11}$$

Gas turbine

$$ZGT = (479.34m70.92 - \eta T)\,Ln(P7P8)\,(1 + exp - (0.036T7 - 54.4)) \tag{12}$$

2.4 Cost performance

The framework all out cost rate, barring fuel costs $\dot{Z}$ is the summation over all parts of $\dot{Z}_k^M$ from following condition [2]:

$$\dot{Z}_T = \sum_k \dot{Z}_k = \sum_k \left(\dot{Z}_k^N + \dot{Z}_k^{OM}\right) = \frac{\sum_k CRF\ \beta(1+\gamma)PEC_k}{\tau} \tag{13}$$

2.5 Assumptions

The overall presumptions made for the recreation of the joined framework are recorded as follows:

1. All part of the joined framework works under consistent state conditions.
2. Compositions of air at the channel of AC are 79% N_2 and 21% O_2.
3. Natural gas is totally oxidized in the CC.
4. Ideal gas standards apply to the fume's gases.
5. The CC is protected totally.

2.6 Boundary conditions

Inlet air conditions: Temperature and pressure of the environment is defined as input parameters.

•Relative temperature of inlet temperature fluctuates from Zone A 25°C to Zone C 50°C.

•Pressure ratios: Regulation of the pressure ratio of the compressor and the turbine is conducted to observe the effects that it has on efficiency and cost.

•Exhaust temperature: The exhaust gas temperature is measured and changed while discussing its impact on the cycle efficiency.

•Solar irradiation: The efficiency of the solar panels and the value of irradiation are considered to assume the power provided by solar energy.

•Implementation in MATLAB/Simulink: Thermodynamic Equations: MATLAB/Simulink is applied to evaluate the energy balance equation, mass flow rate equation, and isentropic efficiency equation as seen in Figure 2.

•Photovoltaic (PV) panel simulation: The PV panel performance is simulated using variables such as temperature coefficient, solar irradiance and reference rating of the manufacturer among others.

•Compressor and turbine models: By using isentropic relations and efficiency, formulas MATLAB scripts determine work done on the compressor and work done on the turbine.

•Implementation in EES: Energy and Exergy Analysis: EES is used for the thermodynamic calculations' energy and exergy of the Brayton cycle components.

•Economic analysis: EES is also used to carry out a cost calculation i.e. capital costs, operating cost and cost per MWh for the generated electrical energy.

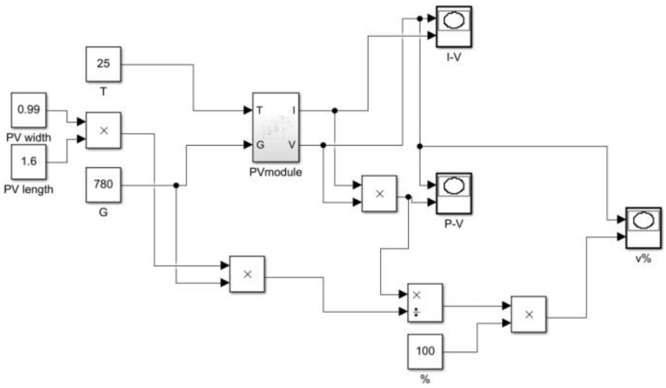

Figure 2. Simulink programing

2.7 MATLAB Simulink equations

The energy yield of the PV panels depends upon many factors such as panel efficiency, irradiation, area of the panel, and others. Two key factors are solar irradiation and panel temperature considered for the ease of this simulation study. Observed the thermal and electrical properties of the photovoltaic panel, specifically on the effects of different radiation and temperature levels of the panel on both panel voltage and power. Simulation of the PV module power was carried out using input V_{OC} and I_{SC} from the experimental data and formulation by temperature coefficient (T_P). Parameters of p-n junction panel were gained from the electrical equivalent diagram: solar panel output current (I), dark saturation solar panel current (I_{OS}), and generating current by solar irradiation (I_{LG}) were provided by the following equations:

$$I = I_{LG} - I_{OS}\exp\left[\left(\frac{q}{nkT_P}\left(V + IR_f\right)\right) - 1\right] - \frac{V + IR_S}{R_{SH}} \tag{14}$$

$$I_{OS} = I_{OS}\left(\frac{T_P}{T_R}\right)^3 \exp\left[\frac{qE_{GO}}{Ak}\left(\frac{1}{T_R} - \frac{1}{T}\right)\right] \tag{15}$$

$$I_{LG} = [I_{SCR} + K(T_P - 25)]G/100 \tag{16}$$

$$P_{\max} = I_{\max}V_{\max} \tag{17}$$

$$P_{\max} = I_{sc}V_{oc}FF \tag{18}$$

$$FF = \frac{P_{\max}}{I_{sc}V_{oc}} \tag{19}$$

The V_{OC} is as well the voltage drop across the diode, when a photocurrent I_{LG} runs through it. I_{LG} is an analogue of the photocurrent I=0. The quantity enclosed inside the bracket goes for V_{OC} calculation.

$$V_{oc} = \frac{kT_R}{e} \ln\left(\frac{I_{sc}}{I_o} - 1\right) = V_t \ln\left(\frac{I_{sc}}{I_o} + 1\right) \quad (20)$$

where, V_t - thermal voltage (V) given by

$$V_t = \frac{kT_R}{e} \quad (21)$$

All of the values in the above equations are created by evaluating the product's manufacturer's own ratings and then plotting the IV curve after that. These formulations are employed with MATLAB/Simulink in which the programming is done. MATLAB/Simulink is applied for this experimental study. In a nutshell, the photovoltaic effect is the process of generating electricity by irradiating semiconductor material. Irradiation represents the photon effect and allows the electron and hole to disassemble to form a useful electric current.

$$V_{OC} = 22.384 - 0.0627T_P \quad (22)$$

where, T_P is in °C.

In addition, the linearity between solar radiation (G) and short circuit current (I_{SC}) data is represented by

$$I_{SC} = 0.0967 + 0.0032G \quad (23)$$

where, G is in $\mathrm{W/m^2}$.

To perform a comprehensive economic analysis, we need to consider various scenarios and economic factors such as subsidies, solar panel cost variations, and operational cost changes. Here, we will analyze the impact of these factors on the overall economic viability of the proposed system.

Baseline economic parameters

Initial capital cost of solar panels: $1,000 per kW

Maintenance cost of solar panels: $10 per kW per year

Natural gas cost: $4 per MMBtu

Interest rate: 10%

System lifetime: 20 years

Annual energy production: 700,000 MWh (as calculated previously)

Capital and operational costs

Capital cost: Capital Cost-100 MW×$1,000 per kW-$100,000,000

Annual maintenance cost: Maintenance Cost -100,000 kW×$10 per kW/ year -$1,000,000

Fuel cost savings

Assuming a 20% reduction in natural gas consumption: Annual Natural Gas Consumption Reduction -700,000 MWh×0.20 - 140,000 MWh

Converting MWh to MMBtu (assuming 1MWh=3.412 MMBtu): Reduction in MMBtu -140,000 MWh×3.412 MMBtu/MWh - 477,680 MMBtu

Annual fuel cost savings: Fuel Cost Savings -477,680 MMBtu×$4 per MMBtu - $1,910,720

Total annual cost savings

Total Cost Savings -$1,910,720 - $1,000,000 (maintenance) -$910,720

Net Present Value (NPV)

Using CRF for a 10% interest rate over 20 years:

$$\mathrm{CRF} - \frac{i(1+i)^{\mathrm{n}}}{(1+i)^{0} - 1} - \frac{0.10(1+0.10)^{20}}{(1+0.10)^{20} - 1} - 0.11746$$

Annualized capital cost: $100,000,000×0.11746-$11,746,000

Annual net savings: $910,720

Net annual cost: $11,746,000 - $910.720 - $10,835,280

3. RESULTS AND DISCUSSION

In this paragraph, all the results obtained through the EES simulation program in the Brighton cycle will be reviewed regarding adding power from the solar panels to the system by changing several variables.

The study examines the sensitivity of solar panels to various parameters in the Brayton cycle power system. It reveals that the efficiency of the system decreases with rising ambient temperatures, necessitating advanced cooling systems. Solar panels can mitigate some efficiency losses by reducing the overall cost, but careful design and placement of PV arrays are critical. The integration of solar panels enhances the economic viability of operating at higher pressure ratios, leading to significant cost savings. The study emphasizes the importance of compressor efficiency, turbine efficiency, and exhaust temperature in achieving better cycle performance and lower operational costs. The study also highlights the need for careful system design and optimization, with sensitivity analysis highlighting the importance of selecting the right components and operational settings. Future research should perform detailed sensitivity analyses, validate numerical simulations through real-world experiments, and implement advanced optimization techniques.

The integration of solar energy into the Brayton cycle can significantly reduce greenhouse gas emissions by reducing reliance on fossil fuels. The traditional Brayton cycle power plant uses natural gas, emitting CO_2 and other greenhouse gases. By integrating solar panels, a portion of the energy required for the cycle is supplied by renewable sources, reducing overall fossil fuel consumption. A solar panel setup that reduces the total cycle cost by around 5.2 USD/MWh without solar panels to 4.3 USD/MWh with solar panels can infer a significant reduction in fuel usage.

3.1 Effect the temperature ambient

Ambient temperature plays a key role in determining the performance of a Brayton cycle power system, especially in cases where the PV panels are used as the source for the air compressor. Rising temperatures because the air density to decrease in turn, the condenser efficiency is reduced leading to significant energy loss as well. Monitoring PV production reduction at higher temperature, temperature compensation technologies incorporated help to maintain the best output. High performance of system would be possible through cooling of it up, where active systems like air cooling are also being provided for the compressor and panels. System design is a key factor to achieve the aim of PV placement in the Brayton cycle, with attention being given to the right orientation and positioning of the PV arrays, the performance of the efficient cooling systems, and accounting for thermal effects over the performance of the components.

Figure 3 shows the effect of using the PV panel on the total cost as well as the efficiency, as it shows the change in the inlet temperature, as the increase in inlet temperatures reduces the efficiency of the cycle in general, as it reached 25.6%. The inlet temperature is 50 degrees Celsius. As for the total cost, it reached 2.4 USD/MWh at a temperature of 50 degrees Celsius without using a solar panel setup, and when using solar panels, it reached 1.4 USD/MWh at a temperature of 50 degrees Celsius. This shows the benefit of using solar panels in reducing the total cost of the cycle.

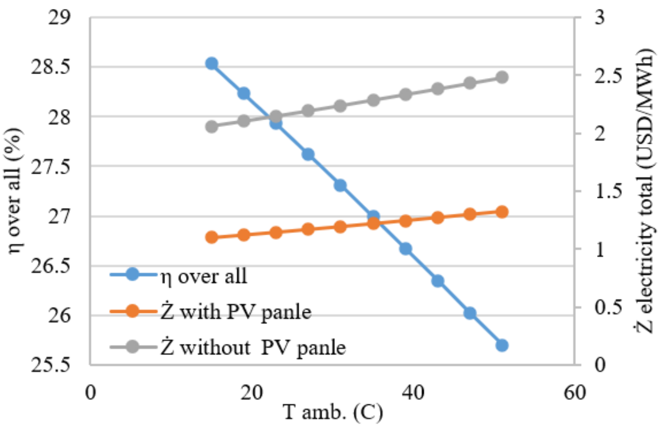

Figure 3. Variation of η energy overall and Ż electricity total with ambient temperature for with and without PV panel

3.2 Effect the pressure ratio

The effective operation of a Brayton cycle system has a lot of dependency on the ratio of pressure because of bringing PV arrays for power generation. A high ratio provides maximum air compression efficiency, more turbine work and less energy additionally used. PV installations can not only attenuate the power distribution constraints but also generate electricity from sunlight instantly, thus, a clean and renewable energy source is offered without the need to burn fuels. Correct system architecture and optimization practices such as the sizing of the PV array, the implementation of high efficiency power conversion and control systems as well as factors like variability in solar irradiance, go a long way in enhancing the gains from integration of renewable PV panels in the energy generation process within town cycle of Brayton.

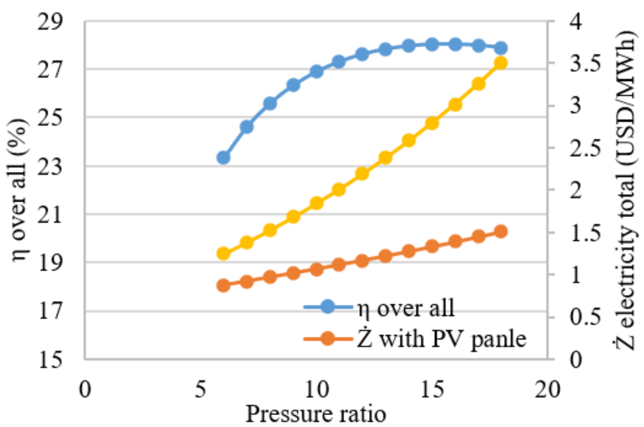

Figure 4. Variation of η energy overall and Ż electricity total with pressure ratio for with and without PV panel

Figure 4 shows the effect of using the PV panel on the total cost as well as the efficiency, as it shows the change in the pressure ratio, as the increase in pressure ratio increase the efficiency of the cycle in general, as it reached 28%. The pressure ratio is 18. As for the total cost, it reached 3.6 USD/MWh at a pressure ratio of 18 without using a solar panel setup, and when using solar panels, it reached 1.6 USD/MWh at a pressure ratio of 18. This shows the benefit of using solar panels in reducing the total cost of the cycle.

3.3 Effect the compressor efficiency

The compressor in the air-based compression cycle in a Brayton generator assembly system is the most crucial component, especially with its use of PV panels supplying power to the air compressor. A compression system efficiency higher than usually means that energy consumption is lower and that the complete system is more efficient. Solar panels, as well, can give an independence to systems effecting the process of electricity generation by using sunlight radiantly. This renewable source of energy can minimize the energy spend for air compression and can upgrade the energy efficiency wisely. It would then help the situation by reducing the impact on the environment. The irrefutable fact that robust design and optimization of the systems will entail maximum gain and benefits of the PV panel in the system is a core point to consider in the Brayton cycle.

Figure 5 shows the effect of using the PV panel on the total cost as well as the efficiency, as it shows the change in the compressor efficiency, as the increase in compressor efficiency increase the efficiency of the cycle in general, as it reached 31%. The compressor efficiency is 0.9, as for the total cost, it reached 6.2 USD/MWh at a compressor efficiency of 0.9 without using a solar panel setup, and when using solar panels, it reached 1 USD/MWh at a compressor efficiency of 0.9. This shows the benefit of using solar panels in reducing the total cost of the cycle.

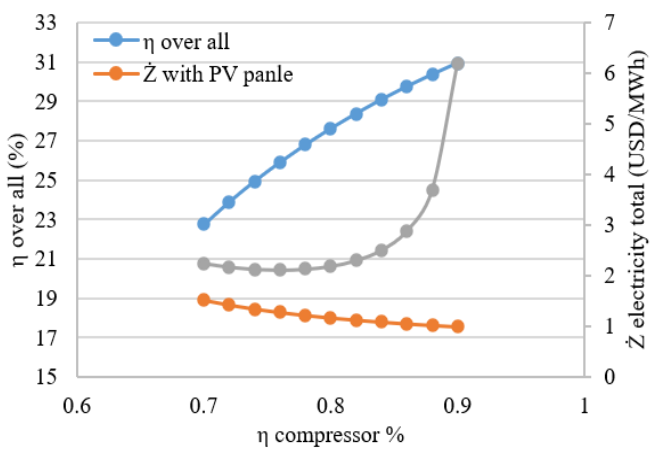

Figure 5. Variation of η energy overall and Ż electricity total with compressor efficiency for with and without PV panel

3.4 Effect the turbine efficiency

Directly does the performance of a turbine in a system of Brayton cycle power efficiency. These is related to energy conversion efficiency. Increased turbine efficiency results in increased power production per fuel unit, higher conversion efficiency at processing stage, and smaller power demand for the air compressor. Collocating PV panels that supply power to the air compressor can contribute to the main heat engines' efficiency by lowering the necessity to use regular power supply sources. Solar energy can be a helpful tool to save for running the motor compressing air and lead to achieve energy saving purpose and decrease carbon emission. The correct configuration and optimization of rocket engine is the best method to get better performance of PV integration and overall satisfaction of the system.

Figure 6 shows the effect of using the PV panel on the total cost as well as the efficiency, as it shows the change in the turbine efficiency, as the increase in turbine efficiency increase the efficiency of the cycle in general, as it reached 32%. The turbine efficiency is 0.9, as for the total cost, it reached 3.3 USD/MWh at a turbine efficiency of 0.9 without using a solar panel setup, and when using solar panels, it reached 2.3 USD/MWh at a turbine efficiency of 0.9. This shows the benefit of using solar panels in reducing the total cost of the cycle.

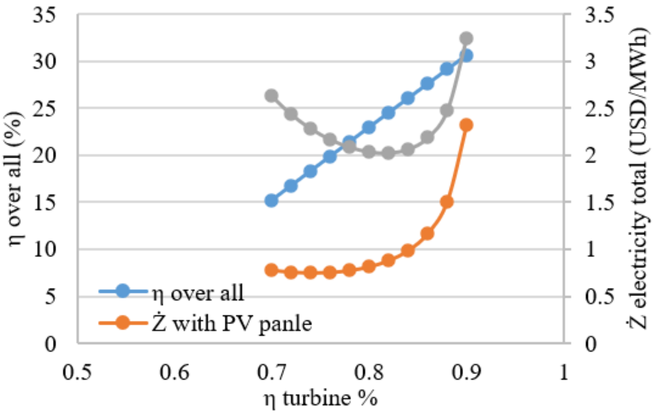

Figure 6. Variation of η energy overall and Ż electricity total with turbine efficiency ratio for with and without PV panel

3.5 Effect the temperature of exhaust

The main role of engine exhaust temperature on the performance of Brayton pulverized coal power systems is its important need when boosting air compressor with photovoltaic panels. Operating temperatures can be an equally unexpected challenge, sometimes causing a reduced cycle thermal efficiency, translated into power output decrease and low energy conversion efficiency. On the one hand, exhaust heat loss could be a challenge as it could result in losing the heat energy that could be reclaimed through heat exchangers. This sort of pressure on air compressor could in the long run cause the compressor to malfunction through negative affect on its working. PV panels allow overcoming these situations generating electricity directly from sunlight, which will give a product a renewable and a clean energy source.

Figure 7 shows the effect of using the PV panel on the total cost as well as the efficiency, as it shows the change in the temperature of exhaust, as the increase in temperature of exhaust increase the efficiency of the cycle in general, as it reached 29%. The temperature of exhaust is 1550°C, as for the total cost, it reached 5.2 USD/MWh at a temperature of exhaust of 1550°C without using a solar panel setup, and when using solar panels, it reached 4.3 USD/MWh at a temperature of exhaust of 1550°C. This shows the benefit of using solar panels in reducing the total cost of the cycle.

When attempting a critical assessment of the results presented in the document, one has to study the consequences of such efficiency raise and cost cutting and come up with responses to possible shortcomings and vagueness of the given data. In particular increased efficiency and reduced costs. The inclusion of PV has led to enhance the systems efficiency and cost reduction of the Brayton cycle system. Higher efficiency of the compressor incorporated with PV panels improves the efficiency of the system. It points that the efficiency of the cycle ranges from about 31% to use solar panels; however, without the use of the solar panels the efficiency is lower. This can be translated to a great decrease in the total cost from 6. From 2 USD/MWh to 1 USD/MWh at the condition of a compressor efficiency of 0.9. Likewise, there is an enhancement of the turbine efficiency when PV is integrated into the system. The use of solar panels in the cycle boosts the efficiency to 32 percent cuts the cost to 3.3 USD/MWh to 2.3 USD/MWh at a turbine efficiency of 0%. 9. This shows that in addition to boosting efficiency, PV panels also considerably reduce the operational expenses. Thus, with increasing the exhaust temperature, the efficiency of the system increases and reaches 29%. It is reduced from to 5.2 USD/MWh to 4. The minimum MOC cost is $3 USD/MWh using the amount of solar panels with an exhaust temperature of 1550°C.

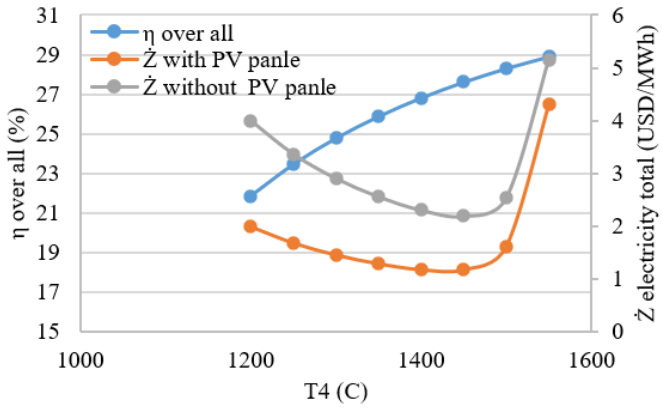

Figure 7. Variation of η energy overall and Ż electricity total with temperature of exhaust for with and without PV panel

It can be noted that the cost has been brought down by half from $5.2 USD to $4. An outcome of 3 USD per MHW is quite tangible and shows that the proposed system is economically feasible. Conversely, this finding goes in line with Ohara, and Lee et al. [23] who showed that gas turbine power plant integration with solar-exhibited cost benefits. Such operational cost reduction can be explained by the reduction in fuel utilization since part of the energy is generated from the solar panels. There is supporting evidence of an increase in thermal efficiency of the combustion process that is evident from the rise in exhaust temperature to 29%. Signs of the high exhaust temperature normally mean that combustion is complete, and fuel is optimized in the cylinder.

The study highlights a reduction in CO_2 emissions by approximately 70,000 tons annually for a 100 MW power plant. Similar environmental benefits were reported by Ho et al. [22], who emphasized the role of solarized S-CO_2 Brayton cycles in minimizing greenhouse gas emissions. When comparing efficiency versus pressure ratio, your study reported a maximum efficiency approximately 9% lower than that of Moreno-Gamboa et al. [26]. This discrepancy may be attributed to differences in modeling methodologies, system design, or working fluids.

Compared with the conventional cycle, the solar-integrated Brayton cycle is economic, which improves energy security and develops renewable facility. Challenges associated with the system are, the capital cost, reliability, availability of space and integrating the technology. Solving these problems, it is necessary to develop more efficient control systems, guarantee the efficiency of energy storage, and provide corresponding policies. Future research should be aimed at adaptation and costs' analysis in order to identify how this approach could be applied on large scale.

3.6 Validation

According to the established definition, a research paper aims to answer a question or solve a problem, giving a detailed analysis. The work begins with the literature review section briefly describing the research problem and its importance. The paper studies the related literature to understand the context and background for the proposed topic. This one specifies how it was done, inclusive of ways data was obtained and ways it was analyzed. The findings' section applies a tabular or graphic format when disseminating the results of the study for the sake of clarity. This is done by carrying out a discussion that analysis the findings and aims at explaining the outcomes, their consequences and its importance. The paper also discusses any possible restrictions encountered in the course of the investigation. Lastly, it develops the main findings and recommends relevant focuses for further research. Stating the facts, all the sources and references are cited to acknowledge the earlier work that contributes to the overall credibility of the paper [26].

Figure 8 compares overall cycle efficiency (%) against the pressure ratio for two studies: Moreno-Gamboa et al. [26] and the present work. Both are represented in blue, with the former peaking at a pressure ratio of 10 and achieving a maximum efficiency of approximately 0.275. The present work, depicted by the orange line, shows its highest efficiency between a pressure ratio of 8 and a maximum of about 0.25. Generally, the efficiency of the present work is roughly 9% lower than that achieved by Moreno-Gamboa et al. [26]. This comparison suggests potential differences in methodology, working fluids, or system design, which could be explored to enhance overall efficiency in future research.

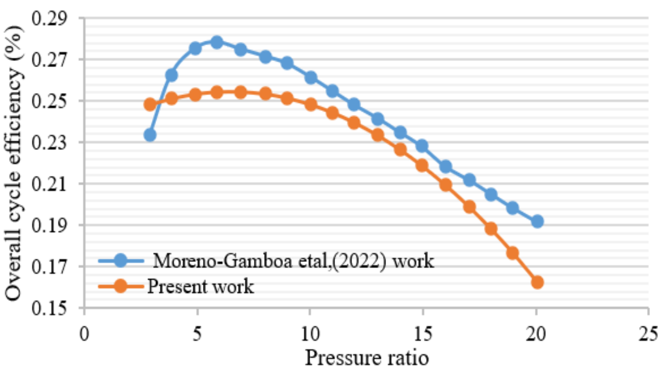

Figure 8. Influence of pressure ratio on overall cycle efficiency

4. CONCLUSIONS

It is the mixture of renewable sources of energy along with traditional energy generation systems that there is no doubt about that will be the future of sustainable energy production. In this research, evaluations of the appropriateness, and efficiency of incorporating solar energy into the power plant of Brayton cycle are carried out using numerical simulations. An integration opportunity for this cycle, which is associated with high efficiency and the correct use of energy sources results in the Brayton cycle. This job the CH_4 cycle explains the processes in a gas turbine, burner and air blower that are referred to gas turbine, burner and air blower.

The results summarized as follows:

1. By applying the model, it is found that in using a PV panel there is 25.6% less cost and efficiency as the temperature rises to 50 degrees Celsius; while in installing solar panels, the total cost of power generates is as low as 1.4 USD/MWh. This clearly indicates the great cost saving in this way.

2. The research proves that the PV panels influence the average cost and efficiency. The improvement in terms of efficiency is up to 28% at the pressure ratio equals 18. The aggregated total cost fell 2.2 USD/MWh from the first value of 3.6 USD/MWh being without panels to 1.6 USD/MWh.

3. The research reveals the cost-effectiveness to a great extent and get the efficiency in compressor up to 31%. The wholesale price dropped from 6.2 USD/MWh to 1 USD/MWh with Solar panels which shows that the prices are heavily discounted.

4. The work highlights the effect of PV panels compared to lower cost and efficiency with addition turbine efficiency bringing down the cycling efficiency by 32%. This total price went down from $3.3/MWh without solar panels to just $2.3/MWh.

5. The research indicators the bearing on the overall cost and efficiency during the cycle in the event that PV panel is used and efficiency in the efficiency stands at 29%. The funds needed fell down from 5.2 USD/MWh without solar panels to 4.3 USD/MWh involving solar.

The study explores the economic and environmental benefits of integrating solar energy into a Brayton cycle power plant. It reveals that the integration of solar panels results in significant cost savings, reducing the overall cost of power generation from $5.2 USD/MWh to $4.3 USD/MWh, and annual net savings of $910,720. Government subsidies further enhance the economic attractiveness, lowering the net annual cost to $7,311,480. The study also highlights the environmental impact of solar integration, reducing CO_2 emissions by approximately 70,000 tons annually for a 100 MW power plant, contributing to climate change mitigation and reducing reliance on fossil fuels. The study concludes that effective system design and optimization are crucial for maximizing benefits.

Potential for future research

•Detailed sensitivity analyses: To advance the knowledge in the future studies, the sensitivity analysis on other facets can be prescribed for improvement of the model and its estimates.

•Experimental validation: That is why, real-world experiments and pilot projects are required to prove the theoretical advantages and fine-tune adoptions.

•Advanced optimization techniques: Applying higher optimization methods may suggest the most suitable configurations for integrating solar, as well as improving the both economic and sustainability aspects.

•Lifecycle assessment: A life cycle assessment would have given more amplified information about this light and shade of integrating solar systems to the Brayton cycle at a later stage.

Further research should be dedicated to experimental implementation of the technology with the help of pilot projects, assessment of the implementation of global integration and the search for the factors of scale economy.

Investigate combined wind, geothermal and hydro renovation arrangements. Research on lightweight materials, robotics, and power sources for optimization. Consider the GA, as the company should initiate lifecycle assessments and consider carbon capture technologies. Examine different policy frameworks, market characteristics to look at, and realistic business models for commercialization.

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