

OPTIMUM PERFORMANCE ENHANCING STRATEGIES OF THE GAS TURBINE BASED ON THE EFFECTIVE TEMPERATURES

Thamir K. Ibrahim^{1,a}, M. M. Rahman², Obed M. Ali², Firdaus Basrawi¹ and Rizalman Mamat²

¹Energy Sustainability Focus Group (ESFoG), Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

²Automotive Focus Group (AUTO), Faculty of Mechanical Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia.

Abstract: Gas turbines (GT) have come to play a significant role in distributed energy systems due to its multi-fuel capability, compact size and low environmental impact and reduced cost. Nevertheless, the low electrical efficiency, typically about 30% (LHV), is an important obstruction to the development of the GT plants. New strategies are designed for the GT plant, to increase the overall performance based on the operational modeling and optimization of GT power plants. The enhancing strategies effect on the GT power plant's performance (with intercooler, two-shaft, reheat and regenerative) based on the real power plant of GT. An analysis based on thermodynamics has been carried out on the modifications of the cycle configurations' enhancements. Then, the results showed the effect of the ambient and turbine inlet temperatures on the performance of the GT plants to select an optimum strategy for the GT. The performance model code to compare the strategies of the GT plants were developed utilizing the MATLAB software. The results show that, the best thermal efficiency occurs in the intercooler-regenerative-reheated GT strategy (IRHGT); it decreased from 51.5 to 48%, when the ambient temperature increased (from 273 to 327K). Furthermore, the thermal efficiency of the GT for the strategies without the regenerative increased (about 3.3%), while thermal efficiency for the strategies with regenerative increased (about 22%) with increased of the turbine inlet temperature. The lower thermal efficiency occurs in the IHGT strategy, while the higher thermal efficiency occurs in the IRHGT strategy. However, the power output variation is more significant at a higher value of the turbine inlet temperature. The simulation model gives a consistent result compared with Baiji GT plant. The extensive modeling performed in this study reveals that; the ambient temperature and turbine inlet temperature are strongly influenced on the performance of GT plant.

1 Introduction

The GT system had been used for many years to get maximum potential from different utilities [1]. Now many developments and modifications have been made on it which has fostered the power generation output and increased the efficiency of the thermal power plants. The modification of the GT was started in 1930s, with the core purpose of propulsion for the jet aircraft. However, the sufficient development in the efficiency and productivity of the GT plants was started after 1980s as a mean of developing high power stationary programs [2]. The size of the gas power generator plant is ranging from 30kW to 350kW [3]. The performance of the GT plant is established by the condition of the ambient, which varies from time to time [4]. Hot ambient creates low pressure and low air mass flow which leads to low air density, compression ratio and energy output. This low pressure also reduces the

performance of the GT. So, it is right to say that the reduction in the energy output and the increase in the fuel consumption are caused by increasing ambient temperature [5]. All those factors which can reduce the performance of the GT are humidity, air pressure and temperature [6]. The reduction in the performance of the GT in hot days reflects following results:

- i. Decrease of the humidity of the air.
- ii. Decrease in the circulation amount of the air.
- iii. Decrease in the compression ratio.
- iv. Reduction of the power output which is caused by the low compression and mass flow rate.
- v. Increase of the fuel consumption.
- vi. Reduction of the thermal efficiency caused by all above mentioned conditions.

The increase of the ambient temperature in the GT reduces the air pressure and increases the air

^a Corresponding author: thamirmathcad@yahoo.com

temperature [7]. There many researches have been conducted on this matter which confirms that the overall performance of the GT is depending upon the air temperature [8, 9]. Erdem and Sevilgen [10] revealed that the monthly reduction in power which is 1.7 to 7.2 %, triggered by the ambient temperature. Because of the high ambient temperatures, decrease in electricity generation is noticed and this causes the increase in fuel consumption [11]. The power generated is raised from about 0.40 to 7.5% in the result of decreased surrounding temperature up to 10 °C [10].

The thermal efficiency of GT plant was continuously being developed for the previous 70 years by increasing the turbine inlet temperature. This increase was adopted by enhancing the technology of materials involved and different cooling methodologies of the blades [12]. The enhanced version was utilized of steam air cooling of metallic blades in CCGT power plants having the efficiency of about 60% [13]. Turbine inlet temperature was increased up to 1800 K for the advancement of huge GT plants [14]. Utilization of ceramics material in blades manufacturing and difficult cooling ways in small GT plants are in practice. The huge power generation from the plants is only because of the high turbine inlet temperatures [15]. The thermodynamic model has been suggested by Kurt et al. [16], the model measured the performance of the ideal open GT cycle. During the open GT cycle, the effect of parameters has been investigated, such as ambient temperature, compression ratio and turbine inlet temperature. Furthermore, it has been assumed that such factors must be constant, like an isentropic compressor and turbine efficiency, combustion efficiency and low heat value. The inductor of the performance of the GT cycle has been the fuel consumption, power output and thermal efficiency [17]. It has been observed that the optimum thermal efficiency and power output happens at low ambient temperature and high turbine inlet temperature.

The parametric analysis of GT based on parameters of ambient temperature, turbine inlet temperature and comparative humidity performance and the six different shapes of GT were presented by Bassily [18]. The study based on the results of optimal increases of compression ratio about 1.5 with increase in temperature of inlet turbine to 100K. Bassily [19], stimulation model based on the study of various parameters like the compression ratio, ambient temperature, turbine inlet temperature, the effectiveness of the regenerated heat exchanger and ambient relative humidity which is used to evaluate the performance of all types of GT. The increase in the resultant capacity of the regenerative heat exchanger is directly proportional to the turbine inlet temperature. Thermal efficiency of GT cycle depends upon the increase the effectiveness of regenerated heat exchanger. The performance of simple GT cycle, number of advance GT cycles and equivalent CCGT

cycles are extracted from optimum efficiencies and work out puts used in thermodynamic analysis by Ilett and Lawn [20]. However, it is found that performance of advanced CCGT cycles is comparatively better than the performance of simple GT cycle. Consequently, a parametric study on the effect of the operating temperatures requires managing the temperatures of the system. Thus, the aim of the present work is to develop a strategy to determine the performance of the GT power plant utilizing the effect of ambient temperature and turbine inlet temperature.

2 Modelling of complex gas turbine

By proposing an integrated strategy inclusive if all enhancing elements (modification), this thesis has in essence made a significant contribution with regards to the improvement of GT plants' performance. For the effect of turbine inlet temperature and ambient temperature on performance of a gas turbine whilst utilizing all enhancing elements like reheating, intercooler, regenerative and two-shaft, these strategies offer optimization tools and incorporated simulation. Different configuration of enhancing elements is utilized for demonstrating the influence on the total performance of a GT plant taking into account turbine inlet temperature and ambient temperature. This is the main purpose of using these strategies. The results of the performance enhancing strategies (PES) are then used for validating the data of a real GT performance.

2.1 Simple gas turbine cycle

Figure 1 shows the schematic diagram for a simple GT [20]. The compressors draw the air that is subsequently transmitted to the combustion chamber. A combustion process is utilized for increasing the temperature of compressed air through the use of natural gas fuel. The turbine is expanded by hot gases emitting from the combustion chamber. Work is hence produced before being discharged into the atmosphere (refer to 1,2,3 and 4 in Figure 2) [21]. For the success of a GT power plant, efficient compression of large air volume is vital [22]. The axial flow compressor and the centrifugal compressor are the two main kinds of compressors. In order to obtain adequate air through the diameter of the compressor, most of the power plants have design compressors. This has the ability to retain comparatively high efficiency and aerodynamic stability over the operating range together with minimum stages [23].

Equation (1) shows the calculation for the net work of the gas turbine (WGnet):

$$W_{Gnet} = C_{pg} \times TIT \times \eta_t \left(1 - \frac{1}{r_p^{\frac{\gamma_g-1}{\gamma_g}}} \right) - C_{pa} \times T_1 \left(\frac{r_p^{\frac{\gamma_a-1}{\gamma_a}}}{\eta_m \eta_c} \right) \quad (1)$$

Where (r_p) defines the compressor compression ratio [14], From figure (2) T_{2s} and T_{4s} denotes isentropic temperatures of outlet compressor and outlet turbine respectively, whereas compressor inlet and outlet air temperature are expressed by T_1 and T_2 respectively, $\gamma_a = 1.4$ and $\gamma_g = 1.33$, η_m is the mechanical efficiency of the compressor and turbine while C_{pa} is the specific heat of air which can be fitted by Eq. (2) for the range of $200K < T < 800K$ [24]:

$$C_{pa} = 1.0189 \times 10^3 - 0.13784 T_a + 1.9843 \times 10^{-4} T_a^2 + 4.2399 \times 10^{-7} T_a^3 - 3.7632 \times 10^{-10} T_a^4 \quad (2)$$

where $T_a = \frac{T_2 + T_1}{2}$ in Kelvin.

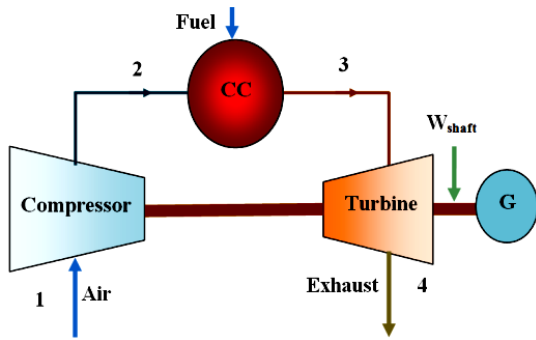


Figure 1. Schematic diagram for simple GT cycle

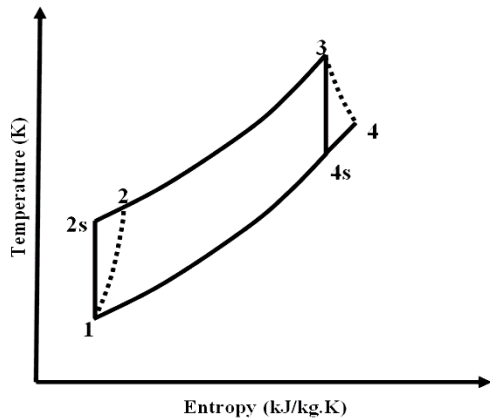


Figure 2. Temperature-entropy diagram for simple GT cycle Equation (3) demonstrates specific heat of flue gas (C_{pg}) [24].

$$C_{pg} = 1.8083 - 2.3127 \times 10^{-3} T + 4.045 \times 10^{-6} T^2 - 1.7363 \times 10^{-9} T^3 \quad (3)$$

Equation (4) expresses the energy balance in the combustion chamber:

$$\dot{m}_a C_{pa} T_2 + \dot{m}_f \times LHV + \dot{m}_f C_{pf} T_f = (\dot{m}_a + \dot{m}_f) C_{pg} \times TIT \quad (4)$$

where LHV is low heating value, C_{pf} is specific heat of fuel, \dot{m}_a is air mass flow rate (kg/s), T_f is temperature of fuel, \dot{m}_f is fuel mass flow rate (kg/s) and $T_3 = TIT =$ turbine inlet temperature.

Equation (5) expresses the net power output of the turbine (P):

$$P = \dot{m}_g \times W_{Gnet} \quad (5)$$

where the mass flow rate of the exhaust gases through the gas turbine is denoted by \dot{m}_g and Eq. (6) demonstrates this:

$$\dot{m}_g = \dot{m}_a + \dot{m}_f \quad (6)$$

Equation (7) below is used for determining the specific fuel consumption (SFC):

$$SFC = \frac{3600 f}{W_{net}} \quad (7)$$

Equation (8) is another way of expressing the heat supplied:

$$Q_{add} = C_{pgm} \times \left[TIT - T_1 \times \left(1 + \frac{r_p^{\frac{\gamma_a-1}{\gamma_a}} - 1}{\eta_c} \right) \right] \quad (8)$$

Equation (9) can now be used for calculating the GT thermal efficiency (η_{th}) [25]:

$$\eta_{th} = \frac{W_{Gnet}}{Q_{add}} \quad (9)$$

2.2 Intercooler-two shaft gas turbine

The work down for intercooler-two-shaft GT cycle (ITGT) is as shown Figure 3a:

$$W_{Gnet} = C_{pg} (T_6 - T_7) \quad (10)$$

Equation (11) expresses the heat supplied for intercooler-two-shaft GT cycle (ITGT):

$$Q_{add} = C_{pg} \left[TIT - T_1 \times \left(1 + (2-x) \left(\frac{r_p^{\frac{\gamma_a-1}{\gamma_a}} - 1}{\eta_c} \right) + (1-x) \left(\frac{r_p^{\frac{\gamma_a-1}{\gamma_a}} - 1}{\eta_c} \right) \right) \right] \quad (11)$$

2.3 Regenerative-two shafts gas turbine

From Figure 3b the Eq. (12) expresses the work net of the regenerative two-shaft GT cycle (RTGT):

$$W_{Gnet} = C_{pg} (T_5 - T_6) \quad (12)$$

Equation (13) expresses the heat supplied for the RTGT:

$$Q_{add} = C_{pg} (TIT - T_3) \quad (13)$$

2.4 Intercooler-regenerative gas turbine

From Figure 3c the Eq. (14) expresses the work net of the intercooler-regenerative GT cycle (IRGT):

$$W_{Gnet} = C_{pg} (TIT - T_7) \quad (14)$$

Equation (15) expresses the heat supplied for the IRGT cycle:

$$Q_{add} = C_{pg}(TIT - T_5) \quad (15)$$

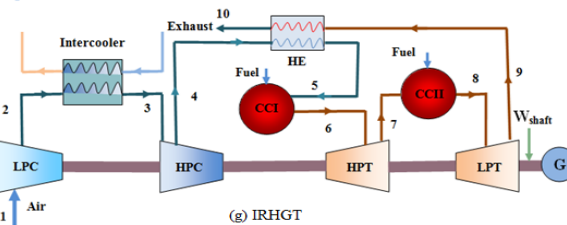
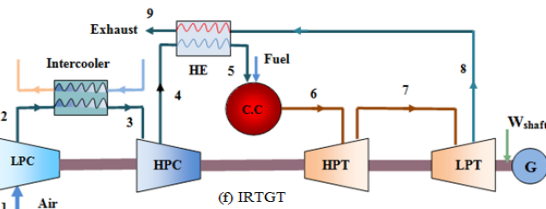
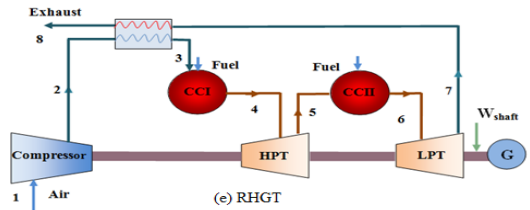
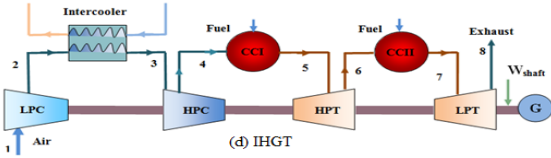
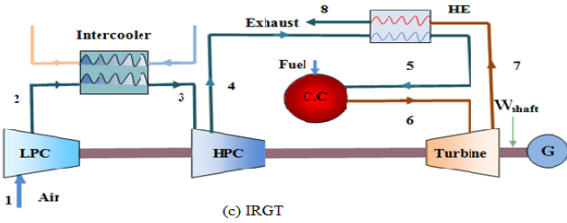
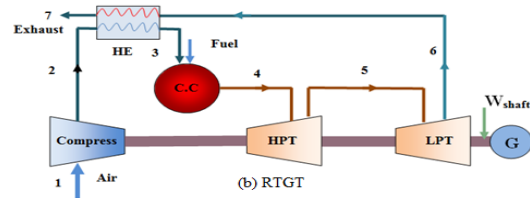
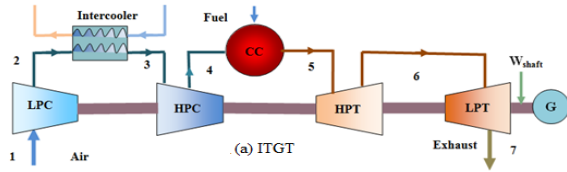


Figure 3. Configurations of the GT performance enhancing strategies.

2.5 Intercooler-reheat gas turbine

From the energy balance for Figure 3d the Eq. (16) expresses the work net of the intercooler-reheat GT cycle (IHGT):

$$W_{Gnet} = C_{pg}(TIT - T_8) \quad (16)$$

Equation (17) expresses the heat supplied for the IHGT cycle;

$$Q_{add} = C_{pg}(TIT - T_4) + \frac{C_{pg}(\dot{m}_a + \dot{m}_f + \dot{m}_{fad})}{(\dot{m}_a + \dot{m}_f)}(TIT - T_6) \quad (17)$$

where the Eq. 18 expresses the additional fuel burning the second combustion chamber and is equal to \dot{m}_{fad} .

$$\dot{m}_{fad} = \frac{C_{pg}(\dot{m}_a + \dot{m}_f)(TIT - T_6)}{(LHV \times \eta_{comb} - C_{pg}TIT)} \quad (18)$$

2.6 Regenerative-reheat gas turbine

From the energy balance for Figure 3e the Eq. (19) expresses the net work of the regenerative-reheat GT cycle (RHGT):

$$W_{Gnet} = C_{pg}(TIT - T_7) \quad (19)$$

Equation (20) expresses the heat added for the RHGT cycle:

$$Q_{add} = C_{pg}(TIT - T_3) + C_{pg}(TIT - T_5) \quad (20)$$

2.7 Intercooler-regenerative-two-shaft gas turbine

From the energy balance for Figure 3f the Eq. (21) expresses the net work of the intercooler- regenerative-two-shaft GT cycle (IRTGT):

$$W_{Gnet} = C_{pg}(T_7 - T_8) \quad (21)$$

Equation (22) expresses the heat added for the IRTGT cycle:

$$Q_{add} = C_{pg}(TIT - T_5) \quad (22)$$

2.8 Intercooler-regenerative-reheat gas turbine

From the energy balance for Figure 3g the Eq. (23) expresses the net work of the intercooler- regenerative-reheat GT cycle (IRHGT):

$$W_{Gnet} = C_{pg}(T_8 - T_9) \quad (23)$$

Equation (24) expresses the heat added for the IRHGT cycle:

$$Q_{add} = C_{pg}(TIT - T_5) + C_{pg}(TIT - T_7) \quad (24)$$

3 Results and discussion

The parameter influence in terms of ambient temperature and turbine inlet temperature on the performance of the GT cycle power plant for different performance enhancing strategies is presented in this section. The effects of these parameters on the power output, specific fuel consumption and thermal efficiency are obtained by applying the energy-balance utilizing MATLAB software.

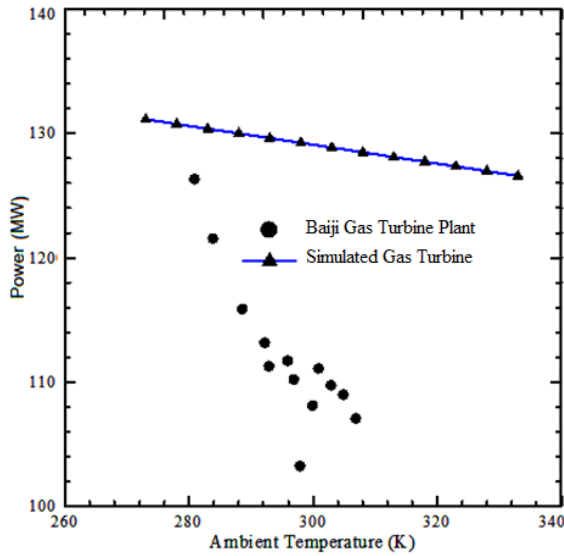


Figure 4. Comparison between simulated power outputs versus real results from Baiji gas turbine power plant.

Figure 4 shows the comparison between the simulated power outputs and the real results obtained from Baiji GT power plant. The increase in the power consumption in the compressor with increased ambient temperatures leads to a decrease in the power output of the GT plant. This results in the decrease of the thermal efficiency and power output. As compared to the real data from Baiji GT power plant, the simulated output power is higher. This is because of an incomplete combustion caused by the usage of fuel oil instead of natural gas in the Baiji plant. The effect of the ambient temperature on the exhaust temperature of the GT for different performance enhancing strategies is shown in

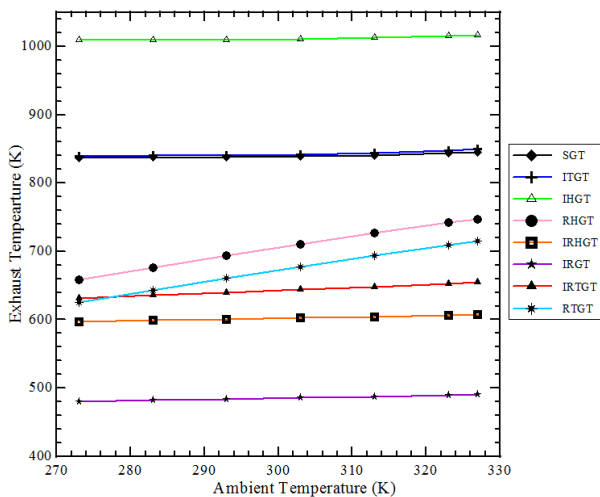


Figure 5. Effect of ambient temperature on the exhaust temperature of the gas-turbine plants.

Figure 5. The exhaust temperature increased gradually from 10 to 20K for all the GT strategies, when the ambient temperature increased from 273 to 327K. While in the RHGT and RTGT strategy the exhaust temperature increased about 85K, when the ambient

temperature increased from 237 to 327K. In the IRGT strategy of the GT plant, the lowest exhaust temperature obtained was 481K. Under the effect of the ambient temperature, the higher exhaust temperature was about 1017 K in the IHGT strategy of the GT. Since the high ambient temperature leads to increase the work of the compressor, then decreased the work net thus increased the losses with exhaust gases [16, 26]. At the same time, at the high ambient temperatures, the variations in the exhaust temperature of the GT were significant.

The variation in thermal efficiency with ambient temperature for all performance enhancing strategies of the GT at a compression ratio of 12, a constant turbine inlet temperature of 1450 K and an ambient relative humidity of 60% and are shown in Figure 6. The losses in the thermal efficiency due to use all performance enhancing strategies of the GT increases as the ambient temperature increases. This is owing to the decrease in the net power output and an increase in the work of the compressor [27, 28]. It further increased the losses of the exhaust gases with the increase in the ambient temperatures, which led to a reduction in the thermal efficiency of GT. This is shown by Figure 5. The lowest efficiency occurs in the IHGT strategy, while the highest thermal efficiency occurs at IRHGT strategy. The maximum reduction in the thermal efficiency was occurred in the RTGT strategy, from 48.5 to 41.7% when the ambient temperature increased from 273 to 327K.

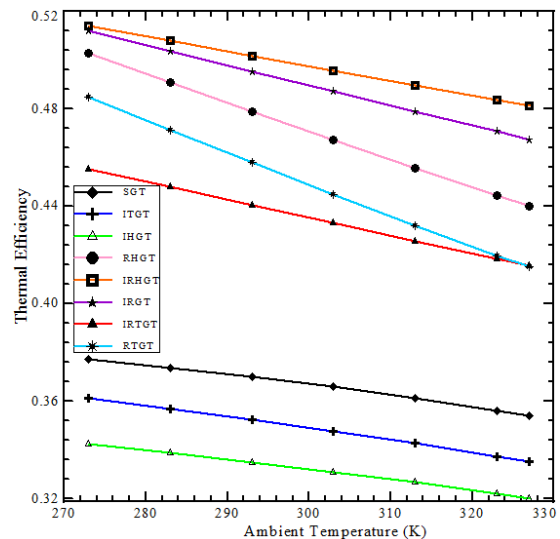


Figure 6. Effect of ambient temperature on the thermal efficiency of the gas-turbine plants.

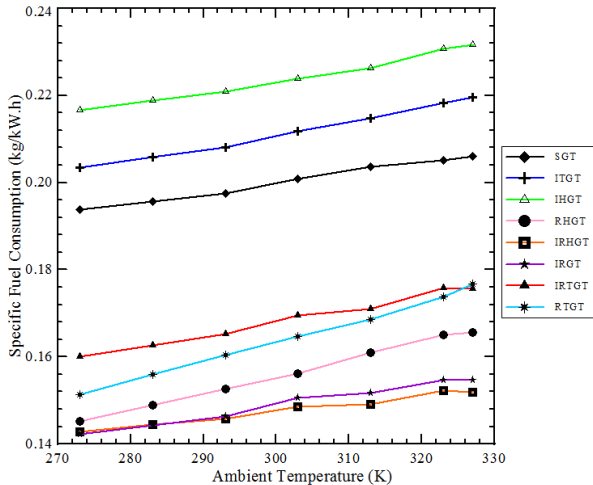


Figure 7. Effect of ambient temperature on the Specific fuel consumption of the gas-turbine plants.

The variation of the specific fuel consumption with the effect of the ambient temperature for various performance enhancing strategies of the GT is shown in Figure 7. Figure 7 demonstrate that the increase in the ambient temperatures led to an increase in the specific fuel consumption. The specific fuel consumption increased about 0.01 to 0.028kg/kWh, when the ambient temperature increased from 273 to 327K. The reason behind the usage of more fuel to reparation the power that consumption in the air compressor of the GT. When the ambient temperature increased to 327K, the higher specific fuel consumption (0.234kg/kWh) occurred at the IRHGT strategy. In the IHGT strategy, the lower fuel consumption occurs and is increasing from 0.142 to 0.151kg/kWh when the ambient temperature increased from 273 to 327K. The variation of the power output with effect of the ambient temperature for different performance enhancing strategies of the GT plants is shown in Figure 8. There is a reduction in the energy losses for all the performance enhancing strategies of the GT with the increase in the ambient temperature. This is owing to the increase in the compressor work and a decrease in the net power output [29]. In addition, the losses increased with an increase in the exhaust temperature which eventually led to a decrease in the power output [28]. A drop in the mass flow rate of the air enters to the GT occurs due to the decrease in the density of the inlet air to the compressor [29]. At the same time, there are decreases in the power output due to the increase in the work required to compress the hot air in the compressor of the GT [30]. When the temperature of the air falls, there is an opposite effect [31]. The higher power output occurred in the IHGT strategy, which was decreased from 248 to 242 MW. The lower power output was obtained in the IRGT strategy. When the ambient temperatures were increased from 273 to 327K, the power output was reduced from 159 to 151MW. A positive effect is obtained generally by increasing the turbine inlet temperatures in all the GT performance parameters. This behaviour is more

prominent at the higher turbine inlet temperature due to the least importance given to the component losses [32].

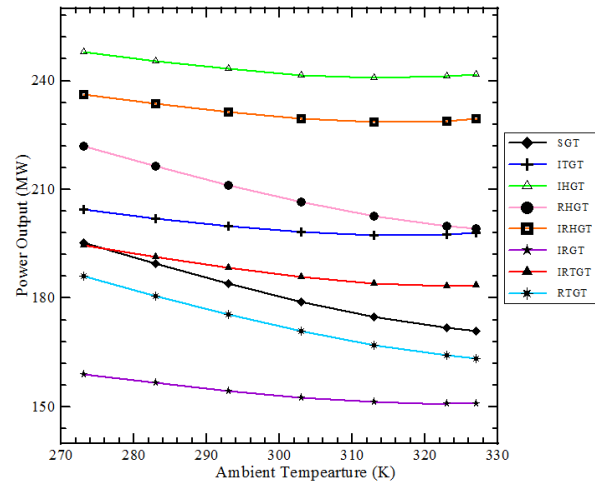


Figure 8. Effect of ambient temperature on the power output of the gas-turbine plants.

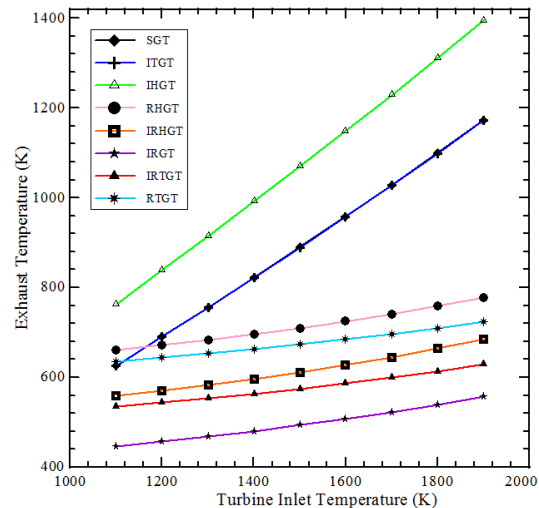


Figure 9. Effect of the turbine inlet temperature on the exhaust temperature of the gas-turbine plants.

The variation of the exhaust temperature of the GT with effect of the turbine inlet temperature for different performance enhancing strategies is shown in Figure 9. Generally, with an increase in the turbine inlet temperature, there was an increase in the exhaust temperature. A high increase is in the exhaust temperature is evident after an increase in the inlet temperature for all the strategies of the GT plant. In all the strategies that were not based on the regenerative (STG, ITGT and IHGT), there is an increase in the turbine inlet temperatures with an increase in the exhaust temperatures reaching to about 680K. On the contrary, in strategies that were based on the regenerative strategies (RHGT, IRHGT, IRGT, IRTGT and RTGT), the increase in the turbine inlet temperature led to a gradual increase of the exhaust temperatures reaching to about 120K. The lowest exhaust temperatures seem to occur in the IRGT strategy, while

the highest exhaust temperatures occurred in the IHGT strategy. At the higher inlet temperature, the deviation in the exhaust temperatures is significant.

The variation in thermal efficiency with the turbine inlet temperature for different performance enhancing strategies of the GT at an ambient relative humidity of 60%, constant compression ratio of 12 and an ambient temperature of 288 K are shown in Figure 10. The heat supply to the GT increases with the increase in the turbine inlet temperatures [18, 19]. Therefore, for all the performance enhancing strategies of the GT plant, there is an increase in the thermal efficiency. It is evident that with an increase in the turbine inlet temperature, there was a gradual increase in the thermal efficiency of about 3.3% for the GT for all the strategies that were not based on the regenerative model (STG, ITGT and IHGT). On the other hand, there was a sharp rise in the thermal efficiency of 22% for the GT of the strategies based on the regenerative with an increase in the turbine inlet temperature. The higher thermal efficiency occurred in the IRHGT strategy, while the lowest thermal efficiency occurred in the IHGT strategy.

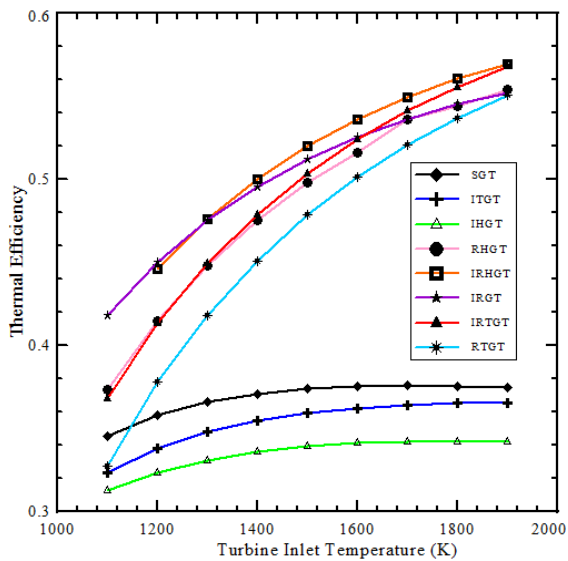


Figure 10. Effect of the turbine inlet temperature on the thermal efficiency of the gas-turbine plants.

The variation of the specific fuel consumption for different performance enhancing strategies of the GT with effect of the turbine inlet temperature was shown in Figure 11. When the turbine inlet temperature increased at a fixed value of air mass flow rate at 500.4kg/s and compression ratio at 12, there was a decrease in the specific fuel consumption for all the strategies of the GT plant. As the turbine inlet temperatures increased, there was a gradual decrease in the specific fuel consumption by 0.016kg/kWh for all the strategies without regenerative (STG, ITGT and IHGT). There is a reduction in the specific fuel consumption of the GT for these strategies by 0.076kg/kWh at a steeper slope with an increase in the

turbine inlet temperature for all the strategies based on the regenerative (RHGT, IRHGT, IRGT, IRTGT and RTGT). This was owing to the reduction in the burnt fuel due to the use of the exhaust gases to warm the air entering the combustion chamber in the regenerative [23]. The lowest specific fuel consumption happens in the IRHGT strategy, while the highest specific fuel consumption occurred in the IHGT strategy.

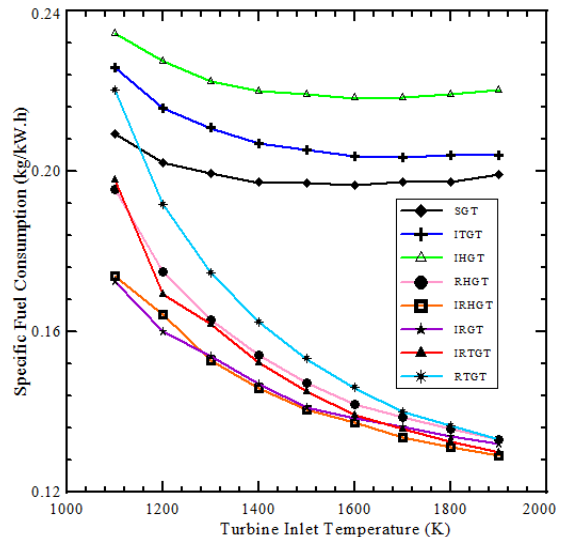


Figure 11. Effect of the turbine inlet temperature on the specific fuel consumption of the gas-turbine plants

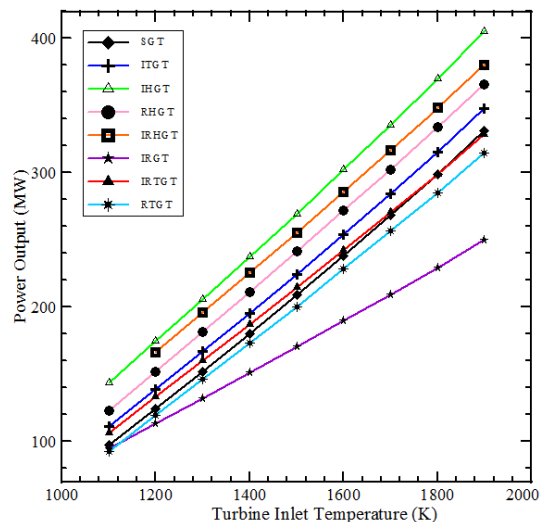


Figure 12. Effect of the turbine inlet temperature on the power output of the gas-turbine plants.

Figure 12 shows the variation in the power output in terms of the turbine inlet temperature for the various performance enhancing strategies of the GT plant. The increase in the turbine inlet temperature leads to a linear increase in the power output. Therefore, a significant enhancement in the power output for all the strategies may be expected with an increase in the turbine inlet temperature. The average temperatures at which the heat is supplied increases with the increase in the turbine

inlet temperature, which eventually leads to an increase in the power output [19]. However, at the higher value of the turbine inlet temperature, there is a noticeable variation in the power output. When the turbine inlet temperatures are increased from 1100 to 1900K, the highest power output of IHGT is obtained. In the case of the IRGT strategy, the highest power output occurs from 96 to 264 MW when the turbine inlet temperatures are increased from 1100 to 1900K. As a result, at the higher turbine inlet temperature of the GT plants, the power output is significant. These results were in agreement with the results of the studies previously conducted by Polyzakis, et. al., [32].

4 Conclusions

Thermal analysis of the GT plant along with the configurations is performed, so that better strategies can be presented. The assessment of the impact of turbine inlet and ambient temperature is done. The development of performance model code took place for the development of the GT plant. For creation of the most favourable strategy for the GT, the effectual parameters have been proposed. The parameters include turbine inlet temperature, and ambient temperature. In the presence of IHGT strategy a power output of 404 MW is produced, which is the highest. When intercooler-regenerative-reheated GT strategy (IRHGT) is applied then we observe best thermal efficiency i.e. of 57%. If comparison is made between Baiji GT plant and simulation model, then simulation model is found to be on an upper hand. It has been revealed by extensive modelling that these effective parameters affect the presentation of the GT plant.

Acknowledgement

The authors would like to thank Universiti Malaysia Pahang for providing laboratory facilities and financial.

References

- Ghazikhani, M., Passandideh-Fard, M. and Mousavi, M., Two new high-performance cycles for gas turbine with air bottoming. *Energy*, 2011, 36(1), 294-304.
- Avval, H. B., Ahmadi, P., Ghaffarizadeh, A. R. and Saidi, M. H., Thermo-economic-environmental multiobjective optimization of a gas turbine power plant with preheater using evolutionary algorithm. *International Journal of Energy Research*, 2011, 35(5), 389-403.
- Dries V. and Carlos B., Impact of heat transfer on the performance of micro gas turbines. *Applied Energy*, 2015, 138, 445-449
- Tarek N., Performance characterization of different configurations of gas turbine engines. *Propulsion and Power Research*, 2013, 3(3), 121-132.
- Ameri, M., Hejazi, S. H. and Montaser, K., Performance and economic of the thermal energy storage systems to enhance the peaking capacity of the gas turbines. *Applied Thermal Engineering*, 2005, 25(2-3), 241-251.
- Rahman, M. M., Thamir, K. Ibrahim. Kadirgama, K., Mamat, R., Bakar, R. A., Influence of operation conditions and ambient temperature on performance of gas turbine power plant, *Adv. Mater. Res.*, 2011, 189-193, 3007-3013.
- Rahman, M. M., Ibrahim, T. K., Abdalla, A. N., Thermodynamic performance analysis of gas-turbine power-plant. *International Journal of the Physical Sciences*, 2011, 6(14), 3539-3550.
- Najjar, Y. S. H., Comparison of performance for cogeneration systems using single- or twin-shaft gas turbine engines. *Applied Thermal Engineering*, 1997, 17(2), 113-124.
- Thamir K. Ibrahim and Rahman M. M. , (2014). Effective Parameters on Performance of Multipressure Combined Cycle Power Plants. *Advances in Mechanical Engineering Volume 2014* , Article ID 781503, 14 pages.
- Erdem, H.H. and S.H. Sevilgen. Case study: Effect of ambient temperature on the electricity production and fuel consumption of a simple cycle gas turbine in Turkey. *Applied Thermal Engineering*, 2006, 26(2-3), 320-326.
- Coogan, S., Brun, K. and Teraji, D., Micromix Combustor for High Temperature Hybrid Gas Turbine Concentrated Solar Power Systems. *Energy Procedia*, 2014, 49, 1298-1307.
- Hongguang, J., Hui, H. and Ruixian, C., A chemically intercooled gas turbine cycle for recovery of low-temperature thermal energy. *Energy*, 2006, 31(10-11), 1554-1566.
- Thamir K. Ibrahim and Rahman M.M., Effect of the Compression Ratio on the performance of different strategies of the Gas Turbine. *International Journal of Automotive and Mechanical Engineering*, 2014A, 9, 1747-1757.
- Cengel Y. A. and Michael A. *Thermodynamics an engineering approach*, McGraw-Hill Science/Engineering/Math; 8 edition, New York 2015.
- Dellenback, P. A., Improved gas turbine efficiency through alternative regenerator configuration. *ASME, Journal of Engineering for Gas Turbines and Power*, 2002, 124(6), 441-446.
- Kurt, H., Recebli Z. and Gedik, E., Performance analysis of open cycle gas turbines. *International Journal of Energy Research*, 2009, 33(3), 285-294.
- Thamir K. Ibrahim, Rahman, M. M., Abdalla, A. N., Study on the effective parameter of gas turbine model with intercooled compression process.

- Scientific Research and Essays, 2010, 5(23), 3760-3770.
18. Bassily, A.M., Performance improvements of the intercooled reheat regenerative gas turbine cycles using indirect evaporative cooling of the inlet air and evaporative cooling of the compressor discharge. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, 2001, 215(5), 545-557.
 19. Bassily, A. M., Performance improvements of the intercooled reheat recuperated gas-turbine cycle using absorption inlet-cooling and evaporative after-cooling. *Applied Energy*, 2004, 77(3), 249-272.
 20. Ilett, T. and Lawn. C.J., Thermodynamic and economic analysis of advanced and externally fired gas turbine cycles. *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy*, 2010, 224(7), 901-915.
 21. Mahmood, F. G. and Mahdi, D. D., A New Approach for Enhancing Performance Of A Gas Turbine (Case Study: Khangiran Refinery). *Applied Energy*, 2009, 86(12), 2750–2759.
 22. Rahman, M. M., Thamir, K. Ibrahim, Taib, M. Y., Noor, M. M., Kadrigama, K. and Rosli, A. Bakar, Thermal analysis of open-cycle regenerator gas-turbine power-plants, *World Academy of Science, Engineering and Technology Journal*, 2010, 68, 94-99.
 23. Basha, M., Shaahid, S. M. and Al-Hadhrami, L., Impact of Fuels on Performance and Efficiency of Gas Turbine Power Plants. *Energy Procedia*, 2012, 14, 558-565.
 24. Thamir, K. Ibrahim, Rahman, M. M., Abdalla, A. N., Optimum Gas Turbine Configuration for Improving the Performance of Combined Cycle Power Plant, *Procedia Engineering*, 2011, 15, 4216 – 4223.
 25. Chandraa, H., Aroraa, A., Kaushik, S.C., Tripathi, A. and Rai, A., Thermodynamic analysis and parametric study of an intercooled–reheat closed-cycle gas turbine on the basis of a new isentropic exponent. *International Journal of Sustainable Energy*, 2011, 30(2), 82–97.
 26. Graus, W. and E. Worrel. 2009. Trend in efficiency and capacity of fossil fuel power generation in the EU. *Energy Policy*, 37(9): 2147-2160.
 27. Nishida, K., Takagi, T. and Kinoshita, S., Regenerative steam-injection gas-turbine systems. *Applied Energy*, 2005, 81(3), 231-246.
 28. Thamir K. Ibrahim, and Rahman M.M., Effect of the isentropic efficiency and enhancing strategies on the performance of gas turbine. *Journal of Mechanical Engineering and Sciences*, 2013, 4, 383-396.
 29. Yang, W., Reduction of specific fuel consumption in gas turbine power plants. *Energy Conversion and Management*, 1997, 38(10–13), 1219-1224.
 30. De Sa, A. and Al Zubaidy, S., Gas turbine performance at varying ambient temperature. *Applied Thermal Engineering*, 2011, 31(14–15), 2735-2739.
 31. Bannai, M., Houkabe, A., Furukawa, M., Kashiwagi, T., Akisawa, A., Yoshida, T. and Yamada, H., Development of efficiency-enhanced cogeneration system utilizing high-temperature exhaust-gas from a regenerative thermal oxidizer for waste volatile-organic-compound gases. *Applied Energy*, 2006, 83(9), 929-942.
 32. Polyzakis, A. L., Koroneos, C. and Xydis, G., Optimum gas turbine cycle for combined cycle power plant. *Energy Conversion Management*, 2008, 49(4), 551-563.