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Original research article

The Effect of Ambient Temperature on Electric Power Generation in Natural Gas Combined Cycle Power Plant: A Case Study

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Abstract: Natural gas combined cycle power plants (CCPPs) are widely used to meet peak loads in electric energy production. Continuous monitoring of the output electrical power of CCPPs is a requirement for power performance. In this study, the role of ambient temperature change having the greatest effect on electric production is investigated for a natural gas CCPP. The plant has generated electricity for fourteen years and setup at 240 MW in Aliağa, İzmir, Turkey. Depending on the seasonal temperature changes, the study data were obtained from each gas turbine (GT), steam turbine (ST) and combined cycle blocks (CCBs) in the ambient temperature range of 8-23°C. It has been found that decreases of the electric energy in the GTs because of the temperature increase and indirectly diminishes of the electricity production in the STs. As a result, the efficiency of each GT, ST and CCB reduced, although the quantity of fuel consumed by the controllers in the plant was decreased. As a result of this data, it has been recommended and applied that additional precautions have been taken for the power plant to bring the air entering the combustion chamber to ideal conditions and necessary air cooling systems have been installed.

Keywords: energy efficiency; combined cycle power plant; energy losses

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1. Introduction

Energy founds in various forms such as heat, light, electricity, kinetic and potential in the environment. Today, energy is among the indispensables of mankind. Among the energy types, electricity energy is used often because it can be easily converted into other energy resources. While fossil fuels such as petroleum, natural gas and coal are used for the production of electricity, renewable energy resources such as wind, sun and geothermal also are used much more recently.

Electric power generated by using fossil fuels is employed in conventional power plants. Thermal power plants, natural gas and nuclear power plants are among these traditional power generation plants. These plants account for about 80% of electricity energy production in the world [1]. This amount is quite high [2]. When energy expenditures and energy policies are considered in the world, it is not expected that this amount would fall in the future at a great rate. Because the unit production cost of renewable energy resources is still higher than the ones using traditional energy resources [3]. When the studies are examined, researches are conducted in that these plants are modernized and are made less harmful to the environment [4-7]. Since these power plants are highly powerful, the smallest improvement proves to achieve a power level of MWs [8].

Conventional electric energy production plants have advantages such as higher power generation, being able to be installed close to energy resources, being able performed to meet peak

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loads when required, and being easier to access their technology [9]. However, the fact that the gases emitted from these power plants cause damage to the environment and cause acid rain, also has the disadvantages such as throwing away the water used in the power plant without cleaning it [10]. But these disadvantages can be minimized by taking effective measures [7].

In conventional electric power generation plants, both gas turbines (GT) and steam turbines (ST) are used. There are also natural gas combined cycle power plants (CCPPs) that use these two types of turbines together [11] and have recently received great attention due to their efficiency [12]. Bronton Cycle in GTs of CCPPs and Rankine Cycle in STs are used [13, 14]. Therefore, CCPPs provide lower environmental gas emissions, higher thermal efficiency and flexibility than other conventional power plants [15].

Monitoring of electric energy production since the installation of natural gas CCPPs is important for ensuring continuity of installed power efficiency [16, 17]. Moreover, their thermodynamic modeling and continuous analysis of all hardware is an important measure to keep the yield value high [18-20]. Considering all these facts, various studies have been carried out in the literature in order to increase the yields for natural gas CCPPs, to improve the working conditions of CCPP by performing energy and exergy analyzes and to minimize the harmful effects on environment.

Almutairi et al. [21] The energetic and exergetic analyzes of a 2 GW CCPP operating at a yield of 54.5% on regional conditions have been carried out in their study. They argued that low-temperature heat source technologies would increase plant performance without additional fuel entry. Ameri et al. [22] they have conducted analyzes of a 420 MW CCPP. In their work, Neka calculated the assesment of the irreversibility of each part of the CCPP. Within all the energy losses, the fuel chamber has shown that it generates 83% of the GT, channel burner and heat recovery steam generator (HRSG) losses. In addition to these, Tüfekci [23] based on six years of acquired CCPP data, to get the best out of the CCPP, the machine learning regression method determines how being best CCPP installation. In another study, Herraiz et al. [24] The exhaust gas recirculation has been studied in order to provide the best burning in CCPP, to reduce the emission of flue gas and to increase the efficiency and to minimize the environmental damages. Sahin et al. [25] have performed an exergo-economic analysis of a CCPP and have reached different CCPP sizes and configurations in their work in terms of energy-exergy efficiency, electricity cost and total investment criteria, reducing electricity costs, minimizing environmental concerns and reducing investment costs. Ganjehkaviri et al. [26] have suggested that maintaining at 88% the steam quality at the turbine outlet station is a more realistic and feasible value for operating the ST in the CCPP at the optimum level. Kilani et al. [27] made the comparison of CCPP in the two different structures in which the vapor in the fuel chamber is different In the first, the injected steam was produced in the HRSG, while the other was supplied using the HRSG placed at the outlet of the compressor. According to the results, the second project was more effective in increasing performance.

It is also important to predict the electricity supplied by the natural gas CCPPs to the network in order to meet the peak load [28]. The output powers of the GTs used in these are the most effective parts of the system [29]. For the reuse of unburned gas, processes are operated with additional devices in the CCPP system [30]. These output powers also vary with ambient temperature, pressure, relative humidity, fuel structure, heat and power drawn [31-33]. From these variables, it was determined that the most effective one in the system is the ambient temperature depending on the front four-year data recorded. Depending on this result, additional arrangements for the air cooler section have been added to the system to keep the air temperature entering the fuel chamber at about 8°C. In this way, it is ensured to get the optimum level for the production of electricity of used the energy source and to be operated the plant with the best efficiency.

In the first part of the present study, a brief introduction and literature search are given, then in the second part, combined power plants, plant characteristics and flow chart are presented. In addition, for energy and efficiency analysis the relevant equations are explained. In the third chapter, the obtained results and conclusions are given. Finally, the results are expressed in the fourth chapter.

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2. Material and Methods

2.1. Combined power cycle plants

One of the plants that use fossil fuels is natural gas CCPPs. These natural gas CCPPs are an electric power generation plant that is important for the establishment in the world and especially in developing countries and they use natural gas as fuel type. Energy conversion block diagram of a natural gas CCPP is shown at Figure 1.

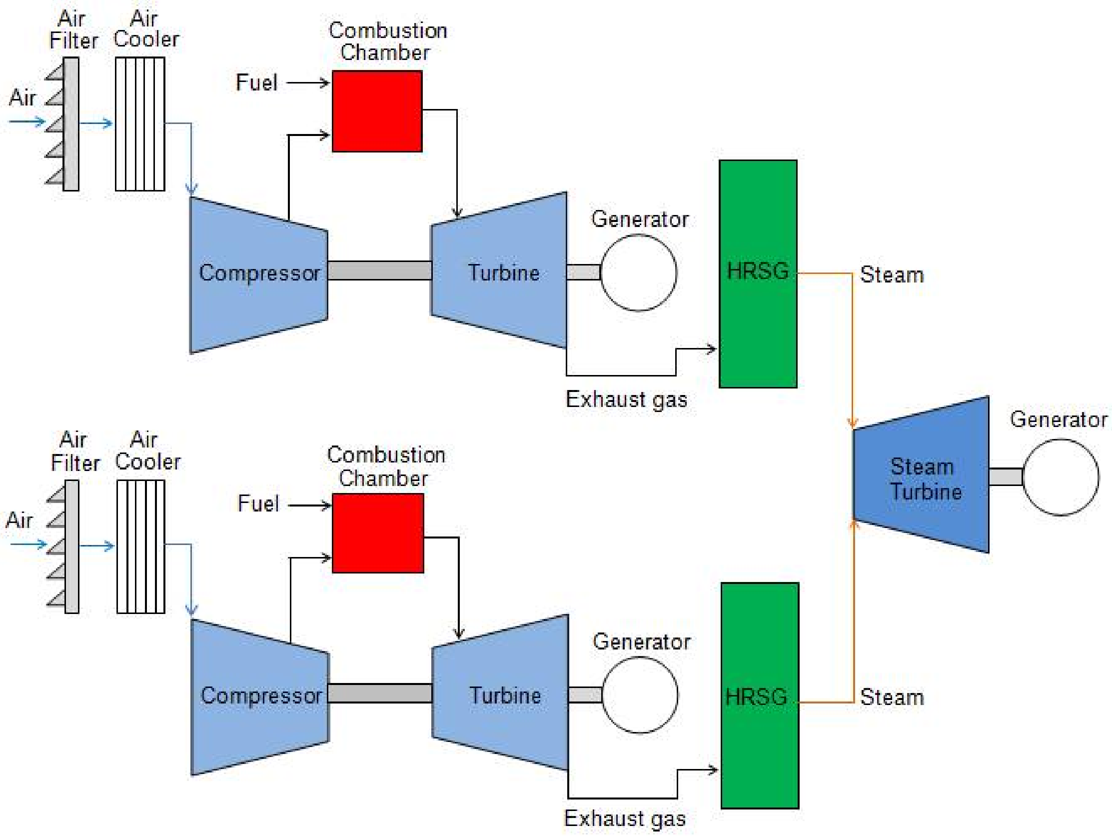

Figure 1. Energy conversion block diagram of a natural gas CCPP.

Natural gas CCPPs are more efficient because they keep at low level the amount of fuel to be used for energy production at the same level compared to single-cycle power plants. In combined cycle systems, as well as being provided cycling of GT with burning fuel, the water, which is heated in the HRSG and transformed to stream with the heat of the released exhaust gases, is sent to ST as hot steam and this provides cycling of ST. Thus, with the fuel burned to cycle the GT, energy is generated from the generators connected to both GT and ST. This increases the amount of energy production and thus increases the efficiency of the combined cycle system.

2.2. Characteristics of the analyzed combined cycle natural gas power plant

In this study, the efficiency of electric energy production is considered according to the ambient temperature of the 240 MW natural gas CCPP installed in the study and the appearance is located at Figure 2. This natural gas CCPP consists of two combined cycle blocks (CCPs), each consisting of two GTs, two HRSGs and one ST in each CCP. The models of the GTs used are the GE LM6000 and the models of the STs are Thermodyn 8-10MC10.

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Figure 2. HABAS natural gas CCPP in Aliağa, İzmir, Turkey.

2.3. Equation

It is important to be able to meet the power demanded by CCPPs. It should be monitored continuously how much electricity the power plant can produce. Efficiency changes from fuel, media and used equipment must also be calculated so that you can estimate how much of the demanded energy can be met. For this purpose, the following equations are needed to calculate the energy efficiencies of CCPP.

The energy released in a combustion gas resulting from a natural gas CCPP (Q_{GYy}- kcall/h); amount of fuel consumed per hour (B_y - m³/h) is proportional to the instantaneous thermal value of the fuel (H_y - kcall/m³) and is given by the following equation:

$$Q_{GTy} = B_y \cdot H_y \tag{1}$$

According to the measurements made in natural gas CCPP, natural gas fuels carry 9564,208 kcal energy. 1 kW is calculated as 860 kcall. The amount of energy released in kW (E_{GYy} - kW/h) is expressed as follows:

$$E_{GTy} = Q_{GTy} / 860 \tag{2}$$

There are four GTs and two STs in the examined natural gas CCPP The amount of electric power generated from these is shown as E_{GT1}, E_{GT2}, E_{GT3}, E_{GT4}, E_{ST1}, and E_{ST2}.

The yield value from a GT (η_{GT}) is described as follows:

$$\eta_{GT} = E_{GT} / E_{GTy} \tag{3}$$

In the examined natural gas CCPP, a CCB called CCB1 consists of two GTs and one ST. Accordingly, the total energy generating of CCB1 (E_{BLOCK1}- kW/h) is given as follows:

$$E_{BLOCK1} = E_{GT1} + E_{GT2} + E_{ST1} \tag{4}$$

Similar to CCB1 in CCB2, it is made from two GTs and one from ST. In this case, the total energy generating of CCB2 (E_{BLOCK2}- kW/h) is described as follows:

$$E_{BLOCK2} = E_{GT3} + E_{GT4} + E_{ST2} \tag{5}$$

After combustion, energy released from GTs (E_{GT1y}, E_{GT2y} - kW/h) forms a part of the input energy quantities of natural gas CCPP. Therefore, the input energy amount of GTs in CCB1 ($E_{BLOCK1y}$ - kW/h) is given as follows:

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$$E_{BLOCK1y} = E_{GT1y} + E_{GT2y} \tag{6}$$

The total of the input energies of the other two GTs in CCB2 (E_{GT3y}, E_{GT4y}, - kW/h) also form the CCB2 GT input energy quantities. The total amount of CCB2 input energy that can be obtained ($E_{BLOCK2y}$ - kW/h) is expressed by the following equation:

$$E_{BLOCK2y} = E_{GT3y} + E_{GT4y} \tag{7}$$

Energy quantities produced in GTs and STs (E_{GT}, E_{ST}) and depending on the amount of energy released after the combustion, GTs (E_{GT}) the efficiency of the CCBs (η_{BLOCK}) is expressed as follows:

$$\eta_{BLOCK} = E_{BLOCK} / E_{BLOCKy} \tag{8}$$

Depending on the amount of energy produced by each blot (E_{BLOCK1}, E_{BLOCK2} - kW/h), the total amount of energy produced in a natural gas CCPP (E_{PLANT} - kW/h) is given as follows:

$$E_{PLANT} = E_{BLOCK1} + E_{BLOCK2} \tag{9}$$

When input energy quantities released from the fuel in each CCB in the natural gas CCPP ($E_{BLOCK1y}$, $E_{BLOCK2y}$ - kW/h) the total amount of energy, which is released as the input energy in the power plant, is calculated (E_{PLANT} - kW/h) is as follows:

$$E_{PLANTy} = E_{BLOCK1y} + E_{BLOCK2y} \tag{10}$$

When the energies obtained in each of the CCBs constituting the plant (E_{BLOCK1}, E_{BLOCK2} - kW/h) and the released energies of both CCBs to after the combustion ($E_{BLOCK1y}$, $E_{BLOCK2y}$ - kW/hare known, total power plant efficiency (η_{PLANT}) is found with the following equation:

$$\eta_{PLANT} = E_{PLANT} / E_{PLANTy} = (E_{BLOCK1} + E_{BLOCK2}) / (E_{BLOCK1y} + E_{BLOCK2y}) \tag{11}$$

3. Results and Discussion

In order to perform the efficient calculations of natural gas CCPP at different temperature values, the necessary data were taken by the transmitters, current, voltage transformers and energy analyzers located in the relevant places of the plant. The energies obtained from GTs and STs between 8-23°C ambient temperatures were calculated based on the equations and these were presented as a whole Table 1.

Table 1. Power generation values of GT and ST between ambient temperature 8-23°C.

Ambient temperature (°C)	Obtained power (MW)						Ambient temperature (°C)	Obtained power (MW)					
	GT1	GT2	GT3	GT4	ST1	ST2		GT1	GT2	GT3	GT4	ST1	ST2
8	46	46.1	45.9	46	21.868	21.86	16	43.3	43.4	43.3	43.4	20.349	20.455
9	45.8	45.9	45.6	45.7	21.76	21.74	17	42.9	43	42.8	43	20.173	20.237
10	45.3	45.5	45.3	45.4	21.592	21.595	18	42.6	42.8	42.2	42.5	19.923	19.783
11	45	45.2	45	45.2	21.388	21.372	19	41.7	42	41,7	41.9	19.567	19.638
12	44.9	45	44.7	44.8	21.25	21.123	20	41.4	41.6	41,3	41.5	19.398	19.466
13	44.3	44.7	44,2	44.4	20.963	20.97	21	40.6	41	40.5	40.7	19.08	19.125
14	44	44.1	44	44.1	20.786	20.869	22	40.3	40.5	40.2	40.1	18.869	18.904
15	43.5	43.8	43.7	43.6	20.588	20.654	23	40	40.1	39.8	39.8	18.71	18.846

Electrical energy generating of GT1, GT2, GT3, GT4, ST1 and ST2 constituting natural gas CCPP are given at the Figure 3. Again at the Figure 3, the combined cycle CCB2 electric energy generating, which is a combination of the combined cycle CCB1 and GT3, GT4 and ST2 combined with the combination of GT1, GT2 and ST1 are presented.

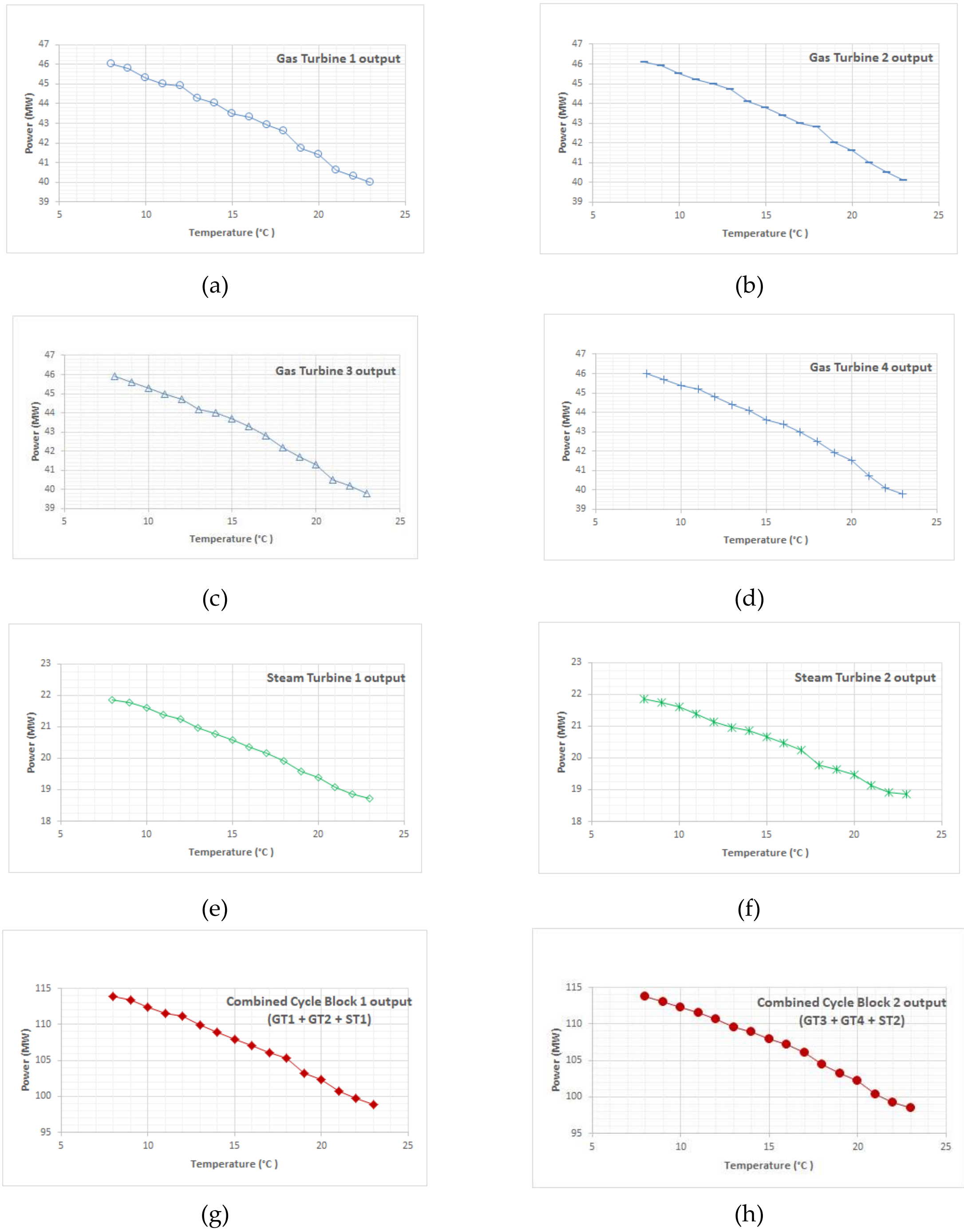

Figure 3. GT, ST, CCB electric energy generating: (a) GT1, (b) GT2, (c) GT3, (d) GT4, (e) ST1, (f) ST2, (g) CCB1 and (h) CCB2.

Figure 3 when examined in detail, the electric energy of GT1 is obtained 46 MW maximum at ambient temperature of 8°C, depending on the sensor data of GT of natural gas CCPP. When the ambient temperature was reached 15°C, the electric energy obtained from the GT1 was reduced to 43.5 MW. When the air temperature reached 23°C, the electric energy generating of 46 MW at 8°C drops to 40 MW, although input was provided to generate maximum power at all temperatures between 8-23°C via the GT1 controller. This situation has also been observed in other GTs. For GT2, electric energy generating at 8°C was 46.1 MW, it was obtained as 43.8 MW at 15°C and 40.1 MW at 23°C. The electrical energy obtained from the GT3 is measured as 45.9 MW, 43.7 MW and 39.8 MW,

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respectively for 8°C, 15°C and 23°C. The decrease value in the electrical energy obtained at the 15°C temperature difference increase in GT3 is 6.1 MW. GT4 has close values to other GTs. The electric energy generating at 8°C is 46 MW when it reaches 15°C and 43.6 MW when the temperature reaches 23°C, despite the value of the controller input for the highest electrical energy generating, the electric energy generating was recorded as 39.8 MW decreasing 6.2 MW.

When the data obtained from all GTs were examined, almost 46 MW of electric energy was generated at 8°C ambient temperature. When the ambient temperature reached 23°C at 15°C temperature increase, their generated electrical energy decrease was estimated to be about 6 MW and it was described as 40 MW.

The vapor produced using the CCBs, which have the exhaust gases from these GTs, combining with the binary outputs formed the input energies of the STs. In other words, the input energies of the STs were formed by the output exhaust energies of the GTs.

HRSG1 and HRSG2 systems were connected to the outputs of GT1 and GT2 in CCB1. The hot exhaust gases obtained from the combustion in the combustion chambers of the GT1 and GT2 form the inputs of the HRSG1 and HRSG2 systems. Here, the water is heated and pressurized into hot steam, and forms the input energy of ST1. Therefore, changes in the generating of electric energy in the GT1 and GT2 affect the generating of electric energy in the ST1.

The electrical energy obtained from ST1 was 21.9 MW when the ambient temperature was 8°C. When the ambient temperature reached 15°C, electrical energy generating was reduced to 20.6 MW. The outputs of the GTs were reduced by about 6 MW with increasing ambient temperature, although the GTs that feed the ST1 was controlled by the controller for maximum power generation at all temperatures between 8-23°C. Depending on the electrical energy generation in this ST1 ambient temperature 23°C, it reached 18.7 MW, decreasing 3.2 MW.

On the other hand, HRSG3 and HRSG4 systems were connected to the outputs of GT3 and GT4 in CCB2. The exhaust gases of GT3 and GT4 also constituted the input energies of HRSG3 and HRSG4. The hot steam which was heated and pressurized by these systems was given to ST2. The generating production of GT3 and GT4 affected the electric energy generating of ST2.

When ST2's electric energy generating was examined, the ambient temperature was 21.9 MW of electric energy at 8°C. When the ambient temperature increased a little and reached 15°C, the amount of electricity generated was slightly reduced and was recorded as 20.7 MW. Even when control signals were sent with the help of a controller to generate maximum power to the GT3 and GT4 that feed this type, when the ambient temperature reached 23°C, the electric energy from the ST2 was 18.9 MW being reduced by about 3 MW.

On the other hand, when electrical energy productions of CCBs were examined, it was observed that this GT and the STs connected to these CCBs differed depending on the energy generating changes. The CCB1 system was created with GT1, GT2 and ST1. In CCB1, when the ambient temperature was 8°C, the maximum electric energy was 114.0 MW, the maximum temperature was 107.9 MW when the ambient temperature increased to 15°C. Although the controller input for generating the maximum power at all temperatures between 8-23° C was provided to the units constituting CCB1, the electric energy generating at 114.0 MW at 8° C has reached the ambient temperature of 23°C, and 15°C temperature raised 15.2 MW down to 98.8 MW.

As for the other cycle block CCB2, the electric energy generating was close to the other CCB1 system. This has been introduced in CCB2 from GT3, GT4 and ST2. The electrical energy produced at ambient temperatures of 8°C, 15°C and 23°C was measured as 113.8 MW, 108.0 MW and 98.4 MW, respectively. The increase in temperature from 8°C to 23°C caused about 15.4 MW of energy loss.

The exhaust output of the two GTs in this natural gas CCPP combined to feed an ST. There are two systems in this cycle. These are CCB1 and CCB2. Combined with these, a combined power conversion plant was established. As a result, electrical energy generating of all natural gas CCPP due to ambient temperature change is shown at Figure 4.

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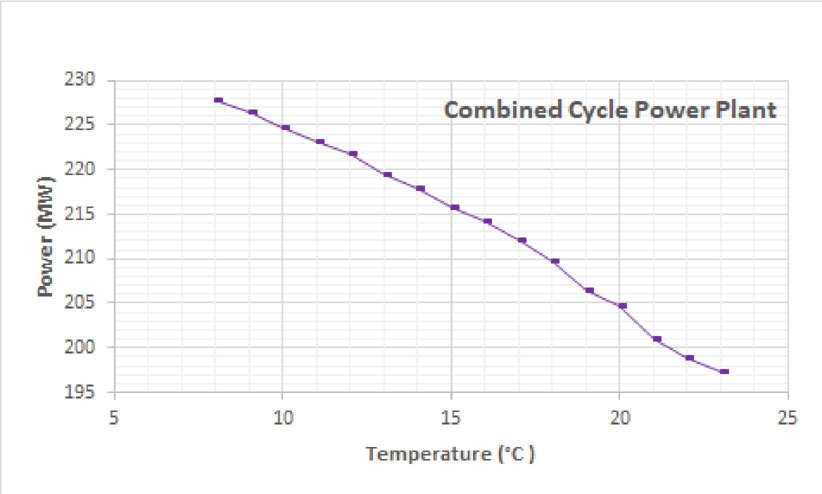

Figure 4. Electrical energy generating of natural gas CCPP.

Since the output power of the natural gas CCPP CCB1 and CCB2 blocks and the CCB1 and CCB2 GTs were affected by the temperature, the overall system output had also changed depending on their output. Figure 4, the electric energy output of natural gas CCPP was 227.7 MW at 8°C. Although the output powers of all the units that make up the natural gas CCPP were adjusted to the maximum power output by the controllers, this output value decreased as the temperature increases. It is from 215.8 MW at 15°C to 197.3 MW at 23°C. There was a 30.4 MW decrease in power consumption achieved at a temperature increase of approximately 15°C.

For all GTs at 8-23° C in the GTs, the amount of fuel going to the combustion chamber for each GT in the combustion reaction (B_y) were measured and recorded with flow transmitters in the fuel line. At the same time, the thermal value of the fuel used (H_y) was confirmed by BOTAS.

When the ambient temperature changes, the amount of oxygen in the air in the unit volume varies. Since the difference in the amount of oxygen is effective in the combustion reaction occurring in the combustion chamber, the amount of fuel entering the combustion chamber is being adjusted by the control system of the GTs. The GT inspection system performs this operation by closing and opening the fuel valve with a proportional valve.

Depending on the amount of fuel coming into the combustion chamber (B_y) and the thermal value of the fuel passing (H_y) through the input power of the GT1, GT2, GT3 and GT4 was calculated (1) and (2). The energy values (E_{GTy} - kW/h) released from the fuel entering the combustion chamber for temperature values between 8-23°C as a result of calculations and measurements were found. Burning the fuel in GTs, the energy was disappointed. The released amount of energy forms part of the input energies of the STs. These values are obtained from (6) and (7) (E_{BLOCKy} - kW/h). Input energy changes of GT1, GT2, GT3, GT4, CCB1 and CCB2 depending on the measured and calculated values are shown as Figure 5.

Figure 5 when examined, the input energy of the GT1 was 131.4 MW when the ambient temperature was 8°C. When the temperature increased to 15°C, the controller of the GT1 tried to regulate the fuel entering the combustion chamber and measured the input power of 124.7 MW. At an ambient temperature of 23°C, the GT1 control system continued to fuel the combustion chamber further and the energy released in the combustion chamber of the GT1 was recorded at 114.8 MW with a reduction of 16.6 MW. In GT2, while it has an input energy of 131.6 MW at 8°C, at 15°C the controller tried to adjust by reducing the fuel entering the combustion chamber and the input power was measured as 125.6 MW. When the ambient temperature reached 23°C, this input power was further reduced and reduced to 115.5 MW. The input energy for the GT3 was 131.5 MW, 126.1 MW and 115.7 MW, respectively for 8°C, 15°C and 23°C. The input energy of the GT4 in CCB2 was measured at 131.4°C at 8°C and 115.9 MW at a temperature increase of 23°C with a reduction of 15.5 MW.

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When GTs are considered collectively, the input power of almost every one at 8°C is 131 MW. Their input power values decreased with temperature increase and were measured as about 115 MW. A decrease of 16 MW was observed when rising the temperature from 8°C to 23°C.

On the other hand, these reductions in the energy input values of the GTs cause the input energies of CCB1 and CCB2 to decrease. In CCB1 the input energy was measured as 262.9 MW and 230.2 MW for 8°C and 23°C, respectively. The fall in input energy has been about 32.7 MW. In CCB2, the total input energy to the open combustion chamber at 8°C was 262.9 MW and 231.6 MW with a reduction of 31.3 MW at 23°C.

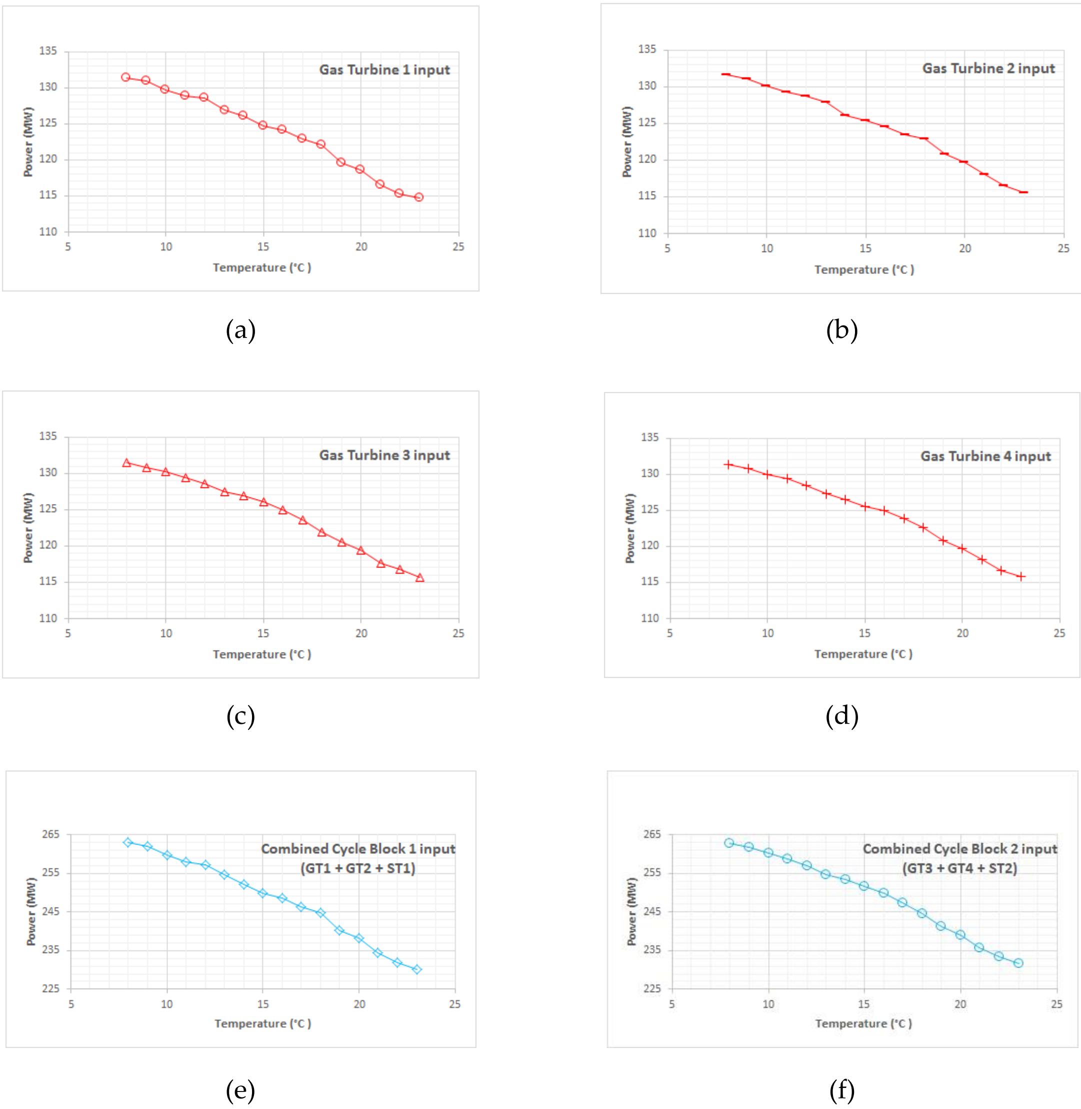


Figure 5. The input energy changes for GT, ST, CCB1 and CCB2 are: the input energy changes (a) GT1, (b) GT2, (c) GT3, (d) GT4, (e) CCB1 and (f) CCB2

As a result, natural gas CCPP energy input (E_{PLANTy} - kW/h) was obtained by the total energies of CCB1 and CCB2 units. The input energy of natural gas CCPP was found to be 525.8 MW for 8°C and 501.6 MW for 23°C with the aid of (10). The increase in ambient temperature from 8°C to 23°C caused a reduction of about 24.2 MW at the input power of natural gas CCPP. The energy input of this natural gas CCPP change is shown at Figure 6.

The efficiency of GTs and CCBs that make up the natural gas CCPP is presented Figure 7 These energy generating efficiency values were met by division the amount of electricity generated in each the ratio of the energy obtained from the fuel that is used to generate electricity and by being expressed as a percentage.

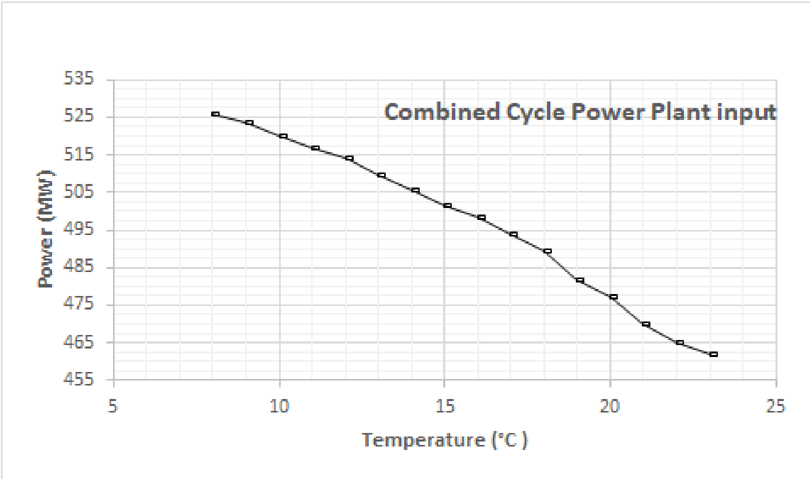
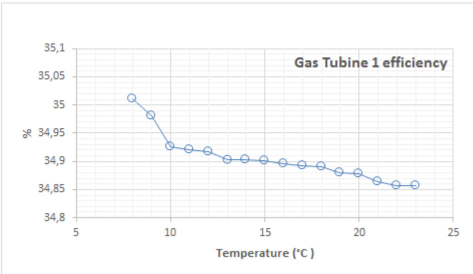


Figure 6. Natural gas CCPP energy input.



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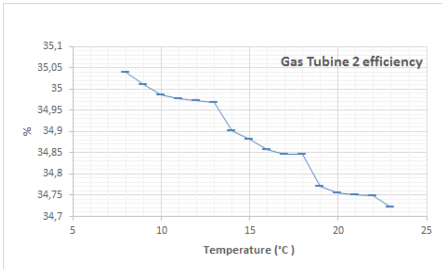

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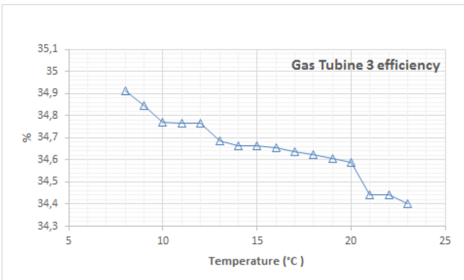

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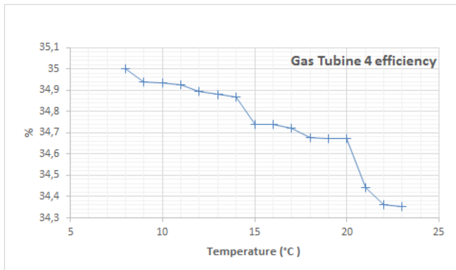

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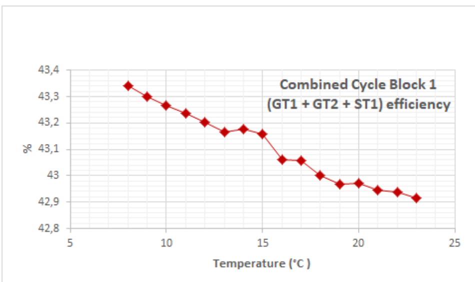

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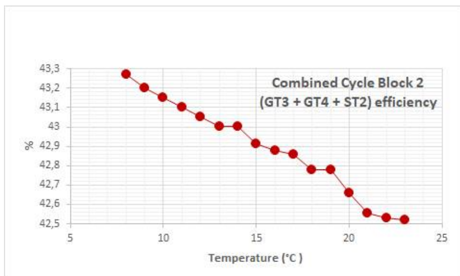

(f)

Figure 7. GTs and CCBs efficiency: (a) GT1, (b) GT2, (c) GT3, (d) GT4, (e) CCB1 and (f) CCB2.

With the increase in air temperature in the GT1, the energy output of 46 MW at 8°C declined to 40 MW at 23°C, despite the command to generate maximum power to the GT1, the energy released from the fuel entering the combustion chamber at 8°C was 131.4 MW, and at 23°C it was 114.8 MW.

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The control system of the GT2 is equipped with temperature transmitters and gets ambient temperature information. Since the amount of oxygen in the unit air is reduced as the temperature increases, the control system attempts to reduce the amount of fuel entering the combustion chamber so as to prevent excess fuel from entering the combustion reaction and to prevent it from being thrown out. By doing so, the efficiency was tended to stabilize but the efficiency decreased from 35.0% at 8°C to 34.9% at 23°C. Despite the increase in ambient temperature in GT2, the electric energy generating at 46.1 MW at 8°C declined to 40.1 MW at 23°C, despite the command to generate maximum power to GT2. The energy released from the fuel entering the combustion chamber at 8°C was 131.6 MW, and at 23°C it was 115.5 MW. Depending on these, the electricity production of GT2 was calculated as 8°C and 23°C, 35.0% and 34.7%, respectively. The output value of the GT3 is also close to that of the GT1 and GT2 and has decreased with the increase of the air temperature. These values were found to be 34.9% for 8°C and 34.4% for 23°C. The efficiency of GT4 in CCB2 was also 35.0% and 34.4% for 8°C and 23°C, respectively.

Efficiency calculations have been made for CCBs. The efficiency values of CCBs are significantly affected by the efficiency changes of GTs. The hot gas obtained from the outputs of the GTs was reused in the HRSGs by heating the water into hot pressurized steam. This has increased the efficiency of the system. In the established power generation system, these increase the efficient values of each CCB. As a result, the minimum efficient value of CCB1 at 8° C was 43.3%, while this value was 42.9% at 23°C. Whereas for CCB2 it was 43.3% and 42.5% for 8°C and 23°C, respectively. The efficient of natural gas CCPP is also dependent on the efficient of GTs, STs and CCBs, being consisted by them. The total system was calculated as 43.3% for 8°C and 42.7% for 23°C, depending on the obtained temperature, depending on the obtained data. For the examined natural gas CCPP, the efficient, which varies depending on the ambient temperature is shown at Figure 8.

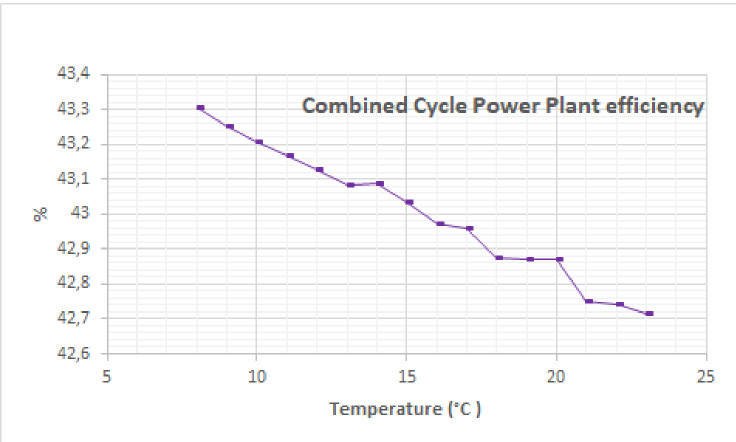

Figure 8. Depending on the ambient temperature for the natural gas CCPP.

All of these results, depending on the temperature increase in the natural gas CCPP productivity, the reason of reduction is interchange of the amount of oxygen inside the air entering the combustion chamber. If the amount of fuel entering the low air temperature is injected into the combustion reaction when the temperature of the incoming air is high, the reaction can't be carried out fully because the oxygen in the air entering the reaction is low. As a result, neither the desired amount of energy is released nor the unburned fuel is discharged as waste in the combustion reaction. This leads to an increase in the amount of natural gas used as input energy. In another respect, hydrocarbons are formed out of combustion due to oxygen and the natural gas imbalance. These situations increase both costs and reduce the efficiency.

Data were recorded with data acquisition cards (Data Acquisition Card - DAQ) from the installation of this combined cycle power plant until nowadays. When the system was first installed, it reached 240 MW at 8°C, which is the ideal operating temperature. The daily of electric power generating is 227.7 MW maximum. The decline in the generating of this electric energy was due to erosion dependent on time in the system. These erosions can be generally expressed as mechanical

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and thermal fatigue. Time dependent abrasion losses, occurring working under pressure in the compression ratios in turbines also affect too. Moreover, the soot formed in the combustion chambers, turbine blade abrasion, chilling in the cooling system and corrosive effects play an important role in decreasing efficiency.

4. Conclusions

In this study, the changes in electric energy production of HABAŞ natural gas CCPP, which has an installed capacity of 240 MW, depending on the temperature, were examined using real data recorded for about fourteen years. Electricity energy generating at 8°C of natural gas CCPP was 227.7 MW, while electric energy generating at 23°C was calculated as 197.3 MW with a decrease of 30.4 MW. Depending on the seasonal temperature change, the efficient value was determined as 43.3% at 8°C and 42.7% at 23°C. At measurements made between 8-23°C; although the controllers in the GTs are programmed to generate maximum power, the energy generating of the GTs is reduced as the air temperature increases. These reductions are proportional to the amount of oxygen in the air of the unit volume entering the combustion chamber. The temperature of the air entering the combustion chamber decreases the amount of residual oxygen, which affects the combustion response. Less burnout leads to less energy availability. Although the control systems of the GTs attempt to protect the efficiency by controlling the fuel entering the combustion chamber, the efficiency decreases as the ambient temperature increases in the GTs. To prevent production and productivity loss, in areas where the temperature of the air is high and variable, to bring the highest value of energy production and efficiency the inlet air temperature entering the combustion chamber and to keep it fixed asset, special systems that only cool inlet air should be installed in power plants.

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References

1. Abuelnuor, A.A.A.; Saqr, K.M.; Mohieldein, S.A.A.; Dafallah, K.A.; Abdullah, M.M.; Nogoud, Y.A.M. Exergy analysis of Garri “2” 180 MW combined cycle power plant. *Renewable and Sustainable Energy Reviews*, **2017**, 79, 960-969, DOI: 10.1016/j.rser.2017.05.077
2. Kok, B.; Benli, H. Energy diversity and nuclear energy for sustainable development in Turkey. Renewable *Energy*, *2017*, 111, 870-877, DOI: 10.1016/j.renene.2017.05.001
3. Noroozian, A.; Mohammadi, A.; Bidi, M.; Ahmadi, M.H. Energy, exergy and economic analyses of a novel system to recover waste heat and water in steam power plants. *Energy Conversion and Management*, **2017**, 144, 351-360, DOI: 10.1016/j.enconman.2017.04.067
4. Kotowicz, J.; Brzęczek, M. Analysis of increasing efficiency of modern combined cycle power plant: A case studies. *Energy*, **2018**, 153, 90-99, DOI: 10.1016/j.energy.2018.04.030
5. Cihan, A.; Hacıhafızoğlu, O.; Kahveci, K. Energy–exergy analysis and modernization suggestions for a combined-cycle power plant. *International Journal of Energy Research*, **2006**, 30(2), 115-126, DOI: 10.1002/er.1133
6. Incekara, C.O.; Ogulata, S.N. Turkey’s energy planning considering global environmental concerns. *Ecological Engineering*, **2017**, 102, 589-595, DOI: 10.1016/j.ecoleng.2017.02.033
7. Jović, M.; Laković, M.; Banjac, M. Improving the energy efficiency of a 110 MW thermal power plant by low-cost modification of the cooling system. *Energy & Environment*, **2018**, 29(2), 245-259, DOI: 10.1177/0958305X17747428

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 May 2018 doi:10.20944/preprints201805.0019.v1

8. Blumberg, T.; Assar, M.; Morosuk, T.; Tsatsaronis, G. Comparative exergoeconomic evaluation of the latest generation of combined-cycle power plants. *Energy Conversion and Management*, **2017**, 153, 616-626, DOI: 10.1016/j.enconman.2017.10.036
9. Ersayin, E.; Ozgener, L. Performance analysis of combined cycle power plants: A case study. *Renewable and Sustainable Energy Reviews*, **2015**, 43, 832-842, DOI: 10.1016/j.rser.2014.11.082
10. Zhang, X.; Liu, J.; Tang, Y.; Zhao, X.; Yang, H.; Gerbens-Leenes, P.W.; Michelle, T.H. van Vliet; Yan, J. China's coal-fired power plants impose pressure on water resources. *Journal of Cleaner Production*, **2017**, 161, DOI: 10.1016/j.jclepro.2017.04.040
11. Mohanty, D.K.; Venkatesh, V. Performance analysis of a combined cycle turbine under varying operation condition. *Mechanical Engineering: An International Journal (MEIJ)*, **2014**, 1, (2), 11-25, DOI:
12. Meegahapola, L. Characterisation of gas turbine dynamics during frequency excursions in power networks. *IET Generation, Transmission & Distribution*, **2014**, 8(10), 1733-1743, DOI:
13. Ahmadi, G.R.; Toghraie, D. Energy and exergy analysis of Montazeri steam power plant in Iran. *Renewable and Sustainable Energy Reviews*, **2016**, 56, 454-463.
14. Xiang, Y.; Cai, L.; Guan, Y.; Liu, W.; Han, Y.; Liang, Y. Study on the configuration of bottom cycle in natural gas combined cycle power plants integrated with oxy-fuel combustion. *Applied Energy*, **2018**, 212, 465-477, DOI: 10.1016/j.apenergy.2017.12.049
15. Alobaid, F. Start-up improvement of a supplementary-fired large combined-cycle power plant. *Journal of Process Control*, **2018**, 64, 71-88, DOI: 10.1016/j.jprocont.2018.02.007
16. Pattanayak, L.; Sahu, J.N.; Mohanty, P. Combined cycle power plant performance evaluation using exergy and energy analysis. *Environmental Progress & Sustainable Energy*, **2017**, 36(4), 1180-1186, DOI: 10.1002/ep
17. Kaushik, S.C.; Reddy, V.S. ; Tyagi, S.K. Energy and exergy analyses of thermal power plants: A review. *Renewable and Sustainable Energy Reviews*, **2011**, 15(4), 1857-1872, DOI: 10.1016/j.rser.2010.12.007
18. Promes, E.J.O.; Woudstra, T.; Schoenmakers, L.; Oldenbroek, V.; Thattai, A.T.; Aravind, P.V. Thermodynamic evaluation and experimental validation of 253 MW Integrated Coal Gasification Combined Cycle power plant in Buggenum, Netherlands. *Applied Energy*, **2015**, 155, 181-194, DOI: 10.1016/j.apenergy.2015.05.006
19. Ganjehkaviri, A.; Jaafar, M.M.; Ahmadi, P.; Barzegaravval, H. Modelling and optimization of combined cycle power plant based on exergoeconomic and environmental analyses. *Applied Thermal Engineering*, **2014**, 67(1-2), 566-578, DOI: 10.1016/j.applthermaleng.2014.03.018
20. Javadi, M.A., Ghomashi, H. Thermodynamics analysis and optimization of abadan combined cycle power plant. *Indian Journal of Science and Technology*, **2016**, 9(7) , DOI: 0.17485/ijst/2016/v9i7/87770
21. Almutairi, A.; Pilidis, P.; Al-Mutawa, N. Energetic and exergetic analysis of combined cycle power plant: part-1 operation and performance. *Energies*, **2015**, 8(12), 14118-14135, DOI: 10.3390/en81212418
22. Ameri, M.; Ahmadi, P.O.U.R.I.A.; Khanmohammadi, S.H.O.A.I.B. Exergy analysis of a 420 MW combined cycle power plant. *International Journal of Energy Research*, **2008**, 32(2), 175-183, DOI: 10.1002/er.1351
23. Tüfekci, P. Prediction of full load electrical power output of a base load operated combined cycle power plant using machine learning methods. *International Journal of Electrical Power & Energy Systems*, **2014**, 60, 126-140, DOI: 10.1016/j.ijepes.2014.02.027
24. Herraiz, L.; Fernández, E.S.; Palfi, E.; Lucquiaud, M. Selective exhaust gas recirculation in combined cycle gas turbine power plants with post-combustion CO_2 capture. *International Journal of Greenhouse Gas Control*, **2018**, 71, 303-321, DOI: 10.1016/j.ijggc.2018.01.017
25. Sahin, A.Z.; Al-Sharafi, A.; Yilbas, B.S.; Khaliq, A. Overall performance assessment of a combined cycle power plant: An exergo-economic analysis. *Energy Conversion and Management*, **2016**, 116, 91-100, DOI: 10.1016/j.enconman.2016.02.079
26. Ganjehkaviri, A.; Jaafar, M.M.; Hosseini, S.E. Optimization and the effect of steam turbine outlet quality on the output power of a combined cycle power plant. *Energy Conversion and Management*, **2015**, 89, 231-243, DOI: 10.1016/j.enconman.2014.09.042
27. Kilani, N.; Khir, T.; Brahim, A.B. Performance analysis of two combined cycle power plants with different steam injection system design. *International Journal of Hydrogen Energy*, **2017**, 42(17), 12856-12864. DOI: 10.1016/j.ijhydene.2017.01.233
28. Lee, J.H.; Kim, T.S.; Kim, E.H. Prediction of power generation capacity of a gas turbine combined cycle cogeneration plant. *Energy*, **2017**, 124, 187-197, DOI: 10.1016/j.energy.2017.02.032

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 2 May 2018
doi:10.20944/preprints201805.0019.v1

29. Kim, M., Kim, D., Esfahani, I.J., Lee, S., Kim, M., Yoo, C. Performance assessment and system optimization of a combined cycle power plant (CCPP) based on exergoeconomic and exergoenvironmental analyses. *Korean Journal of Chemical Engineering*, **2017**, 34(1), 6-19, DOI: 10.1007/s11814-016-0276-2
30. Hu, Y.; Ahn, H. Process integration of a Calcium-looping process with a natural gas combined cycle power plant for CO_2 capture and its improvement by exhaust gas recirculation. *Applied Energy*, **2017**, 187, 480-488, DOI: 10.1016/j.apenergy.2016.11.014
31. Amell, A.A.; Cadavid, F.J. Influence of the relative humidity on the air cooling thermal load in gas turbine power plant. *Applied Thermal Engineering*, **2002**, 22(13), 1529-1533.
32. De Sa, A.; Al Zubaidy, S. Gas turbine performance at varying ambient temperature. *Applied Thermal Engineering*, **2011**, 31(14-15), 2735-2739, DOI: 10.1016/j.applthermaleng.2011.04.045
33. Arrieta, F.R.P.; Lora, E.E.S. Influence of ambient temperature on combined-cycle power-plant performance. *Applied Energy*, **2005**, 80(3), 261-272, DOI: 10.1016/j.apenergy.2004.04.007