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Southern Iraq gas station conversation to integrated solar combined cycle

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Abstract. Iraq has a big shortage in the electrical system and this is because of repeated wars that have destroyed the country's economy and infrastructure. In order to improve the situation and progress of the country we see that the exploitation of huge and neglected land, where Iraq has a very featured site can make it a factory for the production of electric power through the exploitation of the vast areas as fields of cells and solar plants to produce electricity. Iraq is characterized by the number of sunny hours during the year and estimated more than 3300 hours. Also, the solar radiation in Iraq, which exceeds 2000 kWh/m^2. Where the production of electricity enough to meet the needs of Iraq and neighboring countries. In this paper we will discuss the development of gas station in southern Iraq by taking advantage of the sun's rays falling and recycling of combustion products from the gas station. The plant consists of 200MW conventional gas turbine plant and two steam turbines of 75MW and 65MW powered by the solar field and gas turbine exhaust. With high insolation during the summer month of June the plant can achieve up to 25% of solar fraction with Integrated Solar Combined Cycle (ISCC) plant.

1 Introduction

The world demand for energy have increased with the increasing population and resources like fossil fuels (coal, natural gas, oil, etc.) are not reliable as it was in the previous century, as unsteadiness in oil prices can be very damaging especially to countries and industries that consider fossil fuel as their base. Renewable energy technologies have become main stream during the last three decades; treaties set by decision makers were signed to establish renewable energy as a worldwide solution to problems such as energy shortage and worldwide warming. Solar power is one of the leading renewable energy resources due to its low price for people and it emitting zero emissions and noise. Two major technologies used under the solar power umbrella are the solar cell 'Photovoltaic' and the solar thermal collector. More than 80% of the 20,132TWh world total electricity production and consumption in 2009 is from fossil fuel [1,2].

With the reality of the effect of global climate change, measures need to be taken to limit pollution (CO_2, CH_4 and NO_x) emission gases coming from the fossil fuel fired power plants. Fossil fuel is limited which require the need to look inward for a sustainable and environmental friendly means of generating electricity. With advances in solar technology in the last two decades, production of electricity from solar has renewed the interest in solar thermal power generation. However, due to high amount of heat lost during start up and shut down, high cost of storing heat energy for off sun period as well as high technical and economical risk, it application has been limited and has given rise to the introduction of the solar hybrid system. Integrated Solar Combined Cycle (ISCC) proposed a means of integrating a parabolic trough solar field with modern combined cycle power plants with the aim of improving system cost and efficiency.

Several works have been carried out to look at the potential and viability of ISSC plant at different locations. The ISCC can either be operated as a direct steam generation (DSG) or using separate fluid such as thermal oil or salt as the heat transfer fluid (HTF). the output power of an ISCCS-DSG power plant to be higher than ISCCS-HTF plant which resulted in less CO_2 emissions, and save about 46 million $ in fuel consumption through the 30 years' operating period and concluded that ISCCS-DSG is the best option for using solar energy, especially in arid countries rich in natural gas like Iraq. Iraq is blessed with abundance solar energy with high solar radiation intensity estimated at 2000 kWh/m2 and rich in natural gas [3].

The cycle that has been adopted for the present study is presented in Fig (1). The plant layout is a gas turbine layout of 200MW capacity located in Basra city, and we adding two steam turbines of 75 MW (high pressure) and 65MW (low pressure), a re-heater and an economizer. Provision for auxiliary energy is incorporated to be used to compliment the solar field or during the night. The

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energy balance equations for the cycle were written and solved by using Engineering equation solver (EES) software.

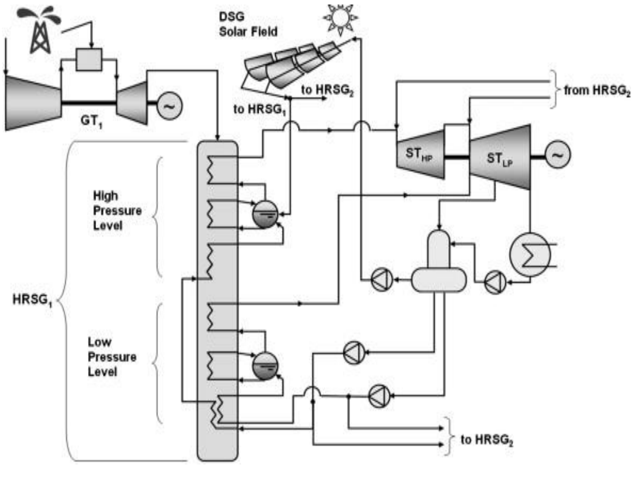

Fig. 1. Integrated Solar Combined Cycle (ISCC) with tow steam turbines

2 Electrical power supply in Iraq

It is clear that electrical power supply and generation have been running short of demand since 1991 after the gulf war. The solution is to invest heavily into solar power generating technology to solve the mounting problem appear in the energy requirement at the present and for the future where full development in the infrastructure of the country are required in many aspects which demanding an immediate solution. The transport and high ways are to reduce CO_2 and flares that coincide with the crude oil production. An infrastructure of both oil production and gas utilization, oil transport and marketing also require huge electrical energy as well [4].

The criteria of using solar power is the best solution in term of investment in such power system in order to gain saving instead of investing huge amount of money in both oil or gas power generation where the solar power and its storage facilities are a solution to reduce CO_2, maintain a clean power for the future and saving in investment. Power supply availability is about 14 hours/day (summer) from the public network; reliance on private diesel generators. Total federal design capacity 28,680 MW in 2017, but available capacity is 20,020 MW (including 2 GW of imports and barges). Loss of generating power in Baiji, Mosul, hydro plants during war against ISIS [5].

3 Geographical location of Iraq

Iraq located in southwest Asia between latitudes 29° 5’ and 37° 22’ N and longitudes 38° 45’ and 48° 45’ E; it forms the eastern frontier of the Arab countries. Iraq has an area of 437072km^2, bordered by Iran from the east, Turkey on the north, Saudi Arabia and Kuwait to the south, the Arabian Gulf to the southeast, and Syria and Jordan to the west [6,15]. The guessed population in July 2018 is 40 185 578 people with a growth rate of 2.5%. The area of Iraq can be divided into four major geographic regions: the Upper Tigris and the Euphrates, the highlands to the southeast, and the Dibba is plain exclusively with scrub plants that extend eastward to Kuwait and south to Saudi Arabia. The climate of Iraq is characterized by being mainly continental climate. It is very hot and very dry most days of the year. The desert climate is moderate, cold, dry, and hot. Climate dangers such as drought, sandstorms and floods are possible in this atmosphere. Iraq is characterized by very high temperatures in the summer and moderate in winter, the highest value in June, July and August between 43 ° C and 52 ° C and in January between 1 ° C to 8 ° C [7]. Iraq is located near the solar belt, which receives a quantity of solar radiation with an average of (6.5-7) kwh/m^2. The periods of sun brightness range from 2800 to 3300 hours per year [8,15]. This gives Iraq the necessary qualifications for the exploitation of solar energy. The highest actual brightness of the sun is in June at an average of 11.4 hours/day, and the lowest in January by 6.3 hours/day. The maximum temperatures range from 16°C in January to 52°C in July. The minimum temperatures range from 4.4°C in January to 25.4°C in July. Wind speed in this country is below average and ranges from 2.5 m / s in December and January to 4.1 m / s in July. Relative humidity ranges from the lowest 25.5% in October to January high of 73.8% [8].

4 The principles of ISCC

The main components of a typical integrated solar combined cycle (ISCC) system are gas turbine unit, steam turbine unit, heat recovery steam generator (HRSG) unit and solar field, which mainly consists of solar collectors and solar steam generator (SSG). The most commonly solar collectors used in the ISCC are parabolic trough type [10], which is assumed in our present study. The operating of the ISCC is derived from the combined cycle power plant, where the hot exhaust gases from the gas turbine are used to generate the steam in the HRSG to drive the steam turbine. While additional amount of steam is generated in the SSG (solar steam) to supplement the steam being produced in HRSG [11]. So, part of the feed water is preheated in the HRSG (economizer)before entering the solar steam generator (ms), where it is converted to saturated steam. This saturated steam is returned to the HRSG where it is superheated by the gas turbine exhaust gases [12]. At night, the power plant operates as a combined cycle unit since, so the thermal energy storage is not considered in the proposed system.

5 The mathematical model

The energy and mass balance equations of component parts are coupled together and solved iteratively to analyze the plant performance characteristics. The equations used for gas turbine and steam turbine analyses are given in literature [13]. Some selected equations are: the useful energy gain from the parabolic trough solar concentrator is given by [14]. A simplified mathematical model of typical ISCC system is developed in this paper. Mass and energy conservation laws were applied to the gas and steam turbine units, heat recovery and solar steam generators using Engineering Equations Solver software (EES) to evaluate the performance of ISCC system.

$$Q_u = F_R * (A_a * DNI * \cos(\theta) * \eta_{optical} * K_\theta - A_r * U_{abs} * (T_r - T_a)) \quad (1)$$

$$K_\theta = 1 - 6.74e(-5) * \theta^2 + 1.64e(-6) * \theta^3 - 2.51e(-8) * \theta^4 \quad (2)$$

$$DNI = I * \cos(\theta_z) \quad (3)$$

$$W_{ISCC} = W_{gt} + W_{T1} + W_{T2} \quad (4)$$

$$\eta_{ISCC} = W_{ISCC} / E_{in} \quad (5)$$

$$F_{solar} = W_{solar} / W_{ISCC} \quad (6)$$

Basra has a good climatic cycles which can be represented by the average day of the months of March, June, September and December. Direct normal insolation (DNI) of the location given in Fig (2) was observed to be highest in June with more than 800W/m^2 at noon local time and least in December with about 400W/m^2 [8,15].

Table 1. Solar radiation falling at region between Basra and Nassrya at 2017, kWh/m2[9,15].

Lat	Lon	Dec	Jan	Feb	
30.25	46.25	4.29	3.54	4.42	
30.25	47.25	4.21	3.44	4.12	
30.25	48.25	4.14	3.27	4.16	
31.25	46.75	4.03	3.18	4.24	
31.25	47.25	4.01	3.13	4.13	
31.25	48.25	4.09	3.14	4.14	
Lat	Lon	Jun	Jul	Aug	Ann
30.25	46.25	8.97	7.53	7.07	5.57
30.25	47.25	7.91	7.37	7	5.47
30.25	48.25	8.87	7.28	6.9	5.41
31.25	46.75	7.87	7.31	6.94	5.35
31.25	47.25	7.82	7.2	6.87	5.33
31.25	48.25	8.94	7.27	6.63	5.37

The expected solar field output is given in Fig (3). The solar field output in June can be observed to be more than of December. This can be attributed to low DNI in the later month.

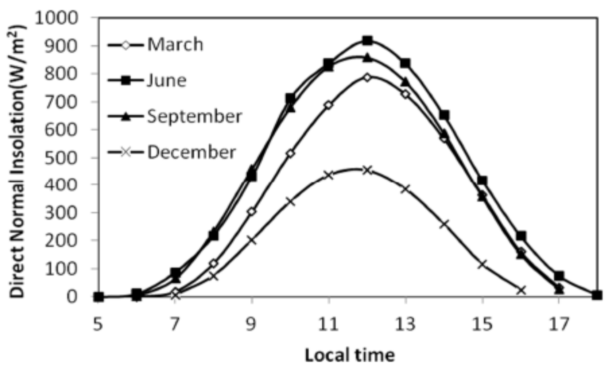

Fig. 2. Direct normal insolation

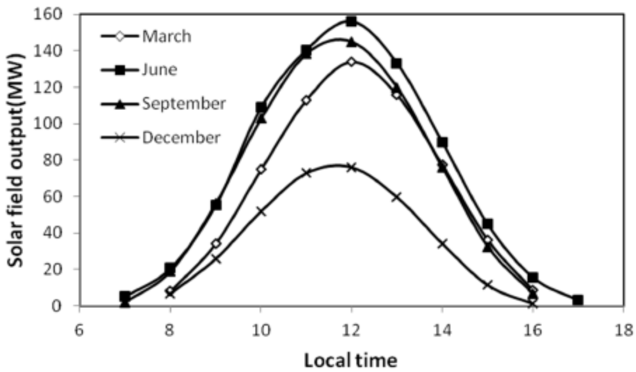

Fig. 3. Solar field output

The result of the integral energy analysis of the proposed plants given in Fig (4) shows that the overall power output is nearly constant for all months during the early and later part of the day.

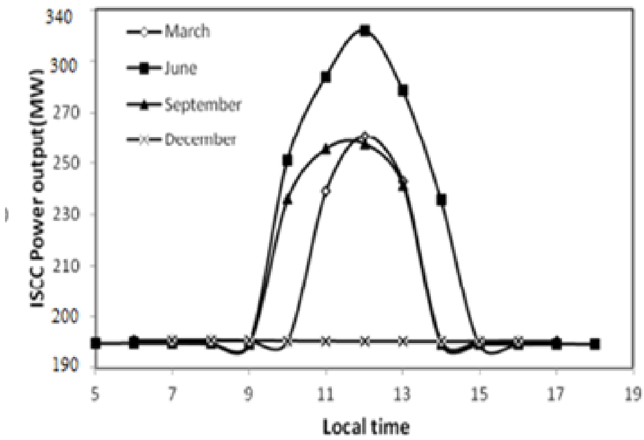

Fig. 4. ISCC power output

This is due to the low solar intensity and collection efficiency, this factor is more dominant in December because of low intensity of solar energy DNI. The ISCC can achieve up to 330MW in June resulting in the combined cycle improvement from the base case efficiency of about 38% to 55% as shown in Fig (5).

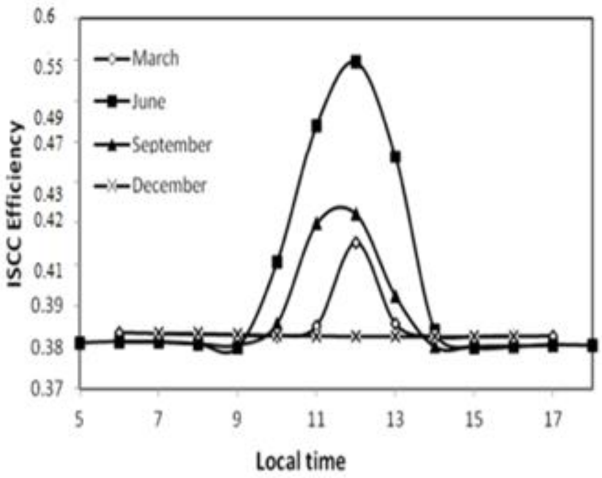

Fig.5. ISCC efficiency

This improvement is not only due to energy from the solar field but also the energy extracted from the gas turbine exhaust. The percentage of power produced due to solar field output referred to as the solar fraction is summarized in Fig (3). It can be observed that solar field output for December is very low. Hence, its solar fraction is not represented in Fig (3). At noon in the month of June, with more than 800W/m^2 DNI, the solar fraction can be nearly 25% which is promising Fig (6).

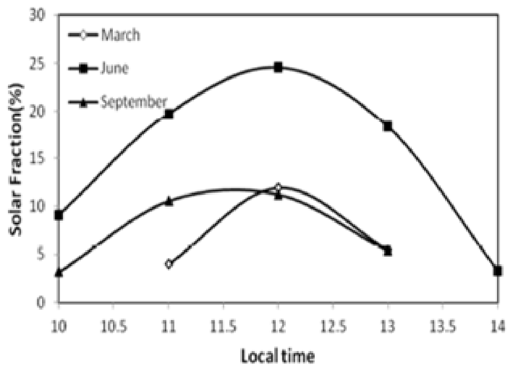

Fig. 6. solar fraction

Figure (7) shows the power comparison that may be typical of the ISCC power plant, while it can be observed that there is availability of power from the solar field both in the earlier and later part of the day, there is no power output from the steam turbines, this can be attributed to the low intensity of solar energy. This energy can however be exploited by the use of auxiliary energy in order to obtain maximum benefit from the solar field and increase the overall efficiency. The effect of solar collector multiple when increasing the number of collectors from 450 to 600 increases the solar fraction from 24% to about 40% and this increase in the solar fraction and efficiency is due to availability of additional energy from the solar field.

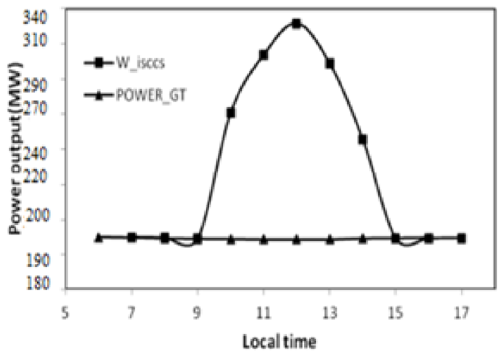

Fig. 7. power comparison

6 Conclusions

Iraq has excellent solarity, ranging from 1,800 to 2,390 kWh/m^2/yr of direct normal irradiation, and much of the flat Iraqi landscape is appropriate for an ISCC plant. The benefits of implementing ISCC plants have also been investigated to support the decision-makers in selecting good future needs. Results showed the following:

- the output power is a strong function of solar heat input at different ambient temperatures, it could reach up to 330MW at solar heat input 880kWh/m2;
- Al Basra ISCC power plant efficiency could reach to 55% which is 20-80% higher than current conventional power plants;
- the kind of fuel, ambient temperature, turbine inlet temperature, solar heat input, capacity factor, and solar fraction are the main factors affecting the performance of the plant;
- the main benefits of ISCC power plant are fuel saving, the reduction of electricity demand at the peak period as well as the reduction of carbon emissions. The expected annual fuel saving in terms of barrel of oil equivalent is around 115350 boe/year, while the carbon emissions reduction will be around 170672 ton/year;
- reconstruction the current conventional plants (gas turbine and steam turbine) to ISCC power plants will reduce millions tons of carbon emissions and save millions barrels of oil equivalent annually, this will save millions $ over the lifespan of the plants.

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