Integrated solar thermal combined cycle for power generation in Iraq

Khalidah A J Al-Qayim

1Department of Oil and Gas Refinery Engineering, Al-Farabi University college, Aldorrah Masafi St., Baghdad, Iraq
*Corresponding author e-mail: Khalidah.alqayim@alfarabiuc.edu.iq

Abstract. Solar thermal power has already shown enormous promise as a source for power generation. With limited environmental impacts and an immense abundance, it offers a reasonable prospect to the sunny countries such as Iraq, that enables the country to lead the development of industrial-scale solar power generation in the region. However, the electricity distribution systems would be confronted by daily and annual variance of solar irradiation. To compensate for this variance the integrated solar combined cycle (ISCC) with a natural gas power plant is the solution. This study investigates the potential of ISCC power plants in Iraq in which preferred technologies and economic feasibility are analysed. The analysis shows it is the best interest of Iraq to invest in at least one large-scale ISCC power plant among the future planned power plants. The most promising location for such a plant would be in Al Anbar, the immense western desert in Iraq, yet other six locations for such power plants have potential as well. The economic analysis showed a high capital cost for the concentrated solar power (CSP) plant compared to the natural gas (NG) plant, as the CSP formed 67% of the total capital investment, though, the operating and maintenance cost of CSP formed only about 5% of the total ISCC plant cost at $1,688,281 per year, and the direct operating and maintenance cost of CSP and NG plants were 34, and 164 $/kW⁻¹, respectively.

Keywords: solar, thermal, Iraq, direct normal irradiation,

1. Introduction
Concentrated Solar Power (CSP) is one of the best affordable technologies in electricity generation to mitigate global warming resulted from the consumption of fossil fuels [1]. Environmental impacts of CSP plants, and life-cycle assessment of the carbon dioxide emissions, demonstrate a great potential in CSP as a solution for greenhouse gases mitigation. It is known that, 200-300 kilograms of annual carbon dioxide emissions can be avoided with each square meter of CSP surface area, depending on its configuration. The consumed energy in building the concentrated solar power plant can be recovered in less than a year. This relates positively to their projected lifetime of 25 to 30 years. In addition, some parts of the solar equipment can be reinstalled in new plants [2]. Solar thermal power can therefore contribute significantly in the reduction of greenhouse gas emissions and their impact on earth global warming.

CSP is based on utilizing direct sunlight, the Direct Normal Irradiation (DNI); i.e. the parallel beams segment of sunlight that reaches the earth’s surface [3]. Thus, regions with high DNI are desirable for CSP. Sites with minimum annual 2,000 kWh.m⁻² sunlight radiation, are appropriate for CSP plants, whereas sites receive more than 2,800 kWh.m⁻² per year are the best [4]. Regions located within 40
degrees of latitude north or south, having low levels of atmospheric humidity, dust and fumes, such as savannas, semi-deserts and fully deserts, are considered characteristic sites for CSP plants [5].

In a CSP plant sunlight beams are receipted and concentrated by reflecting mirrors that focus sunlight onto a receiver containing a heat-transfer fluid (HTF) that is heated and circulated in the receiver to be used to produce steam. The steam powers a generator to produce electricity. Tracking systems are provided to keep the reflectors following the sunlight beams and focusing onto the receiver during the day. A thermal energy storage (TES) unit is now an essential part of the CSP plant to store enough heat for electricity generation in the evening or during cloudy days [2]. One of the TES concepts was proposed by a report to the US Department of Energy in 2011, suggesting thermochemical heat storage, commissioning a pair of reciprocal redox reactions of metal oxides such as cobalt, iron and manganese oxides to store and release heat (6).

1.1. CSP Technologies

There have been a series of technology development to produce the most successful CSP system in terms of sunlight collection, reflection and thermal heat transition. The three most promising solar thermal technologies are [1] [7]:

a. Parabolic trough

As shown in figure 1.a, parabolic trough-shaped mirror reflectors are used to concentrate sunlight on to thermally efficient receiver tubes placed in the trough’s focal line. Because of its parabolic shape, a trough can focus the sunlight from 30 times to 100 times its normal intensity on the receiver pipe. A thermal transfer fluid, such as synthetic thermal oil, is circulated in these tubes. Heated to approximately 400°C by the concentrated sun’s rays, this oil is then used to produce superheated steam through a series of heat exchangers. A steam turbine generator converts the steam energy to electricity, by a conventional Rankine cycle power plant. Nowadays, parabolic trough technology is by large the most proven solar thermal energy generation technology [8].

b. Central receiver or solar tower

A circular arrangement of heliostats (large individually tracking mirrors) is used to concentrate sunlight on to a central receiver mounted at the top of a tower as shown in figure 1.b. A heat-transfer fluid (HTF) in this central receiver absorbs the highly concentrated radiation reflected by the heliostats and converts it into thermal energy to be used for the subsequent generation of superheated steam for turbine operation. Sunlight can be concentrated as much as 1,500 times [7].

c. Parabolic dish

As it can be seen from figure 1.c, a parabolic dish is made of many mirror pieces, to reflect the direct sunlight on to a receiver located at the focal point of the dish. The HTF in the receiver absorbs the concentrated beam radiation and heated to approximately 750°C [1]. This heat is then used to generate electricity in a small piston or Stirling engine or a micro turbine, attached to the receiver, making the system appropriate for remote locations with a capacity of 10 kW power generation [3], or few installations are combined to collect the energy and convert it into electricity at a central generation unit.

1.2. Heat Transfer Fluids (HTF)

Typical heat transfer fluids can be water/steam, molten salts, liquid sodium or air. These mediums are highly used because of their higher heat capacities and heat transfer characteristics. Further, it is possible to pressurize the heated gas or air at very high temperatures of about 1,000°C or more to directly replace NG in a gas turbine, thus the combined cycle efficiency to 60% and more. A new generation of HTF salts was proposed by Li et al. (2014) [9]. They suggested binary and ternary eutectic halide salts mixtures such as KCl-AlCl3 and NaCl-KCl-ZnCl2 that have low viscosities and low vapor pressures that make them very favorable properties for HTF.

Usually in CSP, the two-tank molten salt is used as the TES as well as the HTF with only one set of heat exchangers between the HTF and the steam generators in the energy conversion step. This method
helps to minimize the heat exchanger size and ultimately increase the heat conversion efficiency as well as reducing the heat exchanger costs [10].

Figure 1. CSP technologies: (a) parabolic trough, (b) central receiver, and (c) parabolic dish [1].

1.3. Integrated Solar Combined Cycle (ISCC) Systems
The reduction in electricity generation due to low solar radiation during nights and cloudy periods is now supplemented by hybrid systems that use other conventional power plants (usually natural gas) simultaneously with the CSP plant. The integrated solar thermal with a fossil fuel such as natural gas turbine exceeds solar thermal-to-electric conversion efficiencies of solar-only plants [11]. In addition, the incremental increase in capital cost of ISCC due to a larger Rankine cycle is not comparable to the reduction in the annual levelized cost of solar energy. The first interest in ISCC system was initiated by Luz Solar International in 1990 [12]. In 2000, grants were offered for building ISCC systems to Mexico, Morocco, India, and Egypt by the Global Environment Facility [13]. Investigating the solar electricity efficiency, Behar et al. (2011) found it to be 15% and the ISCC efficiency to be 67% for the 150 MW plant in Algeria [14].

Currently, there are several operational solar thermal power facilities in the world. The oldest CSP facility in the world, is the Solar Energy Generating Systems (SEGS) in the USA. They started operation with one unit in 1984 and increased to combine nine units in 1990 [15]. The facility generates nearly 357 MW of electricity using parabolic trough technology. In addition, there are three other solar thermal power plants currently operating in the USA with generating capacity reaches 810 MW in total.

Many Arab and Middle Eastern countries have taken the initiative to establish ISCC power plants. Oil countries like Algeria and Iran have established CSP projects with 20, 17 MW capacities integrated with 150, 64 MW ISCC, respectively [16]. Also, CSP plants with capacities 380, 100, and 20 MW are currently operational in Morocco, UAE and Egypt, respectively, since 2013 [15]. All these plants are based on concentrating solar parabolic trough technology.

This study investigates the potential of ISCC power generation in Iraq investing in the abundance of sun radiation and natural gas resources. Various areas of Iraq are examined for the best location of projected CSP plant. Also, cost estimation of the ISCC plant is performed.

1.4. Prospect of concentrated solar power in IRAQ
Iraq is one of the main producers of oil and natural gas. The country production reached 4.362 MBur/day crude oil and 420 Billion ft³ NG in 2017. With this capacity Iraq generates 102.64 MT CO₂ annually from flaring and consumption of fossil fuels². Realizing the environmental impact and climate change caused by CO₂ emissions and contributing to the global efforts to mitigate those impacts, would translate into effective actions by looking for available alternatives for energy sources and help reservation of natural resources.

In the same time, Iraq is in one of the characteristic areas for solar thermal power generation. According to MED-CSP-DLR Concentrating Solar Power for the Mediterranean Region report, Iraq has a range of 1800-2390 kWh.m⁻².yr⁻¹ of direct normal irradiation DNI solar energy. This beam radiation can be used in the solar thermal power production. As shown in figure 2 and figure 3, most of Iraqi landscape
is appropriate for installation of CSP plants [3]. From DNI and CSP site mapping in figure 3, taking sites with DNI > 2000 kWh/m²/y as economic potential, Iraq can produce 28,647 TWH/yr as expected by the DLR report mainly in the western parts of the country. Also, the report anticipated Iraq’s power demand in 2050 at 257 TWh.yr⁻¹, of which 74% can be provided by CSP technology. Table 1 represents these data.

Figure 2. Exclusion areas for concentrating solar thermal power plants in Iraq. [3]
Figure 3. Annual direct normal irradiation in kWh/M²/Y in Iraq. [3]

| Power Potential      | Value  | Units                     |
|----------------------|--------|---------------------------|
| Technical potential  | 30,806 | TWh/yr (DNI> 1800 kWh/m²/y) |
| Economic potential   | 28,647 | TWh/yr (DNI> 2000 kWh/m²/y) |
| Power demand 2000    | 31     | TWh/yr                    |
| Power demand 2050    | 257    | TWh/yr                    |
| Tentative CSP 2050   | 190    | TWh/yr                    |

2. Methodology
Data of planned power plants in Iraq for the next five years are collected from the website of Ministry of Electricity and studied as projected locations for the ISCC plants. The selected areas or provinces were examined for the DNI intensity and space availability for a CSP plant combined with NG power stations. Data from NASA Langley Research Center Atmospheric Science Data Center Surface meteorological and Solar Energy (SSE) web portal [17] were used to identify the DNI in each location.

Taking Al-Anbar location as an example of a potential ISCC power plant in Iraq, with CSP capacity of 50 MW and 200 MW NG combined cycle steam turbine, the Jobs and Economic Development Impact model (JEDI)- CSP Parabolic Trough model/NG of National Renewable Energy Laboratory (NREL) – release no. CSP1.0801a and NG1.0801 was used to calculate the cost parameters of the proposed plant. There were reductions in construction costs by 30% and annual personnel expenses by 30% to modify the model to a more realistic assumptions based on Iraqi workforce environment and economic situation.
Also, the steam turbines and generators cost were eliminated from the model assuming it will be included in the NG calculations.

In addition, the RETScreen of Natural Resources Canada; a green energy management software was used to estimate the CO₂ emission mitigation with the proposed CSP plant [18]. Table 4 lists the projected capacity and cost parameters of the plant.

Table 2. Projected capacity and cost parameters of 50 MW CSP/200 MW NG plant based on JEDI model.

| Cost parameter                        | CSP Plant | NG Plant |
|---------------------------------------|-----------|----------|
| Year of Construction                  | 2019      | 2019     |
| Project life span                     | 25        | 25       |
| Solar Direct Normal Resource (kWh.m⁻².yr⁻¹) | 6.33      |          |
| Project Size - Nameplate Capacity (MW)| 50        | 200      |
| Solar Field Aperture Area (m².MW⁻¹)   | 10,000    |          |
| Plant Capacity Factor                 | 33.3%     | 65%      |
| Heat Rate (Btu per kWh)               | --        | 7000     |
| Construction Period (Months)          | 36        | 36       |
| Money Value (Dollar Year)             | 2018      | 2018     |
| Cost of Fuel ($/MMBtu)                | --        | $3.63    |
| Percentage financed by loan           | 60%       | 80%      |
| Years to payback                      | 20        | 20       |
| Interest rate                         | 10%       | 10%      |

3. Results & Discussion

3.1. Projected areas in Iraq for ISCC plants

High solar radiation and plain land are only one good reason to promote Iraq’s solar power technology. The continuous shortage and desperate need for reliable power due to the lack of new power plant projects for many years, continuous war, and rapidly increasing demand for power are equally important reasons. Therefore, Iraq’s Ministry of Electricity (MOE), with the support of international loans, started to invest in rehabilitating and upgrading the electricity grid, and plans to establish 11 plants with a total capacity of 5,250 MW over the next five years. MOE in Baghdad has requested bidding on several power plant projects in different areas all over the country [19]. Table 3 shows the list of those projects, locations, and capacity. Interestingly, there are few projected investment plants for solar power in some of the Iraqi provinces, not clear if they are solar thermal or photo voltaic panels, though. Consequently, there is a possibility to reconstruct the technology of those plants to combine a CSP plant with NG steam generation turbine in an integrated steam combined cycle (ISCC) technology.

The projected locations for those power plants were studied for potential solar-thermal capacity depending on the DNI data that are collected from NASA Langley Research Center Atmospheric Science Data Center Surface meteorological and Solar Energy (SSE) web portal [17]. The annual normal solar radiation measured in kWh.m⁻² of Najaf, Diwaniyah, Kerbala, Nainawa, Al-Anbar and Basrah were plotted in figure 4.
Table 3. Projected power plants for the next five years in Iraq [19].

| Governorate                         | Station                   | Fuel      | Total MW | No. of units |
|-------------------------------------|---------------------------|-----------|----------|--------------|
| Middle Electricity Co.              | East Baghdad              | Fuel oil  | 250      | 8            |
| Babil                               | New Babil                 | fuel oil  | 1000     | 4            |
| South Electricity Co.               | Mobile Stations           | Fuel oil  | 420      | 14           |
| South Electricity Co.               | Mobile Stations           | Fuel oil  | 175      | 6            |
| Ninevah                             | Mobile Stations           | Fuel oil  | 375      | 12           |
| Al-Najaf                            | Najaf Gas Station         | Gas       | 250      | 2            |
| Al-Najaf                            | Haydariyah gas Station    | Gas       | 500      | 4            |
| Karbalaa                            | Karbalaa Gas Station      | Gas       | 250      | 2            |
| Kirkuk                              | Kirkuk Gas Station        | Gas       | 560      | 2            |
| Al-Basrah                           | Khur Zubair Gas Station   | Gas       | 250      | 2            |
| Al-Anbar                            | Khayarat Gas Station      | Gas       | 1250     | 10           |
| Diwaniyah                           | Dagharrah Solar Power Station | Solar | 5          | 1            |
| Diwaniyah                           | Siniyah Solar Power Station | Solar | 5          | 1            |
| Al-Najaf                            | Haydariyah gas Station    | Solar     | 10       | 1            |
| Maysan                              | Wind power station        | Wind      | 5        | 1            |
| Al-Muthanna                         | Al-Salman power station   | Solar     | 50       | 1            |

Figure 4. Average annual normal solar irradiation in six Iraqi cities.

From figure 4, it can be seen that all locations have DNI more than 2000 kWh.m⁻².yr⁻¹, with the highest value in Al-Anbar at 2310.45 kWh.m⁻².yr⁻¹, which makes it the most prominent location for a CSP plant in Iraq. With simple calculations for a certain area such as 200,000 m² the possible annual power capacity from solar thermal radiation in Al-Anbar city will be 52.75 MW. Table 4 shows the possible power generation in six projected locations.
Table 4. Possible CSP power production at 200,000 m² in selected areas of Iraq.

| Area in Iraq | Lat., Longitude | Av. daylight h.day⁻¹ | AV DNI, kWh.m².day⁻¹ | kWh.m² yr⁻¹ | MWh.yr⁻¹ | Possible Power capacity, MW |
|--------------|-----------------|----------------------|----------------------|-------------|-----------|-----------------------------|
| Naenawa      | 43, 44          | 12.16                | 6.00                 | 2190        | 438,000.00 | 50.00                       |
| Al-Anbar     | 33.5, 42.5      | 12.14                | 6.33                 | 2310.45     | 462,090.00 | 52.75                       |
| Kerbalaa     | 31, 44          | 12.13                | 6.11                 | 2230.15     | 446,030.00 | 50.92                       |
| Al-Najaf     | 31, 45          | 12.12                | 6.09                 | 2222.85     | 444,570.00 | 50.75                       |
| Diwaniyah    | 30, 46          | 12.11                | 6.00                 | 2190        | 438,000.00 | 50.00                       |
| Al-Basrah    | 30, 47          | 12.11                | 5.76                 | 2102.4      | 420,480.00 | 48.00                       |

However, the monthly DNI data in these locations, indicate that there will be high reduction in power generation of winter months. This is due to less daylight hours and DNI amount. Figure 5 shows the monthly DNI on the projected locations.

3.2. Economic Advantages of ISCC

As mentioned in section 3.1, the ISCC enables the country to cover winter time with gas-generated power. Meanwhile, highest DNI during summer time in Iraq, responds to the peak demand of power and reduce the need for gas-produced power. Combined cycle with a gas plant would also offer free transition lines for the solar plant, a critical technical and economical factor for many renewable power plants.

More importantly, combining a solar parabolic trough plant with a gas-powered plant reduces costs of the second steam turbine, second generator, and associated equipment. Depending on the cost share with the conventional fuel plant, the overall cost of the solar thermal system can be reduced by 20 percent or more. Far more from other emerging concentrating solar technologies, parabolic trough technology is commercially proven at scale. This should make donors or lenders such as the European governments more comfortable to support with loans or grants for an ISCC plant, rather than a CSP plant alone.
3.3. Monthly power output
The variance of monthly solar irradiation resulted into variant CSP power output throughout the year. During summer the highest power output is in June at 21,276 MWh, whereas, the minimum power output is in December at 7740 MWh. During winter months the reduction in the CSP plant can be subsidized by increasing the NG power generation. Thus, the total monthly power output will remain constant at 107,813 MWh. The total annual power output is 1,284,654 MWh and the annual power output of the CSP plant is 145,854 MWh that is 11.3% of the total power generation. Figure 6 shows the variation of CSP and NG power plants output throughout the year.

Figure 5. Monthly average direct normal radiation of selected areas in Iraq.

Figure 6. Monthly power output in MWh for CSP, NG, and total ISCC.
3.4. Cost Estimation of ISCC power plant

Taking Al-Anbar location as an example of a potential ISCC power plant in Iraq, with CSP capacity of 50 MW and 200 MW NG combined cycle steam turbine, the JEDI- CSP Parabolic Trough model/NG of NREL – release no. CSP1.0801a and NG1.0801 were used to calculate the cost parameters of the proposed plant. Economic calculation results are listed in Table 5. Clearly, the capital cost of the CSP is about four times of an NG plant with similar capacity, however, the annual operational cost would be less than 50% of NG plant with the same plant size. This result indicates the economic benefits of the CSP technology for the long-term operation.

The levelized cost of electricity (LCOE) in $/MWh was calculated as follows:

$$LCOE = \frac{\text{total life cycle cost}}{\text{total lifetime of energy production}}$$  \hspace{1cm} (1)

From the cost analysis in Table 5, the addition of CSP power plant with 50 MW capacity increased the LCOE only by 11%.

| Parameter                  | CSP plant | NG plant | Total ISCC |
|---------------------------|-----------|----------|------------|
| Capacity, MW              | 50        | 200,000  | 250        |
| Capacity factor           | 33%       | 65%      |            |
| Yearly operation, h       | 2,917     | 8760     |            |
| Annual power gen, MWh     | 154,958   | 1,138,800| 1,284,654  |
| Construction cost, $/kW   | 3,630     | 1,820    | 5,451      |
| O&M Cost, $/kW            | 34        | 164      | 197        |
| Total Capital cost, $      | 181,507,794 | 91,024,638 | 272,532,432 |
| Total annual O&M cost, $   | 1,688,281 | 32,717,249 | 34,405,530 |
| LCOE, $/MWh               | 58        | 32       | 35         |
| Jobs created              | 548       | 310      | 858        |

3.5. CO2 emission mitigation

According to the RETScreen software of Natural Resources Canada, the CO2 emission factor of NG fuel consumption is 0.556 tCO2/MWh. Thus, producing 50 MW of electricity with CSP technology will save the globe 81,030 tCO2 emission, that is equal to 405 tCO2 per each square meter of CSP. It is equivalent to not using 16,473 cars. Assuming a Carbon Credit trading for this CO2 emission, in a price of $40 /ton, there will be a total saving of $ 3,241,200 per year. Knowing that Iraq has signed the 2015 Paris agreement of climate change, the country can trade this carbon credit to other industrial countries. This will contribute in reduction of annual cost by 5.4% and contribute to the global adaptation to climate change.

4. Conclusions

Iraq has excellent solar radiation on most of its landscape, ranging from 1,800 to 2,390 kWh/m2/yr of direct normal irradiation, being a flat plane makes it appropriate for a CSP plant. Further, the abundance of natural gas resources for power generation, enhances the opportunity for integrated solar combined cycle power plant (ISCC), specially with the Ministry of Electricity plans to develop new 5,500 MW in total capacity conventional power plants. These planned plant locations were analysed for potential ISCC
sites. All of these sites receive enough solar radiation, though, the optimal site would be in Al-Anbar, which according to NASA data receives 2,310 kWh.m\(^{-2}\).yr\(^{-1}\). Compared to a similar 50 MW of NG plant, combining a relatively small, 50 MW concentrating solar thermal plant to one of the planned 200 MW NG plants would reduce the annual operating and maintenance cost by 8%, reduce carbon dioxide emissions in Iraq by nearly 81,000 metric tons per year, increase the LCOE by 9%, though. Co-locating with a gas plant would also offer free transition lines for the solar plant, though, a critical technical and economical factor for many renewable power plants.

Moving forward with solar thermal technology would show that Iraq is technically recovering, and empowering Iraqi expertise in an emerging power generation technology with a potential of export. This prove Iraq’s contribution to the international commitment to climate change mitigation. Further investigations on other CSP technologies such as the central tower and energy storage possibility is recommended.

References

[1] R. Aringhoff, G. Brakmann, M. Geyer and S. Teske, “Concentrated solar thermal power -now!,” European Solar Thermal Industry Association, Brussels, 2005.
[2] R. Sioshansi and P. Denholm, “The Value of Concentrating Solar Power and Thermal Energy Storage,” NREL, Golden, CO, USA, 2010.
[3] F. Trieb, “Concentrating Solar Power for the mediterranian region,” German Aerospace Center (DLR), Stuttgart, Germany, 2005.
[4] A. Leitner and B. Owens, “Brighter than a Hundred Sun: Solar Power for the Southwest,” National Renewable Energy Laboratory, Golden, CO, USA, 2003.
[5] Observatoire Méditerranéen de l’Energie, “Solar Thermal In The Mediterranean Region: Solar Thermal Action Plan,” UNDP, Nanterre, France, 2012.
[6] General Atomics, “Therochemical Heat Storage for Concentrated Solar Power,” US Department of Energy, Washington DC, 2011.
[7] EIA, “Solar explained: Solar Thermal Power Plants,” US Energy Information Administration, 16 1 2018. [Online]. Available: https://www.eia.gov/energyexplained/?page=solar_thermal_power_plants. [Accessed 30 10 2018].
[8] O. Abdalla, R. Al-Badwawi, H. Al-Hadi, H. Al-Riyami and A. Al-Nadabi, “Steady-State and Transient Performance of Oman TRansmission System with 200MW concentrated Solar Power Plant,” Helwan University, Oman, 2011.
[9] C.-J. Li, P. Li, K. Wang and E. Molina, 2014 “Survey of Properties of Key Single and Mixture Halide Salts for Potential Application as High Temperature heat Transfer Fluids for Concentrated Solar Thermal Power Systems,” AIMS Energy, 2(2), pp. 133-157.
[10] L. Ciocco, M. Belusko, F. Bruno, J. Boland and P. Pudney, “Optimization of Storge for Concentrated Solar Power Plants,” Challenges, 5(2), pp. 473-503, 2014.
[11] B. Kelly, U. Herrmann and M.-J. Hale, “Optimization studies for integrated solar combined cycle systems,” in Proceedings of Solar Forum Solar Energy: The power to choose, Washington, DC, 2001.
[12] T. e. a. Johansson, “Renewable Energy,” in Sources for fuels and electricity, Washington, DC,
Island Press, 1993, pp. 234-239.

[13] Spencer Management Associates, “*Mexico Feasibility Study for an Inegrated Solar Combined Cycle system (ISCCS)*,” World Bank, Washington DC., 2000.

[14] O. Behar, A. Kellaf, K. Mohamedi and M. Belhamel, 2011 “Instantaneous performance of the first Integrated solar Combined Cycle System in Algeria,” *Energy Procedia*, Vol. 6, pp. 185-193, 2011.

[15] SolarPACES, “Worldwide SCP,” SolarPACES, 2017. [Online]. Available: https://www.solarpaces.org/csp-technologies/csp-potential-solar-thermal-energy-by-member-nation/iran/. [Accessed 15 11 2018].

[16] “ABENGOA SOLAR,” Abengoa Solar S.A., 2014. [Online]. Available: http://www.abengoasolar.com/web/en/plantas_solares/plantas_para_terceros/argelia/. [Accessed 15 11 2018].

[17] NASA, NASA Langley Research Center Atmospheric Science Data Center Surface meteorological and Solar Energy (SSE) web portal, 15 10 2008. [Online]. Available: http://eosweb.larc.nasa.gov/. [Accessed 20 11 2018].

[18] Natural Resources Canada, “Natural Resources Canada,” Canadian Government, 20 9 2018. [Online]. Available: https://www.nrcan.gc.ca/energy/software-tools/7465. [Accessed 10 11 2018].

[19] MOE, “MOE-Bidding program,” MOE, 17 July 2015. [Online]. Available: https://moelc.gov.iq/index.php?name=portalallmonaksa. [Accessed 20 11 2018].

Acknowledgement

The solar irradiation data were obtained from the NASA Langley Research Center Atmospheric Science Data Center.