The Potentials of Concentrating Solar Thermal Power (CSTP) in Meeting Saudi Future Energy Gap

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***Abstract*— Saudi Arabia is the world's largest crude oil producers, but second to Venezuela in terms of proven oil reserve, with about 10 million barrels per day of crude oil production. The rapid increase in the domestic consumption is now a concern as it accounts for about a quarter of the daily production. Saudi consume a quarter of its daily crude oil production on desalting water, electricity and transportation. The country's economy hinged on the proceeds from crude oils which is around 45% of its GDP. The government desire to diversify its economy and increase its share of crude oil exportation is attracting efforts in integrating renewable energy into its stream of crude oil base desalination systems and electricity generation. This work review the roles that concentrating solar thermal power technologies can play in renewable energy integration in Saudi Arabia energy consumption.**

***Keywords*—Solar PV; Solar CST; Desalination; Energy; Saudi Arabia**

I. Introduction

The kingdom of Saudi Arabia covers the bulk of the Arabia Peninsula, a region characterize with desert climate of high temperature and less or no precipitation. The country's climate requires huge amount of energy to create comfortable space for human existence (see Figure 1). Energy consumption in Saudi Arabia is the fastest growing in the Middle East, especially energy from electricity due to massive cooling demand because of the weather condition and energy required for sea water desalination. The electricity demand in the last decade grew at an annual average rate of 8%. In 2001, the peak load was 24GW and as at 2011 the peak load was 47.3GW with total installed capacity (both government and private producers) about 53 GW. It is projected that the country peak demand will approach 75GW in 2020 and about 120GW in 2032 if this trends continues [1]. Currently, the mixed of primary energy for electricity generation uses 65% of Oil, 27% of Natural Gas and 8% of waste heat from desalination plants. Since this current trend of energy mixed is not sustainable (due to environmental concerns), the need to integrate conservation policies and alternative energy will alleviate waste and consequently future energy poverty. The Kingdom of Saudi Arabia geographical location place it at an advantage to utilize solar energy in offsetting part of its domestic energy consumption.

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The abundance of freely available solar irradiation, an average of 2,200 thermal kilowatt hours (kWh) of solar energy per square meter of land area every day in Saudi is waiting to be harness for either electricity generation or for thermal energy required in the desalination plants. The intensity of the solar energy per square meter of land area coupled with efficient Photo voltaic (PV) cells or Concentrated Solar Thermal Power (CSTP) technologies will offset the total future energy demand. The King Abdullah City for Atomic and Renewable Energy (K.A.CARE) have targeted about 16GW of electricity from Solar PV and a target of 25GW from Concentrated Solar Thermal Power (CSTP). The realization of these targets are functions of appropriate technology that can efficiently convert the solar energy into useful energy. In light of these, this paper review potential technologies in CSTP.

II. Energy demand and supply in Saudi Arabia

Saudi energy demand has been fueled mainly by increase in population, the climatic condition and cheap cost of energy. According to United Nation statistics on Saudi Arabia, the population grew by more than 180 percent between 1980 and 2010 [2]. The high temperature in the kingdom requires space cooling which account for more than 70% of residential energy consumption. As seen in Figure 1 most months are with daily temperature higher than 32 Celsius. In addition Saudi desalinate an average of 3.5 million cubic meters of water a day, these processes are energy intensive. Energy is also expended in transporting fresh water through a 5000 Km pipes across the country. In fact, the per capita consumption of water in Saudi is 235 liters a day, a value nearly twice the global average. Prices of energy in Saudi is one of the lowest in the world with a liter of gasoline sold for $0.12 and with electricity price of $0.03 and $0.06 per kilowatt/hour depending on use category. Table 1 shows the electricity capacity, transmission and distribution networks in the country [3]. As seen in Table 1 the number of Saudi Electricity Company customers grew from 3.5 million in 2000 to 6.3 million in 2011 a percentage increment of 80.2%

Figure 2 shows the trend of Electricity Consumption per capita from 1971 to 2010. The trend suggest that demand for electricity increases on yearly bases. In Figure 3, it will be observed that the majority of electricty consumption is in the residential sector with about 75% of the total electricity production. Figure 4 shows elecetricty consumption comparison between the day and the night, with a constant difference throughout the year. Figure 5 shows the forecasted peak demand between 2010 and 2032.

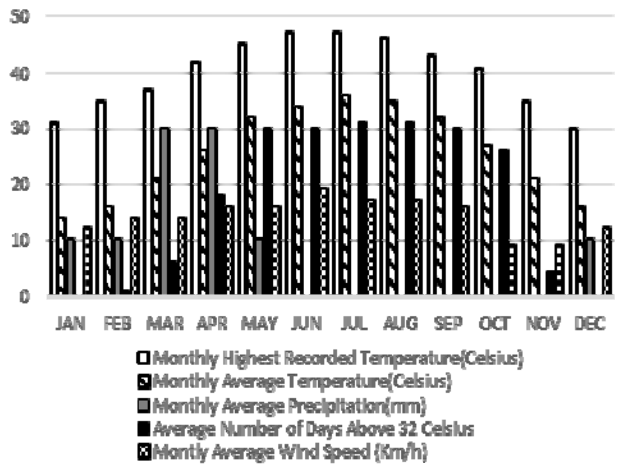

Figure 1. Average Monthly Weather Parameter in Saudi Arabia

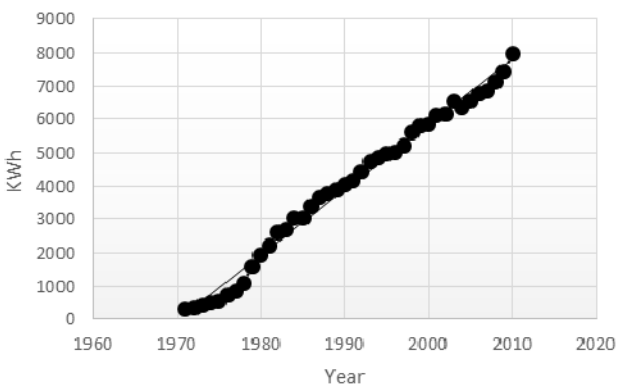

Figure 2. Electricity Consumption per capita (Source: World Bank)

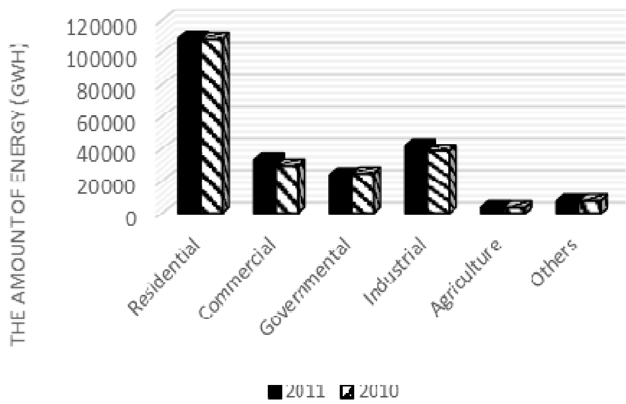

Figure 3. Sectoral Share of Electricity demand in Saudi Arabia

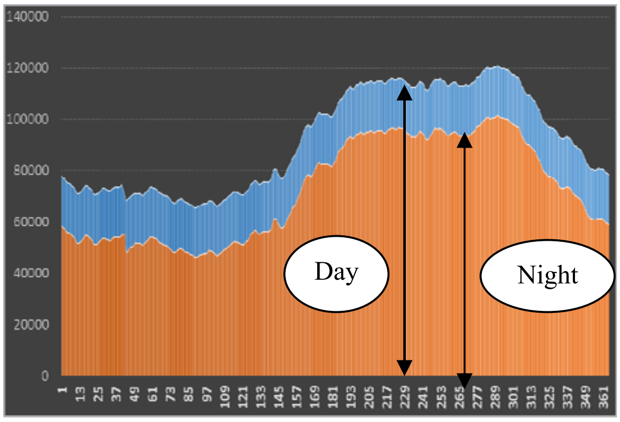

Figure 4. Saudi Arabia Day–Night Load variation for one year (KWh)

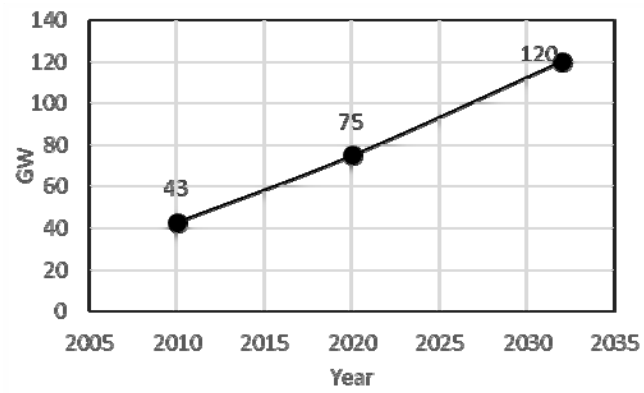

Figure 5. Forecasted Peak Demand (GW)

TABLE I. SAUDI ELECTRICITY KEY INDICATORS [3]

	Year 2000	Year 2011	% of Change
Available Generation Capacity (MW)	24,083	51,148	124
Transmission Network Lines (ckm)	29,166	49,675	70
Distribution Network Lines (ckm)	219,076	409,286	86.8
Number of Customers (Millions)	3.5	6.3	80.2

TABLE II. SUMMARY OF CURRENT CSTP OPERATING CHARACTERISTICS [4]

Operating characteristics of CST technologies							
CST Technology	**Concentration ratio (times)**	**Operating temperature**	**Unit Capacity range**	**Peak efficiency (%)**	**Average Solar to electric efficiency (%)**	**Annual capacity factor**	**Status**
Dish Engine	500-1000	600-1500 °C	5-50 kWe	29	15-30	25 % (p)	Demonstration and testing at 10 MWe scale
Power Tower	10-100	400-600 °C	30-200 kWe	23	12-18	25-70 % (p)	Prototypes tested at 25kWe
Parabolic Trough	600-3000	100-400 °C	30-100 kWe	21	8-12	24 % (d)	20 years of operation

(d) =Demonstrated, (p) = projected based on demonstration testing.

TABLE III. SUMMARY COMPARISON OF THREE DIFFERENT CSTP TECHNOLOGIES [5]

Dish Engine	Power Tower	Parabolic Trough
Applications		
1. Stand-alone, small off-grid power systems	1. Grid connected plants, high temperature process heat	1.Grid connected plants, mid to high process heat
2. Can be clustered to form larger grid connected		
Advantages		
1. Very high conversion efficiency	1. Good prospects for high conversion efficiencies operating potential beyond 1000°C (565 °C proven)	1. Commercially available-over 12 billion kWh in operation
2. 30% Peak Solar to electrical efficiency	2. Storage at high temperature	2. Operating temp potential up to 500°C (400 °C proven)
3. Modularity	3. Hybrid operation possible, but not proven	3. Commercially proven net plant to net electric efficiency (η) of 14%
4. Hybrid operation possible, but not proven		4. Modularity
5. Operational experience on demonstration		5. Commercially proven investment projects and operation cost
		6. Best land use factor of all Solar technologies
		7. Lowest material demand
		8. Hybrid concept proven
		9. Storage capability
Disadvantage		
1. Needs improvement in reliability	1. Projected annual performance values, investment and operating costs still need to be proven commercially	1. Use of oil-base heat transfer limits temperature to 400 °C yielding only moderate steam quality
2. Projected cost goals of mass production		2. Long (70km) continuous still need to be achieved through the parabolic trough collectors which make it susceptible to breakdown interruptions

TABLE IV. SUMMARY OF CURRENT COST ESTIMATES FOR DIFFERENT CSTP TECHNOLOGIES [5]

Cost estimates									
CST Technology	Dish Engine			Power Tower			Parabolic Trough		
	2005	2010	2020	2005	2010	2020	2005	2010	2020
1. Levelized electricity cost (USD/kWh)	0.15	0.10	0.06	0.06-0.11	0.06-0.07	0.40	0.10	0.05-0.08	0.07
2. Capital cost (USD/W)	5.00	3.20	1.20	2.80-4.10	2.10-3.50	1.10-2.50	2.60-3.60	2.20-0.90	1.40
3. O&M costs (USD cents/kWh)	4.00	1.50	0.90	1.00-1.20	0.40-1.00	0.30	1.00	0.50-0.70	0.40
4. Surface costs (USD/m^2)	3000	1500	320	475	265	200	630	315	275
5. Uncertainty		Moderate			Moderate			Low	

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There is now an extensive acknowledgment in Saudi that with the rising local demand for energy (Electricity, Transportation Fuel and Energy for Desalination) there will be a drop in crude oil exportation. The current mixed of energy (Oil, Gas and Steam from Desalination plants) for electricity production is not sustainable and efficient, the need to integrate renewable energy sources is expedient. Consequently the national government is promoting renewable energy by the creation of King Abdullah City for Atomic and Renewable Energy (K.A.CARE). This agency is responsible for Research and Development (R&D), policies and implementation of atomic and renewable energy integration into the energy mix in Saudi through collaboration with higher education institutions and research laboratories. In the Saudi Renewable Energy roadmap, K.A. CARE is targeting 25 GW of energy from CSTP. In order to realize the target, a comprehensive understanding of concentrating solar thermal is required for selection of appropriate technologies. Thus, CSTP technologies trends and feasibility in Saudi were discussed in this work.

III. Concentrating Solar Thermal Technologies

Solar Photovoltaic uses the solar cells to convert the solar energy directly to electricity. The solar cells are usually made of silicon, a semi-conductor material which conduct electricity under certain condition. This type of conversion is characterized with energy losses and are not economical for electricity generation as compared to solar thermal technology. In solar thermal technology, solar thermal collectors are used to convert the solar energy(radiation) to heat, then the heat is used to generate steam which is use to turn turbine (mostly low pressure turbine) or to produce shaft power in driving the electricity generator. The generated heat can be stored in a thermal storage for use at night or the system can be coupled with a fossil power system (in case of Saudi) which will operate when the sun energy is not available. Chein and Lior (2011) pointed out three significant benefits of CST as (i) ability to use conventional technologies and materials allowing for CST systems to scale with existing infrastructure (ii) flexibility and modularity to suit the needs of large utility-scale central power facilities and (iii) relative simplicity in construction, operation, and maintenance because they are comparable in general with conventional thermal power generation systems [5]. On commercial scale operation, this technology has proven to be economical and easy to incorporate technological developments [6]

There are three main types of CSTP technologies depending on the size, operation application and cost. Table 2-4, show the comparison of these technologies in terms of operating characteristics, advantages & disadvantages, and cost. The dish engine is modular meaning it can be used as a decentralized system due to its small capacities. This system will be attractive in case of new electricity production for rural areas of Saudi as a decentralized system feeding small communities, these will save on power transmission cost if the same electricity is to be supply from the centralized system. For integration into the existing system (centralized system), power tower and parabolic trough will much adequate due to high power output potential and can be utilized readily for the transmission network lines available in the kingdom. These two CST types can also be integrated or coupled with other sources for a round the clock electricity generation. The parabolic trough system seems more suitable for use in Saudi due to its proven technology. It is commercially available, fast delivery if required, with proven operational efficiency. In comparison with the other types it has the best land-use factor with lowest material demand and proven hybrid concept. In addition, it has huge storage capability as compare to others. In terms of the levelized electricity costs ($/kWh) there was decrease from 2005 cost of 0.1 to around 0.05 in 2010. Operating and maintenance cost for this type of CST is very low. Although, this system is without short comings such as the need for increase efficiency, susceptible to breakdown interruptions etc.

IV. Feasibility of Parabolic Trough Concentrating Solar Thermal Technology in Saudi

Accessing the potential of parabolic trough system in electricity generation and desalination in Saudi require the identification of influencing parameters such as daily solar radiation, land, medium fluid (water or sand), transmission and power grid, demand, grid infrastructure, economics variables, and environmental consideration. These factors will go a long way in determining the success of implementation of such a system. But with the increase in demand trend of fresh water and electricity consumption, and the concern of environmental pollution from fossil power electricity plant, it is time for Saudi to embark on clean energy.

One viable option is to embark on solar combined-cycle plants where the CSTP is combined with fossil plants. The General Electric (GE) and California solar thermal cooperation that led into the development of a hybrid natural gas and solar thermal technology in 2011 is a classic example. The hybrid plant is referred to as a solar combined-cycle plants. The coupling of an existing conventional plant with a CSTP system is capable of increasing the overall efficiency of the plant. In the General Electric and California solar thermal hybrid system efficiency in the facility is increased up to 70 percent. Additionally, this process helps to significantly reduce the negative impact of emissions. GE's first of such facilities will include 50 megawatts of solar thermal technology, and will be operational by 2015 [8].

Integrating solar-thermal technology with fossil power plants in Saudi means no additional cost involving steam turbines, generators, and pumps, condensers, heat exchangers will be incur, as the fossil power plants already have all these facilities. The desalination and electricity facilities in Saudi already have huge land mass that can accommodate the integration of the parabolic troughs into the environments. The needed direct normal irradiation (DNI) for CSTP system is high in Saudi as seen in Figure 6, especially at the coast where the desalination plants are located. The average DNI is around 2000 kWh/m^2 which highest DNI in Tabuk region with 2400 kWh/m^2. One potential problem with the use of CSTP system in Saudi is the water availability, although areas where DNI are high also have access to seawater. Currently, the potential of sand instead of water in CSTP is been understudy [10].

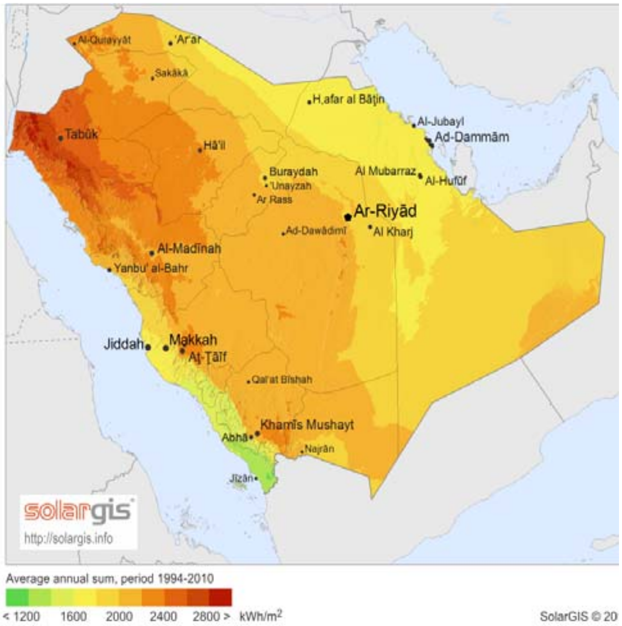

Figure 6. Direct Normal Irradiation (DNI) data for Saudi [9]

V. CONCLUSION

The use of CSTP in Saudi for both electricity and desalination is feasible with some few constrains. One constrain is water availability. But with current research of using sand instead of water, the CSTP is more feasible. Even as it is now, it's feasible with a hybrid system that can use CSTP and fossil fuel for energy production (e.g MED+CSTP system). More research are ongoing on this issue, this work raises the potential of CSTP and certain factors than can limit its use in Saudi. The work revealed the local water and electric consumption in Saudi with yearly growth. The trend suggest that the current energy mix cannot meet the demand without affecting Saudi daily crude oil exportation capacity. The Country need policies that will emphasis energy conservation among the citizen and the integration of the renewable energy sources, especially CSTP and PV, to its existing fossil power electricity and desalination plants.

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