Desalination and Water Treatment
www.deswater.com

36 (2011) 219–238
December

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doi: 10.5004/dwt.2011.2474

Prospect of using alternative energy for power and desalted water productions in Kuwait

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Received 15 November 2010; accepted 5 May 2011

ABSTRACT

Extensive research is conducted in Kuwait to apply renewable energy (RE) for electric power (EP) generation. The Kuwaiti Ministry of Electricity and Water (MEW) formed a committee to study the introduction of solar energy to generate EP. Meanwhile, the government formed a committee to take the necessary steps to build the first nuclear power plant (NPP) for EP production and desalting seawater. This study addresses the technical and economical aspects of using NPP and RE in generating EP in Kuwait in comparison with presently used combined cycle stations which are operated with natural gas or oil fuel. The results of this study indicate that installing wind energy (WE) or solar cells photovoltaic solar cells (PV) power plant (PP) cannot be considered a capacity addition. Capacity addition is required to handle the ever increasing peak load. The WE and PV PPs are primarily fuel savers for the existing fossil fuel plants. The intermittent and the non-dispatchable nature of the WE and PV plants make them unable to generate consistent output like fuel-fired PPs. Their output should be taken by the grid and this decreases the load on the operating dispatchable PPs and thus reduces their fuel consumption. Among the thermal solar concentrating PP options (solar tower, solar dish with Stirling engine, and parabolic trough mirrors), the ones using parabolic trough are the only solar type PP that have reached commercial maturity with well-proven records of reliability and availability. This type of PP should be augmented with supplementary fossil fuel or thermal storage system to become a dispatch-able plant.

Keywords: alternative energy, desalination, electric power, solar energy, combined gas/steam power plants, nuclear power plants, wind energy, levelized energy cost, dispatchability, photovoltaic, concentrated solar power.

1- Introduction

Kuwait is a small country in the North East of the Arabian Peninsula. It has very hot summers and very scarce freshwater resources. Desalted seawater (DW) is the main source of fresh water. Electric power (EP) is essential to drive the desalting water plants, especially the recently used seawater reverse osmosis (SWRO) plants; and the pumps of the widely used multi-stage flash (MSF) desalting units. EP is used to power air conditioning (A/C) units, which are essential for summer living in Kuwait. It also provides power for industrial, residential, and public buildings. The Kuwaiti government carries the responsibility of the EP and DW production and distribution, which is administered by the Ministry of Electricity and Water (MEW). This is due to the high cost needed to build and run both power plants (PPs) and DW plants. The

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government subsidizes both EP and DW to keep them at low prices in order to provide stimulus for economic development. The MEW utilizes the most economical ways to build EP and DW plants.

The MEW published statistical data for the year 2008 [1], pointed out that the population of 3.44 million (M) consumed 45,234 GWh of EP, or 13.14 MWh per capita per year. The installed PPs has 11.64 GW capacity, and the peak load was 9.71 GW, or 83.4% peak to installed capacity percentage ratio. In the period of 1988 to 2008, the annual percentage increases of the relevant parameters were: 0.6% in consumed EP/capita, 5.2% in population, 5.8% in generated and consumed EP, and 5.6% in peak power.

This means that the consumed EP is expected to be doubled every 12 years; and 12 GW new PPs capacity addition are to be added by 2020 to meet the growing demand for EP peak load. The needed PPs are usually large units for base-load cheap electricity production. The needed 12 GW can be provided by, say, 6 large PPs of 2 GW each. Different types of PPs can be installed to meet this demand such as: PPs using fossil fuel (FF), nuclear energy (NE), or renewable energy (RE) sources. Environmental considerations can affect their type choice, but the main factor is the levelized electricity generating cost (LEC).

Few months ago, the MEW contracted with General Electric Company to build new 2 GW capacity Combined Gas-Steam Cycle power plant (GTCC) in Sabbiya North. The GTCC is inexpensive to build but its operation relies on natural gas (NG) fuel, which is expensive when compared with the fuel of nuclear power plants (NPP) or with free solar (SE) or wind energy (WE) sources.

In 2008, the fuel energy consumed by MEW to produce EP and DW was 549,324 billion British thermal units (BTU), or 580 million giga Joules (MGJ) or 94.7 million equivalent barrels (bbl) of oil energy (M bbl-E). The used fuel consisted of 73% oil (gas oil, heavy, and crude oils), and 27% NG at a cost of $6137 M, as estimated by MEW [1].

The annual consumed fuel energy by MEW to produce EP and DW in 2020 is expected to be double that of 2008 or 190 Mbbl-E at a cost of $12,350 M (assuming $65/bbl, as estimated by MEW in 2008).

The Kuwaiti fuel oil reserve is finite. It has better usage than being burned in steam generators (SGs) of steam PP or combustion chambers of gas turbines (GTs). The consumed fuel oil in PP drains the country's wealth gained from oil revenues. This oil can be either sold or kept in reservoirs for future use. Kuwait is the second highest world producer of CO_2 per capita (32.1 ton/y.capita in 2006), [2], due to the heavy usage of FF. The continuous increases in the consumed EP and DW, and thus the FF, prompt the government to look for alternative energy sources to be used for its future co-generation power desalting plants (CPDP). Since NE is a viable alternative energy source and can be used to operate the needed large capacity CPDP, the government formed a committee to take the necessary steps to build the first NPP.

The United Arab Emirates, with similar EP and DW requirements as that of Kuwait signed a $20.4 billion contract in December 2009 to build 5,600 MW NPP consisting of four reactors of 1,400 MW each. The chosen reactor type is light water pressurized water reactor LW-PWR, [3].

The use of NE is opposed by some groups. They suggest that RE such as SE and WE should be the answer to the environmental problems created by the FF combustion and its rising cost.

The benefits of using RE sources for EP and DW generations are undisputable in many aspects. When compared to FF (e.g., fuel oil or NG), the RE is sustainable (naturally replenished), free, and emits no polluting gases (such as sulfur oxides SOx, carbon monoxide CO, and nitrogen oxides NOx; and green-house gases GHG such as carbon dioxide CO_2, methane and NOx. Global energy policies, followed also by Kuwait, aim to reduce the GHG emission, specifically CO_2, through implementing energy efficiency measures and the use of RE. The RE sources used for EP production include hydro-electric, geothermal heat, bio-fuel, sun, wind, tides, wave, etc. The RE of concern here are the WE and SE, as other forms are not applicable in Kuwait.

SE can be converted to EP in two ways: photovoltaic (PV) and concentrating solar power (CSP) plants. The PV solar cells change sunlight directly to electricity. The CSP plants generate electricity by using the heat gained from SE collectors to heat a fluid. This fluid produces steam, which runs steam turbines operating EP generators. Wind turbines (WTs) can be arranged in wind fields located in-shore or off-shore. Both PV and WT generators produce direct current. This has to be converted to alternate current, in order to deliver their output to the electric grid. Presently SE and WE contribute very little to the world's electricity production. PV power generation on large scale is viewed as an emerging technology, while WE and parabolic trough solar thermal PP produce far more power today than PV plants. The solar trough plants have the potential to displace significant fossil-fired power generation, as illustrated later. The rising price for FFs in the next one or two decades can increase the RE economic competitiveness.

On the other hand, consideration of the SE (or WE) as real viable energy source is questionable for large capacity EP production. Their output cannot be considered as available power which can be called upon (*dispatchable*) due to their intermittent nature. Their output can decrease the load on the routinely operating PPs, and thus saves some of these PPs consumed fuel. The SE (or WE) PP cannot work alone. They need high back-up PPs (up to 90%), compared to about 20% back-up for FF or NE plants to allow for maintenance downtime. Other aspects of using RE (SE or WE) are the high cost of EP generation (in terms of \$/kWh) and the need for energy storage (such as batteries) in stand-alone SE (or WE) PP. Another obstacle for the development of RE sources is the lack of transmission systems, which bring the generated power to the load center.

Comparison between the use of NE and FF plants vs. RE (SE or WE) plants should not be given in general terms by numerating their advantages and disadvantages. It should be done for the case at hand to satisfy the specific needs of future plants in terms of PP type, required capacity, expected load, economic competitiveness, and availability.

The feasibility of using (and to what extent) SE (or WE) is discussed in this paper. SE and WE are then compared with the currently used GTCC and NE in view of required capacity. The capacity to be installed within the next 10 years in Kuwait is 10 GW. The GTCC operates with NG and/or oil, has higher efficiency and lower EP production cost than the steam or simple GT cycles. This is to help the decision-makers to make the proper choice.

Discussion is presented after defining some terms relevant to the different types of PP.

2. Capacity factor

The capacity factor (CF) of a PP is the ratio of the actual output from this plant over certain period of time (usually a year) and its output if it was operated at its full capacity over that time (year). Examples of CFs of different PP are: 90% for NPP, 80% for GTCC and conventional steam PP, 20% wind farm power, 11% for solar PV plants.

For example, if a NPP has 1,000 MW capacity and 90% CF, its EP production is:

$$\begin{aligned}\mathrm{EP} &= 0.9(\mathrm{CF}) \times 1000(\mathrm{capacity}) \\ &\quad \times 8760(\mathrm{h/y})/[1000(\mathrm{MWh/GWh})] = 657\mathrm{GWh}\end{aligned}$$

The term 8,760 h/y is the number of hours per year.

High CF (such as 80–90%) is usually obtained for plants that satisfy the base load requirements. It is less than 100% due to maintenance needs and re-fuelling of NPP.

In 2008, the installed capacity of all PP in Kuwait was 11,600 MW and the total EP production was 45,234-GWh, [1], and thus the CF was equal to:

$$\mathrm{CF} = 45234(\mathrm{GWh/TWh})/(11.64\mathrm{GW} \times 8760) = 0.4436.$$

This low (0.4436) CF is due to the fact that some of the PP units are partially operated (or not operated at all) if their output are partially (or not) needed to satisfy the imposed load. The load, most of the time, is usually below the peak load. Peaking units (usually simple GT of low efficiency), for example, may operate several hours only per year, and thus have very low CF.

The reason for low CF for RE PPs such as SE (about 11%) or WE (about 20%) is the unused capacity, when sun is not shining, or wind speed is not high enough to run the WTs. Winds are highly intermittent, and SE is variable due to the earth daily rotation in front of the sun and cloud cover. Meanwhile, solar PPs designed to operate by solar radiation only have power output well matched to summer noon (or afternoon) peak loads in areas of high cooling demands, like Kuwait. The operating periods of solar thermal PPs can be extended by using thermal storage or fuel-assisted boilers.

The CF can be used to adjust the capital cost to consider the PP ability of generating kWh's, rather than its nominal installed kW capacity. Assume, for example, the NPP of CF = 0.9 has a capital cost of \$4,000/kW nominal capacity. The adjusted cost for 100% CF in \$/kW (average generated capacity) is given by (\$/nominal kW)/CF, or \$4,444/kW for NPP. Typical capital cost in \$/kW for different PP types and CFs and the adjusted capital cost/kW are given in Table 1. This can remove the misconception that the wind power cost of \$2,000/kW with CF = 0.2 is cheaper than the more expensive capital cost/kW of \$4,000/kW for the NPP of CF = 0.9.

Table 1
Typical capital cost for different PP and their CF, and adjusted capital cost

Type of plant	Typical CF	Typical nominal Capital cost \$/kW	Adjusted capital cost \$/kW
NPP	0.9	4,000	4,444
CCPP	0.8	1,000	1,250
GT	0.4	600	1,500
PV	0.11	5,000	45,455
Solar thermal	0.11	3,800	34,545
WE	0.2	2,000	10,000

The CF should not be confused with the availability factor. The PP availability factor is defined by the amount of time this plant is able to produce electricity over a certain period, divided by the amount of the time in that period. The solar and wind PPs can have high availability factors, since the SE (or wind) PP can produce electricity almost all the time when sun is shining (or wind is forcefully blowing). For solar and wind power, the time period when sun rays or wind are not available is disregarded (not counted). For example, if the availability of solar PV is almost 100%, it is almost operating all the time when sun is shining.

3. Desalting plant

The most energy-efficient desalting plant type is the SWRO with energy recovery (e.g., pressure exchanger). This is the logical type to be considered for future plants desalting plants. Its specific consumed electric (or mechanical) energy per m^3 of desalted water is in the range of 4–5 kWh/m^3. This is to be compared with the specific energy consumption (SEC) of 20-kWh/m^3 for the existing MSF. The SEC is the equivalent electric energy of both consumed thermal energy and pumping energy. The SEC for the multi-effect boiling (MEB) desalting system is in the range of 10–12 kWh/m^3. The choice of the SWRO system will free the PP from having to be combined with thermally operated desalting units such as MSF or MEB to supply them with relatively low pressure (LP) steam. The role of the PP is to supply the SWRO desalting plant with its required EP. It also concentrates on the comparison between the different plants on EP production only without considering the DW process.

4. Basis for the choice the PP type for Kuwait in the next decade

4.1. Capacity

The required additional capacity of the PP in Kuwait is in the range of 10 GW from 2010 to 2020. A logical capacity choice for each PP is, say, 1000–2000 MW. This matches the already existing PP capacity of 2,400 MW for each of the steam PP in Doha West, Azzour South, and Sabbiya, 2,000 MW for CC in Sabbiya, and the supplement GTCC plant of 862 MW, and DW of 45 million imperial gallons per day (MIGD) added to the Shuaiba North PP. Moreover the typical demand for base-load cheap electricity is usually supplied by large units. Thus, the estimated capacity of any suggested PP is in the range of 1,000 MW.

4.2. LEC

The MEW choice of any new PP type is usually based on the LEC over the plant life span. The LEC is the real annual cost converted to the equivalent present value of money [4]. It is an economic assessment of the cost of the electricity-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, and cost of capital. This annualized cost value allows for the comparison of one technology against the other, while differing annual costs are not easily compared.

The LEC is also defined as the minimum price at which energy must be sold for an energy project to break-even. The LEC is defined in a single formula as

$$LEC = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

[5], where LEC = average lifetime levelized electricity generation cost, I_t = investment expenditures in the year t, M_t = operations and maintenance expenditures in the year t, F_t = fuel expenditures in the year t, E_t = electricity generation in the year t, r = inflation rate, and n = Life of the system in years.

The LEC of PPs strongly depends on the plant type, CF, and the size of the plant. As the size of the plant increases, its cost/kW decreases.

Typical LECs, see Fig. 1, are usually calculated over lifetime years of the PP (say 30 y for GTCC, and 40–60 y for NPP), and are given in the units of currency per kWh, for example $/kWh or $ /MWh.

4.3. Plant characteristics

The available options of PPs for MEW to choose from, and the feasibility of using each option are discussed in this section. These options are:

1. Business as usual using conventional NG operated GTCC.
2. NPP using light water pressurized water reactors LW-PWR, the most safe nuclear reactors, and
3. Use of RE.

The characteristics of both NPP and GTCC-PP are well-known. The NPPs usually work as base load PP, operating all the time except refueling periods (about 15–20 days every 18–24 months). During re-fueling, regular maintenance is usually conducted. The GTCC-PP can operate to cover the base and intermediate loads. The GT of the GTCC can operate solely as peaking load because of its low efficiency.

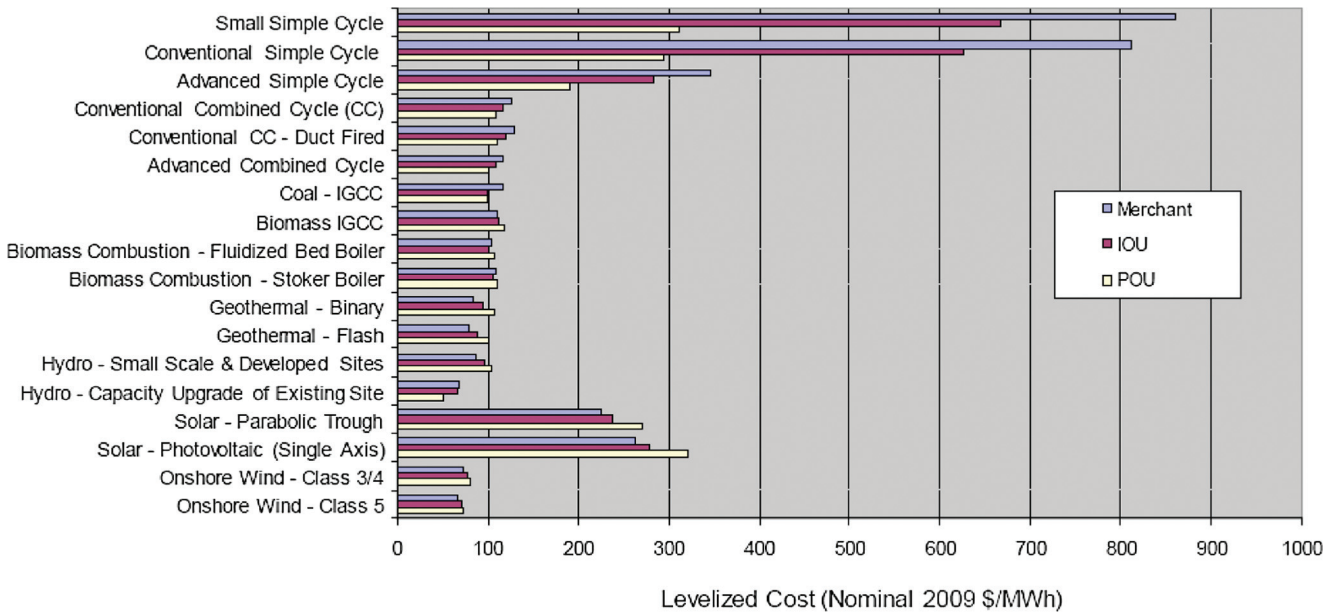

Fig. 1. Comparative cost of central station electricity in California [4].

The characteristics of RE plants, namely, wind farm, solar PV, solar thermal, and hybrid thermal solar systems are briefly discussed here. The discussion outcome shows that only the hybrid solar thermal system may be considered by MEW.

An important characteristic of SE and WE is their intermittent nature of operation. The PV plants generate electricity only when the sun is shining. WTs need sufficient wind speed to produce power. Solar only thermal PPs using CSP produce EP when sufficient direct (beam) solar radiation is available. Direct normal radiation (beam radiation) comes from the sun and passes through the planet's atmosphere without deviation and refraction. Direct radiation is highly sufficient in Kuwait.

4.3.1. Wind power

A large wind farm may consist of tens to hundreds of individual WTs covering a large area of hundreds of square kilometers. But the land between the turbines may be used for other purposes. A wind farm may be located off-shore to take advantage of strong winds blowing over sea surface. The wind PP is non-dispatchable, implying that for economic operation, all of the available output must be taken when available. The 2002 data from Lee Ranch farm in Colorado showed that half of the energy available arrived in just 15% of the operating time [6]. As a result, the WE from a particular WT or wind farm does not have consistent output as fuel-fired PPs. Thus *wind power is primarily a fuel saver, rather than a capacity addition*. The intermittent and non dispatchable natures of WE raise its EP production cost due the additional cost of operating reserve or storage solutions.

As a general rule, wind generators are practical if wind speed is 16 km/h (~4.5 m/s) or more. An ideal location would have a near constant flow of non-turbulent wind throughout the year with a minimum likelihood of sudden powerful bursts of wind. Presently, Kuwait Institute for Scientific Research (KISR) is active in exploring the potential of using WE in Kuwait and indicated that further analysis is required [7,8]. Ref. [7] reported that the annual average wind speed for different sites ranged from 3.7 to 5.5 m/s and a mean wind power density (WPD) from 80 to 167 W/m^2 at standard height of 10 m. Maximum power density at 30 m height is found to vary between 130 and 275 W/m^2. The monthly variation analysis shows high WPD during the high electricity demand summer season than other months with maximum WPD of 555 at Al-Wafra.

An example of a wind farm is the Wattle Point Wind Farm in the south coast of Australia [9]. This farm is operating since April 2005. It has 55 WTs with 91 MW total rated capacity, and covers 17.5 km^2; it was built at a cost of 180 M Australian dollars (AUD). One US $ =1.22 AUD. This gives the capital cost of $1.62 M/MW and the specific area of 192×10^3 m^2/MW.

The MEW main objective, when installing new PPs, is to satisfy the expected increase of peak power demand. No one can be sure that a wind farm power output will cover any load during the peak load. Thus

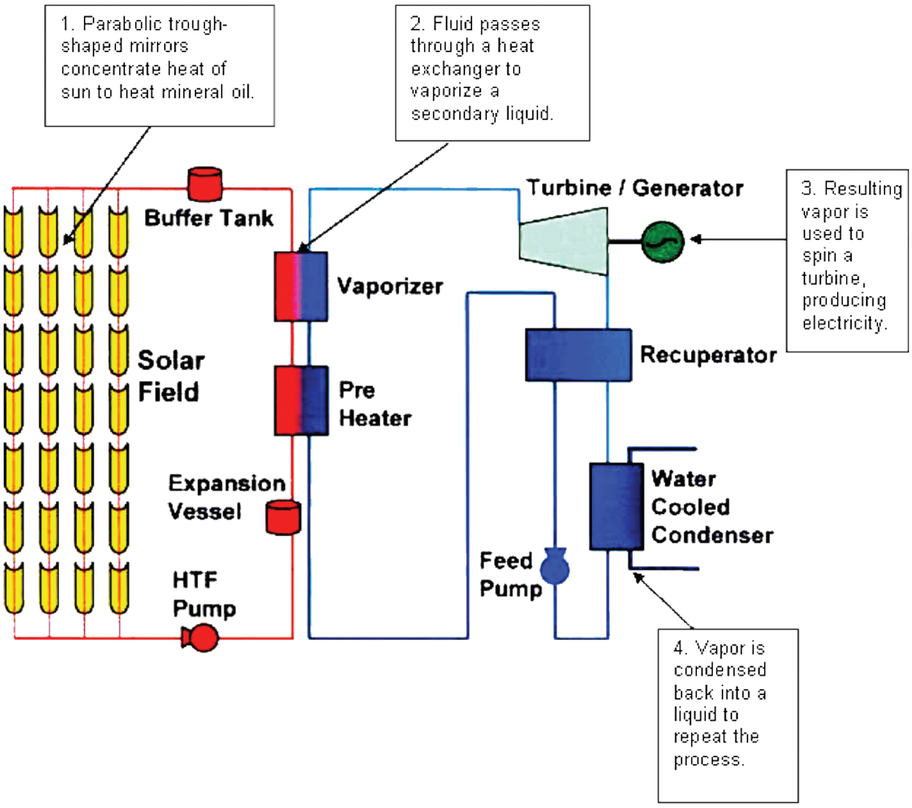

Fig. 2. Schematic diagram of solar only parabolic trough power plant [10].

the MEW will not be interested to install a wind farm for the time-being. This does not mean that Kuwait should not build wind PPs. It can be done for fuel saving after installing enough conventional PPs to satisfy the peak load with reasonable reserve capacity. Alternatively, WE powe plant can be built as pilot (test facility or demonstration) plant for future large wind farms and for training purposes. The same applies to both PV and pure solar thermal power without storage capacities as shown later.

4.3.2. Solar Energy power plants

Kuwait possesses the required conditions to build solar PPs. These are high insolation, near-level, land and proximity to transmission. Moreover, solar PPs naturally have excellent power output matching the load since high sunlight periods create both peak demand and peak EP production. Two types of solar system used in EP productions are: PV and solar thermal systems. The PV system converts sunlight directly into electricity using the PV effect. Solar thermal systems collect the solar heat and use it to generate steam, which is used in thermal power conversion plant to generate electricity, Fig. 2.

In all solar systems, sun radiation may be either absorbed in a flat plate collector or concentrated optically using mirrors or lenses. Meteorological and sun angle effects have higher impact on concentrating than flat plate collectors. Concentrating collectors utilize only the direct rays of the sun, while flat plate collectors utilize both the diffused and direct components. The used CSP technologies used for utility-scale applications include:

1. Parabolic Troughs, Figs. 3 and 4.
2. Power Tower, Fig. 5.
3. Parabolic Dishes with Stirling Engines, Fig. 6.
4. Concentrating PV.

The power tower with molten-salt thermal storage was developed specifically for EP stations. It can be the most efficient and lowest cost solar power systems but it is not commercially established yet. The molten-salt provides efficient, low-cost thermal energy storage (TES) system, and allows solar plants to be designed with high annual CFs or as dispatchable to meet summer load.

Parabolic dish systems use a dish-shaped arrangement of mirror facets to focus energy on to a receiver at the focal point of the collector. A working fluid such as

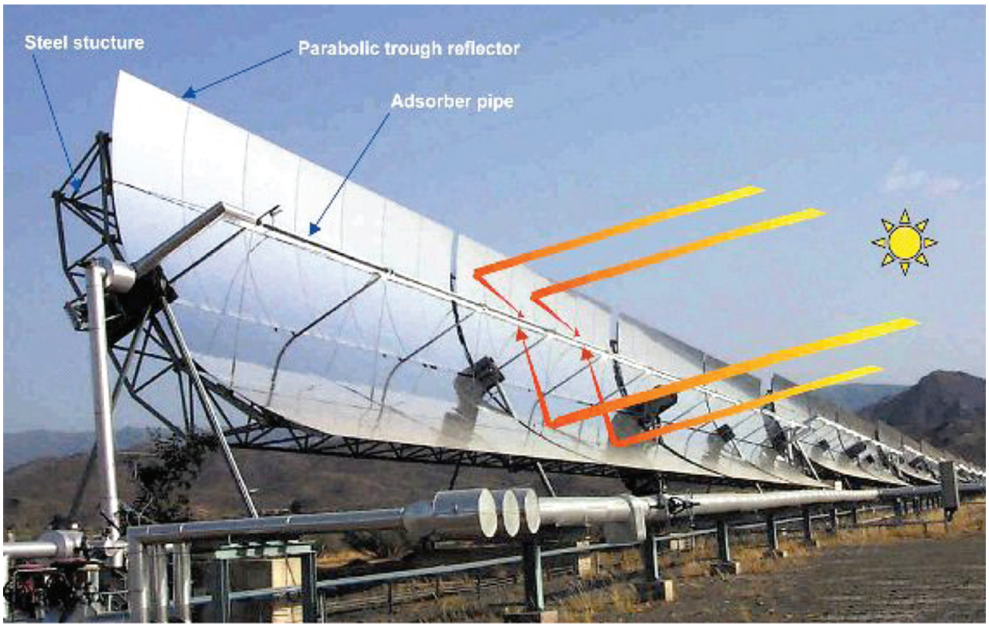

Fig. 3. Photo of parabolic trough system (Source: NREL) [10].

hydrogen is heated in the receiver, which drives a turbine or Stirling heat engine. Most current dish applications use Stirling engine technology because of its high efficiency. Parabolic dishes with Stirling engines demonstrated high solar-to-electric efficiency ($\sim$30%). Its modular nature (25 kWe units) implies that plants

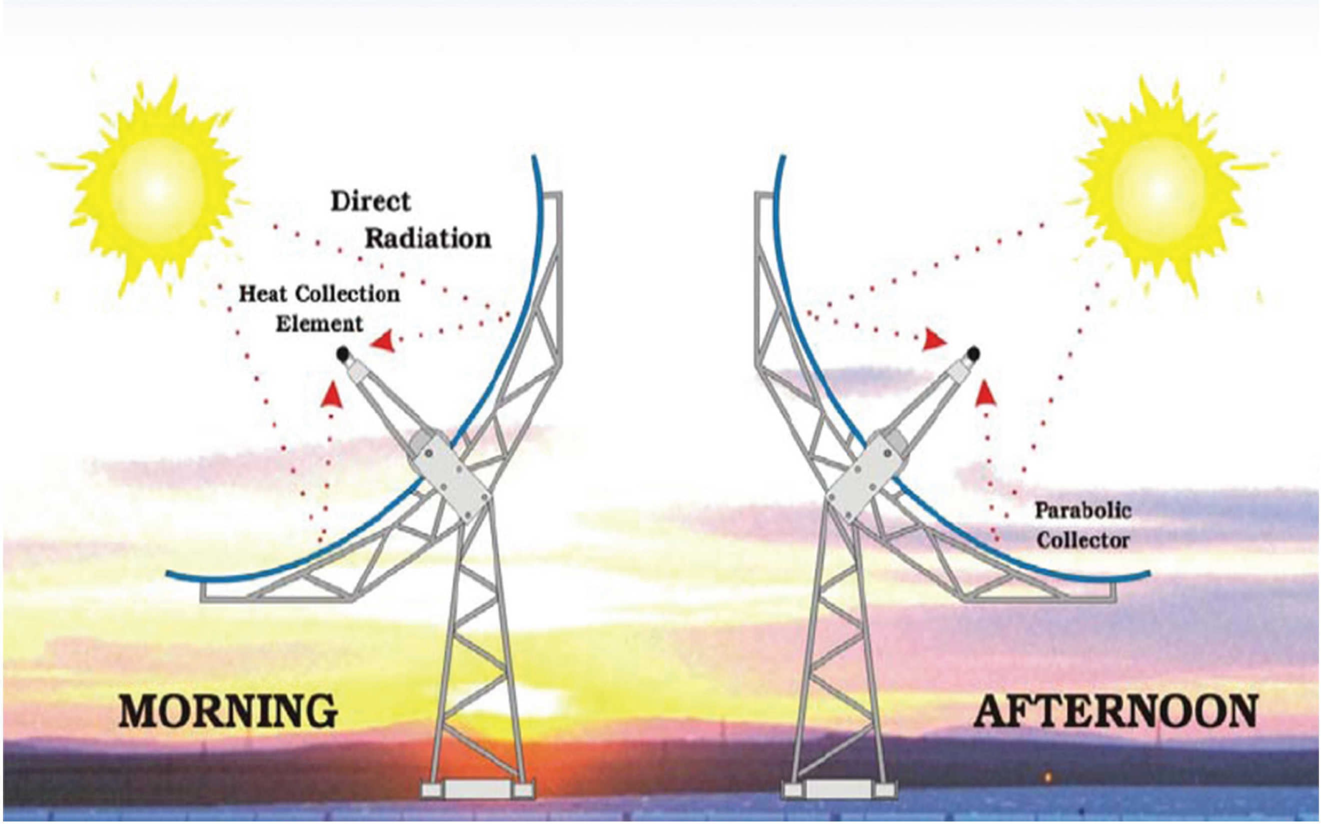

Fig. 4. Solar collector tracking with sun by moving around single axis [10].

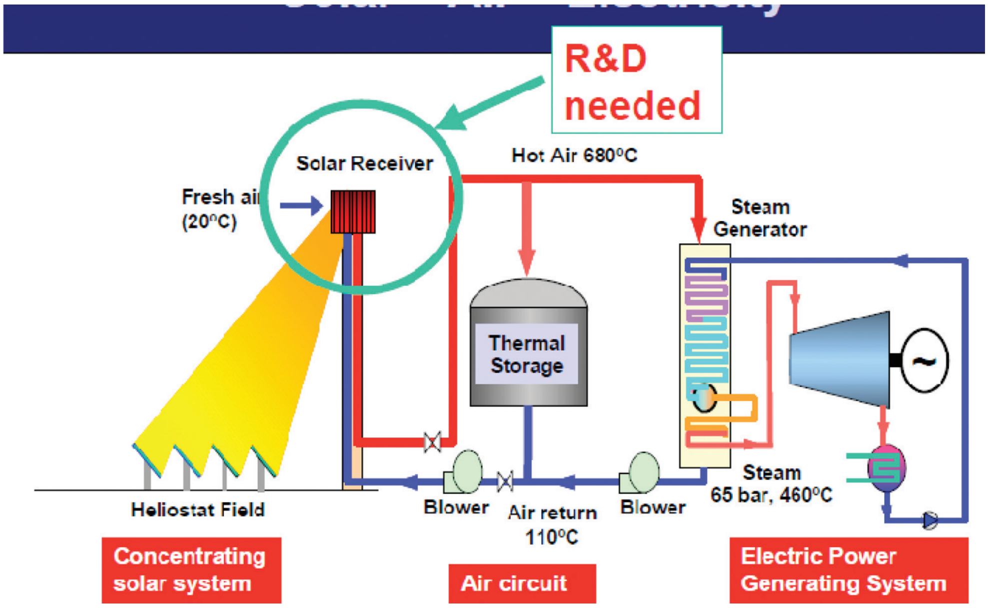

Fig. 5. Schematic diagram of solar tower power plant [11].

of virtually any size could be built or expanded. These systems do not require water for cooling, which is another benefit compared to parabolic troughs system. Current systems have not demonstrated the level of reliability considered necessary for commercial system. There are no operating commercial dish-Stirling PPs.

Concentrating photovoltaic (CPV) systems are currently developed by different companies. Similar to dish/Stirling systems, these systems are modular in nature (25–50 kWe units) and have potential for high solar-to-electric efficiency (>30%). These systems also do not require water for cooling. Manufacturers are currently providing CPV systems but only with a few MWe per year; they still have limited operational experience.

4.3.2.1. Photovoltaic PPs

The current capital costs (initial costs) of the PV panels are high and represent the main barrier to widespread use of the PV systems. While the PV panels expected life is 25 y, the inverter portion of the PV system has anticipated life less than 10 y. The PV systems are typically installed on buildings (Fig. 7) and are considered as distributed energy systems [12]. Distributed energy resource systems are small-scale power generation technologies (typically in the range of 3–10,000 kW), used to provide an alternative to or an enhancement of the traditional EP system. The usual problems with distributed generators are their high costs per kW. A list of the world's largest (utility size) PV PPs is given in Table A1 in Appendix A [13]

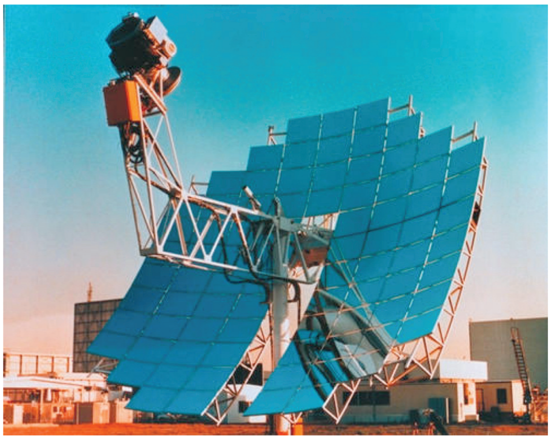

Fig. 6. Dish-stirling system [10]

Fig. 7. PV distributed system on a house [12].

Fig. 8. Moura PV power plant in Portugal [15].

The Moura Photovoltaic Power Station at Amareleja, in Portgal is one of the largest PV PP of its kind, and is built in one of the sunniest regions in Europe, see Fig. 8. It was built in two stages; the first stage was 42 MW and completed in 2008, taking 13 months to install with a capital cost of €250 M. It has 16% CF. Thus, the capital cost is \$8.15 M/MW [14], and [15]. The second stage was 20 MW, to be completed by 2010. Area occupied by power station: 130 ha (total area = 250 ha), one ha = 10,000 m^2.

The first phase of the plant includes 2520 Acciona's single-axis Buskil trackers. Each tracker has an area of 141 m^2 (13 m length and 10.8 m height), 104 polycrystalline silicon modules (total = 262,080 PV modules and 48 cells/module), and reserved area per each tracker is 848 m^2. The solar trackers are oriented at 45° fixed inclination and capable of 240° east-west rotation movement following the sun across the sky. The power station will have an installed capacity of 62 MW with a total of over 376,000 solar panels.

4.3.2.2. CSP

The viability of using solar energy PP in large capacity (discussed in this paper) of 1,000 MW is limited only to solar thermal PP using parabolic trough concentrating solar collectors technology integrated with steam Rankine cycles, Fig. 2. There is enough operating experience to build new plants of this type. Nine PPs, with a total generation capacity of 354 megawatts of electricity (MWe) are called SEGS (Solar Electric Generating Systems) and are operating routinely in the Mojave desert of southern California [16]. Table 2 gives key characteristics of the nine plants. Key advances in this type of PP include the development of TES and hybrid fuel system.

The solar parabolic trough plants can be of different configurations such as:

Solar Only: These can operate with SE only, with no backup fossil firing or TES. An example is the 50 MWe trough plant named Nevada Solar One, Fig. 9, [17].

It went online for commercial use on June 27, 2007 and was constructed in 16 months. The total project site is approximately 400 acres (1.6 km^2), while the solar collectors cover 300 acres (1.2 km^2). The plant uses 760 parabolic troughs (with more than 180,000 mirrors) that concentrate the sun's rays on to thermos tubes (solar receivers) placed at the focal line axis of the troughs, containing the fluid to be heated by solar rays, Fig. 10. These specially coated tubes are made of glass and steel. The plant uses 18,240 of these four-meter-long tubes. The heat transfer fluid (HTF) is heated to 735°F (391°C). The heat is then exchanged to

Table 2
SEGS plant history and operational data [16]

Plant	Year built	Location	Net turbine capacity (MW)	Field area (m^2)	Oil temperature (°C)	Gross solar production of electricity (MWh) 1996	Gross solar production of electricity (MWh) average 1998–2002
SEGS I	1984	Daggett	14	82,960	307	19,900	16,500
SEGS II	1985	Daggett	30	165,376	316	36,000	32,500
SEGS III	1986	Kramer Jct.	30	230,300	349	64,170	68,555
SEGS IV	1986	Kramer Jct.	30	230,300	349	61,970	68,278
SEGS V	1987	Kramer Jct.	30	233,120	349	71,439	72,879
SEGS VI	1988	Kramer Jct.	30	188,000	391	71,409	67,758
SEGS VII	1988	Kramer Jct.	30	194,280	391	70,138	65,048
SEGS VIII	1989	Harper Lake	80	464,340	391	139,174	137,990
SEGS IX	1990	Harper Lake	80	483,960		141,916	125,036

Fig. 9. Solar One Nevada, parabolic trough power plant with solar only heat input [17].

water to produce steam which drives a conventional turbine. This plant type is not dispatch-able, similar to WTs and PVs plants.

Solar/Hybrid: Eight of the nine existing SEGS plants are hybrid plants. They include NG fired boilers or HTF heaters allow them to operate with fossil energy to augment solar generation or when SE is not available. It is likely that in the future a hybrid trough plant would burn NG on-peak or emergency generation.

Solar with TES: The first SEGS plant included 3 hours of TES that allows the plant to dispatch solar output to meet the summer peak periods. A new TES option has been developed based on the molten-salt TES system used at the Solar Two demonstration project. This system uses a conventional HTF in the solar field and has a heat exchanger that is used to charge and discharge the molten-salt storage system. The two 50-MWe trough plants currently under development by Solar Millennium in Spain will include 6–9 h of molten-salt TES.

Storing heat in a thermal solar PP enables the plant to produce electricity when sunlight is weak or unavailable. If storage proves economical for large-scale plants, then solar thermal PP in regions with strong, near continuous daytime sunlight could be operated as dispatch-able plants with firm capacity. *The ability of the PP to meet capacity on demand is one of the most important features of any PP*. The additional cost to gain this advantage to solar plant is typically low.

A number of different technologies were tried to store the sun's energy in order to employ the thermal solar PP more broadly. Storing batteries, compressing air, and pumping water are energy storing examples. The stored energy can be used later when needed, though large energy loss usually occurs between charging and recovery. Melting salts can deliver back as much as 93% of the energy. In addition, the salts used are in abundance. The thermal storage of the Andasol 1 PP [19] allows the plants to provide scheduled power and thus can operate even on overcast days or after sunset. The heat required is stored in a molten salt mixture of 60% sodium nitrate ($NaNO_3$) and 40% potassium nitrate (KNO_3). Both salts are used in food production as preservatives and as fertilizer. The liquid salt thermal storage of Andasol 1 functions under atmospheric pressure and uses two tanks per PP, measuring 14 m in height and 36 m in diameter.

During the pumping process from the ''cold'' to the ''hot'' tank, the molten salt mixture absorbs additional heat at an outlet temperature of approximately 290°C, where it is heated to a temperature of 390°C. A full storage tank can be used to operate the turbine for about 7.5 h.

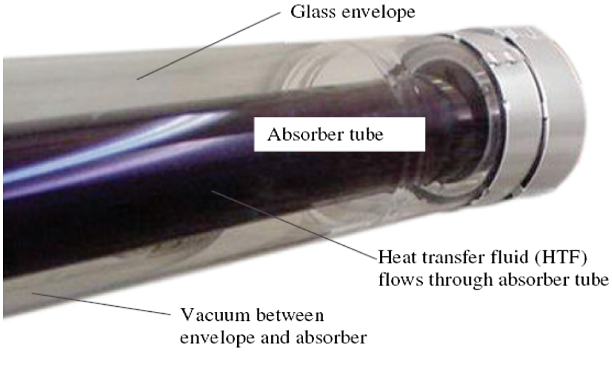

Fig. 10. Solar receiver extended along the focal line of the parabolic trough collector [18].

Fig. 11. Andasol solar power plant, parabolic trough power plant with molten salt thermal storage [19]

The Andasol 1 PP, which costs around $380 million (300 million Euros) to build, is the first to actually use the technology; so it remains to be seen how it will work commercially. Solar Millennium (the installing firm) is so confident that this technology will work; it has applied it in a twin solar thermal PP (Andasol 2), Fig. 11, which is already near completion.

The generated extra energy to be stored comes at a cost. First, it needs enlargement of the capacity of solar collectors to generate the plant in full generating electrical capacity as well as heating up the salts, besides the additional expense of the molten salt storage tanks.

The ability of solar thermal system to use FF also means that peak electric output can always be assured at a low incremental investment cost. Base-load operated hybrid solar integrated with FF supplement can compete with large-scale fossil-fueled PPs. This will be possible where a cheap gas supply is available in high insolation areas. Hybrid solar thermal electric plants are basically conventional thermal PPs with dual fuel source: FF plus solar radiation energy from the sun. Although the ''solar fuel'' is free, the solar field itself represents an investment in the order of 45–55% of the total solar plant's investment cost. Thus investment in dollars today avoids future burning of FF. If FF costs are low, which is currently the case, avoided fuel costs provide minimal payoff of the solar field investments [19].

5. Reference types of PPs and economic analysis

5.1. Reference combined GTCC PP

In GTCC plants, combustion GT is fired by NG to rotate the GT and produce EP. Heat from the hot exhaust gases leaving the GT is captured and used to produce steam in heat recovery seam generator (HRSG). This steam drives a steam turbine to produce more EP. Converting the waste heat from the combustion turbine into useful electricity raises the GTCC efficiencies to about 50%, (compared to 30% simple GT plants). The modern GTCC plants have relatively low construction cost, can be used to meet base-load, intermediate, and peaking demand and can be built quickly. Due to these advantages, since 1995 NG CCPP have been the dominant choice of PP in many parts of the world and accounted for 88% of the all the new generating capacity built in the United States [20].

The referenced GTCC is similar to the PP built in Shuaiba North PP, Fig. 12. It has:

- Three GT generators (GE 9131FA) with dual fuel (oil and NG) firing capability of 215.5 MWe each.
- Three natural circulation HRSG without supplementary firing and integral de-aerator installed on each HRSG.
- Three bypass stacks with diverter dampers.
- One back pressure steam turbine (BPST) of gross output 215.7 MW, steam flow rate HP steam flow at GT base load of 3 × 352.3 = 1056.9 ton/hr at 75 bar, 560°C, and 3556.7 kJ/kg enthalpy.

The flow rate of the LP steam exhausted from the BPST (directed to desalting units) is 1055.7 ton/hr at 2.5 bar, 135°C, and 2781.5.1 kJ/kg enthalpy. The flow rate of the condensate returning from the three desalting is 1055.7 ton/hr at 1.3 bar, 118°C, and 496.1 kJ/kg enthalpy.

If the steam exhausted to the desalting units was expanded in LP turbine to condenser pressure of, say 10 kPa, and isentropic efficiency of 82%, its enthalpy at the condenser inlet would be 2,346 kJ/kg; it would give 128.7 MW more power output and the steam turbine would become condensing turbine of 344.4 MWe, and the plant total output would be 991 MW, less than 1% less of 1,000 MW. In this case, no desalting is served. In other words, due to the production of 3 × 15 MIGD (2,368 kg/s) desalted water, 128.7 MW power output was lost, or the equivalent work to the consumed thermal energy input is 54.86 kJ/kg (15.2 kWh/m^3). When 4 kWh/m^3 pumping energy is added, the SEC is 19.2 kWh/m^3. The above power output was based on ambient conditions of 50°C. Lowering the operating condition to, as an example, 35°C, raises the power output of GT to 15%. Hence, this arrangement would give easily 1,000 MW power output at 35°C ambient condition. For a reference PP, doubling the capacity of the GTCC used in Shuaiba North gives 2,000 MWe. This referenced PP would have two group, each one, as mentioned before, has three GT of 215.5 MW each, three HRSG producing 352.3 tons/steam at 560°C, 75 bar, and one condensing steam turbine of 344.4 MW. The capital cost of the CC is estimated by $1,000/kW capacity and its expected CF is 0.80.

Calculation of the levelized EP cost from GTCC was performed as follows:

Interest rate	6%		8%		10%	
	Total annual cost in $M	Cost $/MWh	Total annual cost in $M	Cost $/MWh	Total annual cost in $M	Cost $/MWh
$6/GJ	406.60	58.02	413.78	59.04	420.95	60.07
$8/GJ	511.72	73.02	518.90	74.04	526.07	75.07
$10/GJ	616.84	88.02	624.02	89.04	631.19	90.07
$12/GJ	721.96	103.02	729.14	104.04	90.07	105.07

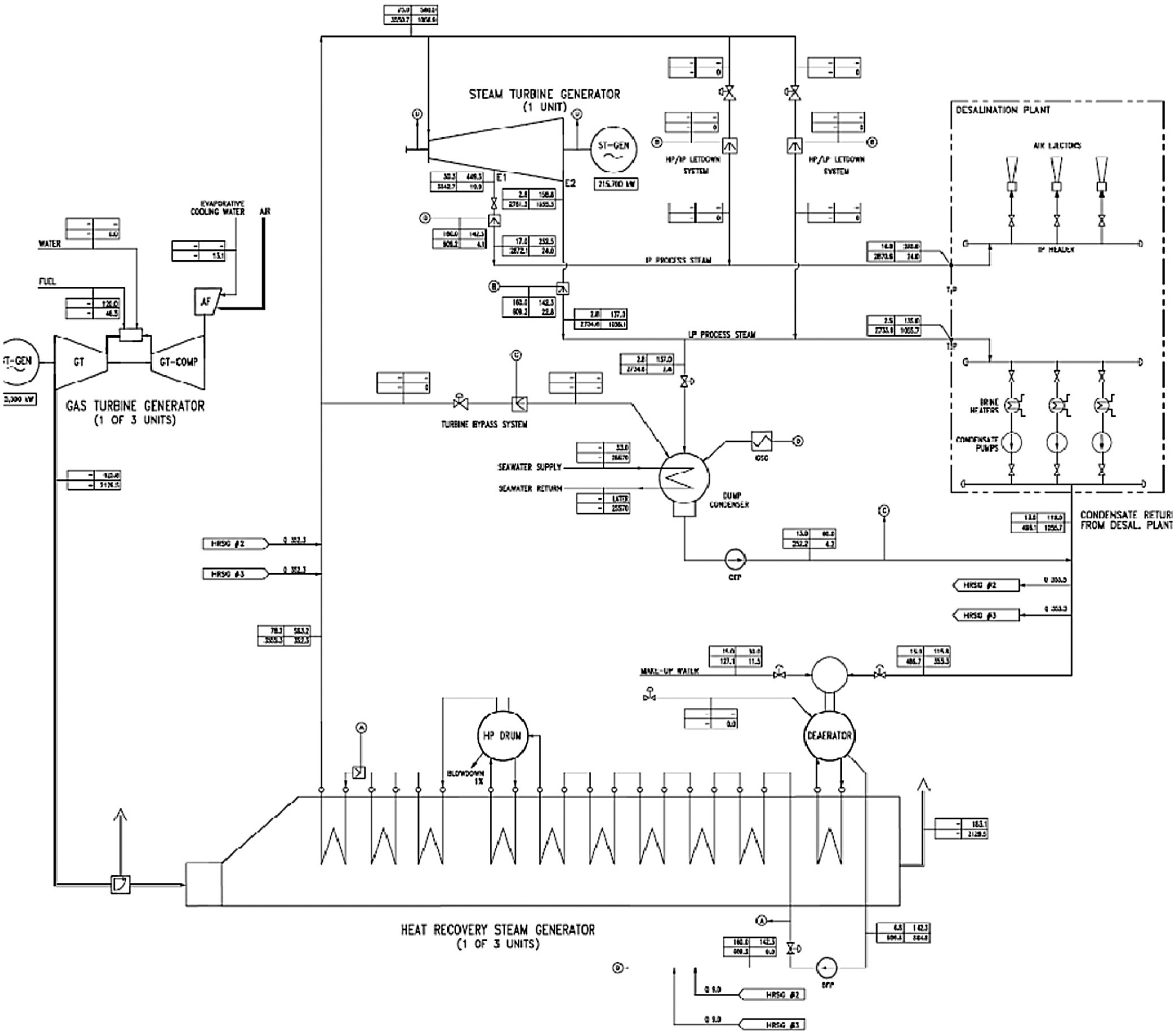

Fig. 12. Combined cycle in Shuaiba North, Kuwait.

The capital cost (for $1,000/kW) is $1,000 M. For 25 years plant life, and 6%, 8% and 10% interest rate (IR), the total principal and interest to be paid are $1,750 M, $2,000 M, and $2,250 M. The annual fixed payment of $70 M, $80 M, and $90 M for 6%, 8% and 10% IR respectively. The real value of the annual payment is decreased due to inflation, and by assuming 3% annual inflation rate, the levelized annual payments for the investment over the 25 years are $50.22 M, $57.39 M, and $64.57 M for 6%, 8% and 10% IR, respectively.

The annual EP output for 80% CF is 8007 GWh, and by assuming the fixed operation and maintenance (O&M) as $20/kWy, variable O&M cost as $2/MWh, PP efficiency 48%, and annual fuel cost of $6/GJ, $8/GJ, $10/GJ and $12/GJ are $315.36 M, $420.48 M, $525.5 M, and 630.72 M, respectively; the annual total cost and the EP cost in $/MWh are given as:

It is clear that the cost/MWh is strongly affected by the fuel cost and the plant efficiency and slightly on the IR, Figs. 13a–13c.

Another problem here is the emission of CO_2 from NG combustion estimated by 0.23 kg/kWh, or 1.61 million ton/year.

5.2. Nuclear PP

NPPs use the heat produced by nuclear fuel fission to produce steam. The steam drives a turbine to generate EP. The NPPs are characterized by high investment costs but low variable operating costs due to minor fuel cost compared to total cost. This makes most NPP operating as base-load plants. Advanced designs of new NPP reduce costs and enhance safety through reducing complexity, standardizing and improving construction

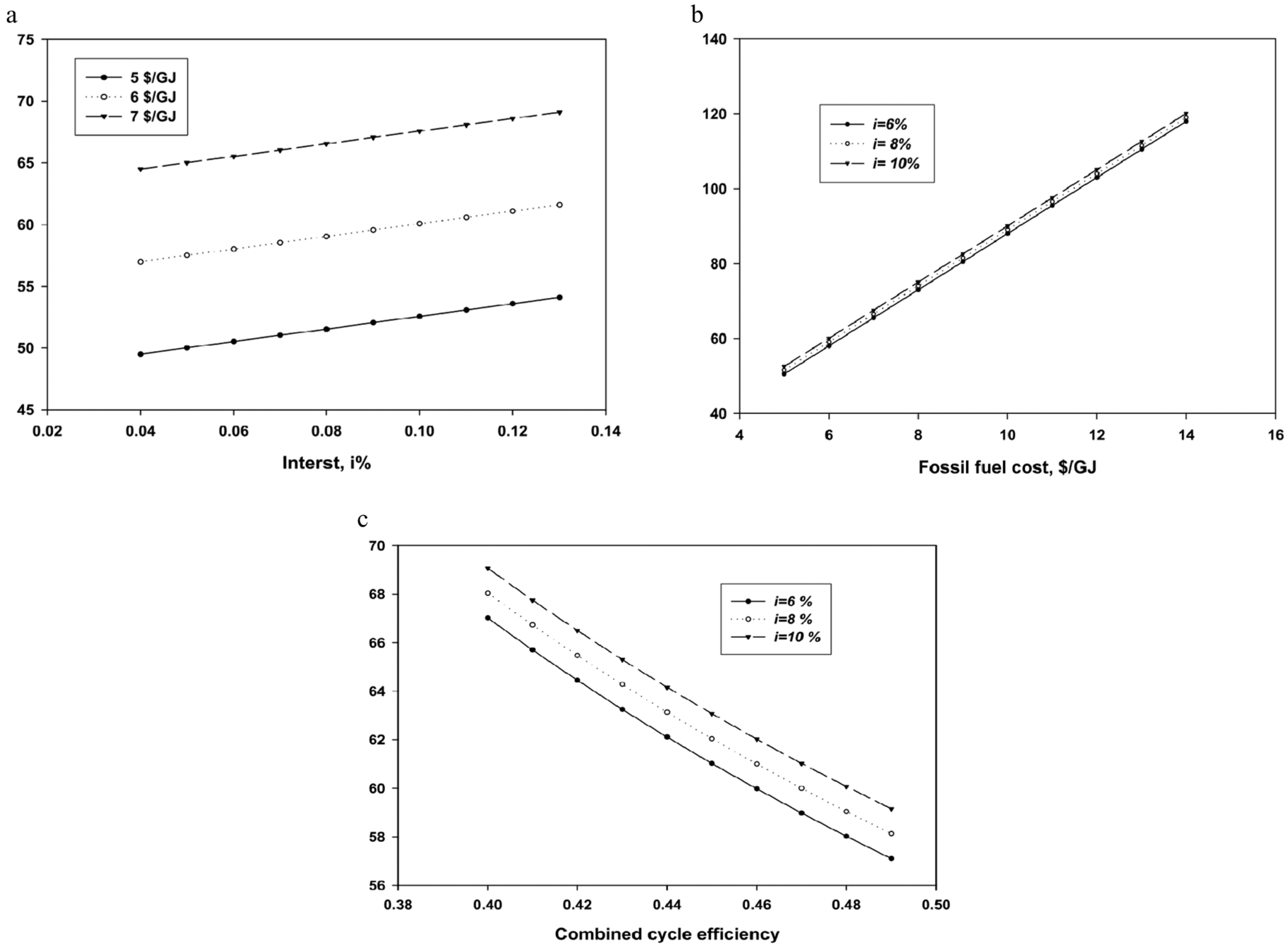

Fig. 13. (a) The effect of interest rate on the EP cost in GTCC. (b) The effect of fuel cost on the EP cost in GTCC. (c) The effect of GTCC efficiency on the EP cost in GTCC.

techniques. Some designs also incorporate passive safety systems that are capable of preventing a catastrophic accident, even without operator action.

NPP is cost-competitive with other forms of EP generation, unless there is free access to low-cost FF. The NPP capital cost is greater than those for GTCC plants. The NPP economics takes into consideration decommissioning of the NPP and waste disposal costs. Gas-operated GTCC is also competitive for base-load power in many places, though rising gas prices can remove this advantage. The NPP is one of best answers to produce EP without emissions such as GHG and other polluting gases. As of March 21, 2010, 30 countries had 437 NPP units with installed electric capacity of about 371 GW in operation, [21], see Table 1B in Appendix B. Additionally, 15 countries have 55 plants with 51 GW installed capacity under construction. At the end of 2008, the total electricity production since 1951 amounted to 62,048 billion kWh. The cumulative operating experience was about 13,475 years by the end of 2008. Thus, the NE is viable and reliable with good record of high CF. A list of 66 under construction (or planned) NPPs in India, China, Russia, Romania and other countries is given in Ref. [22].

The Advanced AP1000 provides 1,117 MWe (LW PWR), an extension of AP600 of 600 MWe. It is chosen in this study as the type that is suitable for Kuwait PP conditions, based on a previous study [23]. The AP1000 design has passive safety features and extensive plant simplifications to enhance the construction, operation, maintenance and safety. Its technology builds on over 35 years of operating PWR experience [24]. The PWR represents 92% percent of all LW reactors under construction. The reactor coolant system (RCS) consists of two heat transfer circuits, with each circuit has one SG, two reactor coolant pumps and a single hot leg and two cold legs for circulating coolant between the reactor and the

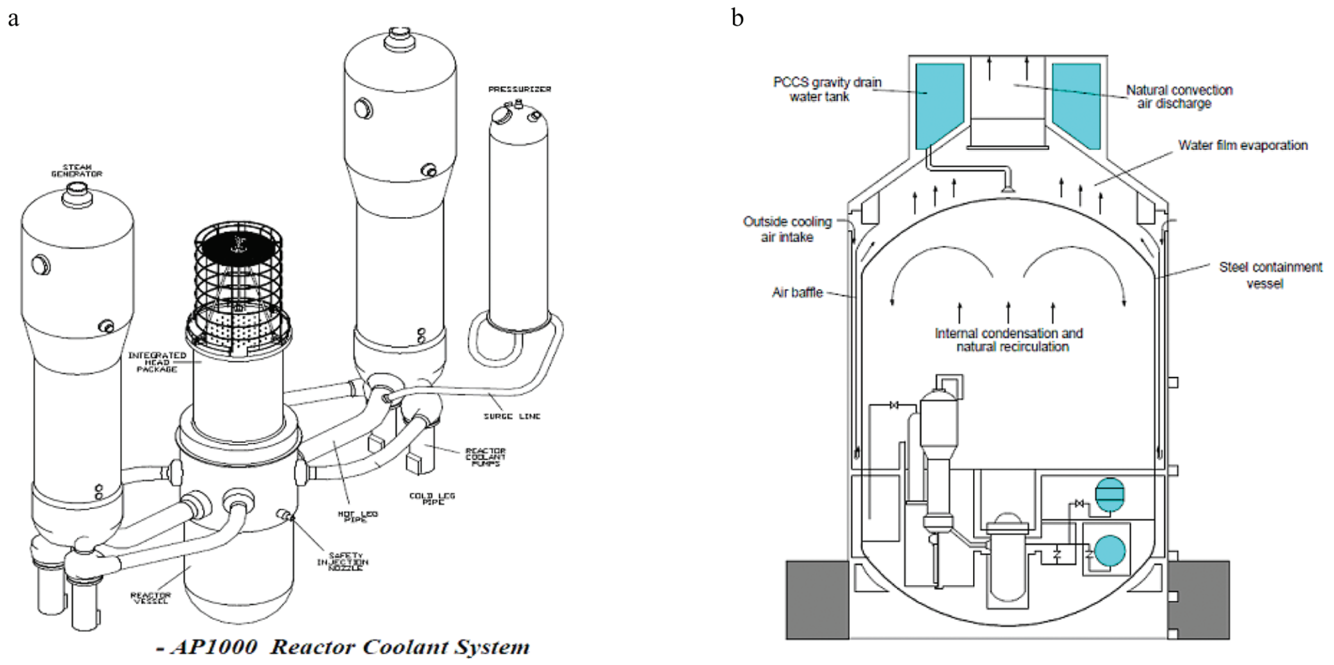

Fig. 14. (a) Schematic diagram of the AP1000 LW PWR reactor, [23]. (b) Schematic diagram of the AP1000 passive cooling system, [23].

SG, Fig. 14a. The RCS includes a pressurizer, interconnecting piping, valves, and instruments necessary for operational control and the actuation of safeguards. All safety-related equipment is located in containment or in the auxiliary building, Fig. 14b. These two buildings are on a common, seismically qualified base mat, greatly reducing the plant's seismic footprint. The AP1000 reactor coolant pump is a modest extension of proven pump designs.

The AP1000 reactor core is comprised of 157 assembly of 4.3 m length and each assembly has 17×17 fuel rods. It has robust design with at least 15% in departure from nucleate boiling (DNB) margin. The fuel performance is improved by zircaloy grids, removable top nozzles and longer burn-up features. This optimized fuel is currently used in approximately 120 operating plants worldwide. The core consists of three radial regions that have different enrichments in the ranges from 2.35% to 4.8%. The temperature co-efficient of reactivity of the core is highly negative. The core is designed for a fuel cycle of 18 months with a 93% CF and regional average discharge burn-ups as high as 60,000 MWd/t. The AP1000 uses reduced-worth control rods (termed ''gray'' rods) to achieve daily load change without requiring changes in the soluble boron concentration. The use of gray rods, in conjunction with an automated load follow control strategy, results in simplified systems through the elimination of boron processing equipment (such as evaporator, pumps, valves, and piping). TheAP1000 has a 4.27 m (14 foot) long core.

The reactor vessel is the high-pressure containment boundary used to support and enclose the reactor core. The vessel is cylindrical, with a hemispherical bottom head and removable flanged hemispherical upper head.

The reactor vessel is approximately 39.5 feet (12.0 m) long and 157 in. (3.988 m) inner diameter at the core region. Surfaces, which can become wet during operation and refueling, are clad with stainless-steel-welded overlay. The AP1000 reactor vessel is designed to withstand the design environment of 2,500 psia (17.1 MPa) and 650°F (343°C) for 60 y [25].

As a safety enhancement, there are no reactor vessel penetrations below the top of the core. This eliminates the possibility of a loss of coolant accident by leakage from the reactor vessel, which could lead to uncover the core. The core is positioned as low as possible in the vessel to limit re-flood time in accident situations.

SG design enhancements include full-depth hydraulic expansion of the tubes in the tube-sheets, nickel chromium iron Alloy 690 thermally treated tubes on a triangular pitch, broached tube support plates, improved anti-vibration bars, upgraded primary and secondary moisture separators, enhanced maintenance features, and a primary-side channel head design that allows for easy access and maintenance by robotic tooling. All tubes in the SG are accessible for sleeving, if necessary. The two SGs used in AP1000 have 39.6 m (130 feet) diameter. The AP1000 use canned motor pumps to circulate primary reactor coolant throughout the reactor core, piping, and SGs. Two pumps are mounted directly in the channel head of each SG.

The safety systems of AP1000 include passive safety injection, passive residual heat removal and passive containment cooling. Passive systems and the use of experience-based components do more than increase safety, enhance public acceptance of nuclear power, they simplify overall plant systems, equipment, and operation and maintenance. The simplification of plant systems, combined with large plant operating margins greatly reduces the actions required by the operator in the unlikely event of an accident. Passive systems use only natural forces, such as gravity, natural circulation, and compressed gas-simple physical principles. The passive safety systems are significantly simpler than typical PWR safety systems. They contain significantly fewer components, reducing required tests, inspections, and maintenance.

The AP1000 has been designed to make use of modern modular construction techniques. Not only does the design incorporate vendor designed skids and equipment packages, it also includes large structural modules and special equipment modules. Modularization allows construction tasks that were traditionally performed in sequence to be completed in parallel. The modules, constructed in factories, can be assembled at the site for a planned construction schedule of 3 y – from groundbreaking to fuel load. This duration has been verified by experienced construction managers.

With short planned refueling outage (17 days) as well as plans to use 18 to 24-month fuel cycle, the AP1000 is expected to exceed the 93% availability goal.

Nuclear overnight capital costs in OECD ranged from US$ 1556/kW for APR-1400 in South Korea through $3,009 for ABWR in Japan, $3,382/kW for Gen III+ in USA, $3,860 for EPR at Flamanville in France to $5,863/kW for EPR in Switzerland, with world median $4,100/kW. The cost considered in this paper is $M4.1/MW. The cost of nuclear fuel is given as 0.71c/kWh [26]. It will be considered here as $1/kWh.

Calculation of the levelized EP cost from NPP was performed as follows:

The capital cost (for $4,100/kW) is $4,100 M. For 40 years plant life, and 6%, 8% and 10% interest rate (IR), the total principal and interest to be paid are $9,020 M, $10,660 M and $12,300 M, respectively. The annual fixed payments are $225.5 M, $266.5 M and $307.5 M for 6%, 8% and 10% IR, respectively. The real value of the annual payment is decreased due to inflation, and by assuming 3% annual inflation rate, the levelized annual payments for the investment over the 40 years are $134.22 M, $158.62 M and $108.03 M for 6%, 8% and 10% IR, respectively.

Table 3
Organization of Economic Development (OECD) electricity generating cost projections for year 2010 on – 5% discount rate, c/kWh, [26]

Country	Nuclear	Gas CCGT	Onshore wind
Belgium	6.1	9.0	9.6
Czech R	7.0	9.2	14.6
France	5.6	-	9.0
Germany	5.0	8.5	10.6
Hungary	8.2	-	-
Japan	5.0	10.5	-
Korea	2.9-3.3	9.1	-
Netherlands	6.3	7.8	8.6
Slovakia	6.3	-	-
Switzerland	5.5-7.8	9.4	16.3
USA	4.9	7.7	4.8
China*	3.0-3.6	4.9	5.1-8.9
Russia*	4.3	7.1	6.3
EPRI (USA)	4.8	7.9	6.2
Eurelectric	6.0	8.6	11.3

The annual EP output for 90% CF is 7,884 GWh, and by assuming the fixed operation and maintenance (O&M) as $40/kWy, variable O&M cost as $5/MWh, and annual fuel cost of 1c/kWhe is $78.84M. The total annual costs are $312.98 M, $337.38 M and $361.79 M for 6%, 8% and 10% IR, respectively. The EP costs in $/MWh are: $39.7/MWh, $42.79/MWh and $45.9/MWh for 6%, 8% and 10% IR, respectively. The results are comparable with those reported in the literature, Table 3. The cost of EP in $/MWh is strongly affected by the interest rate, and slightly affected by the nuclear fuel cost, as shown in Figs. 15a and 15b.

5.3. Solar Energy PPs

Dispatch-ability is a very important characteristic of several CSP technologies, allowing delivery of firm power according to demand. These PPs can have dispatch-ability by using thermal storage. Thermal energy produced by SE can generate EP at a later time. They can also be integrated with supplemental fossil-fired components.

For example, high temperature thermal energy stored during the off-peak periods can be utilized during peak hours or in the evening to generate electricity, Fig. 16. These attributes, along with very high solar-to-electric conversion efficiencies, make CSP an attractive

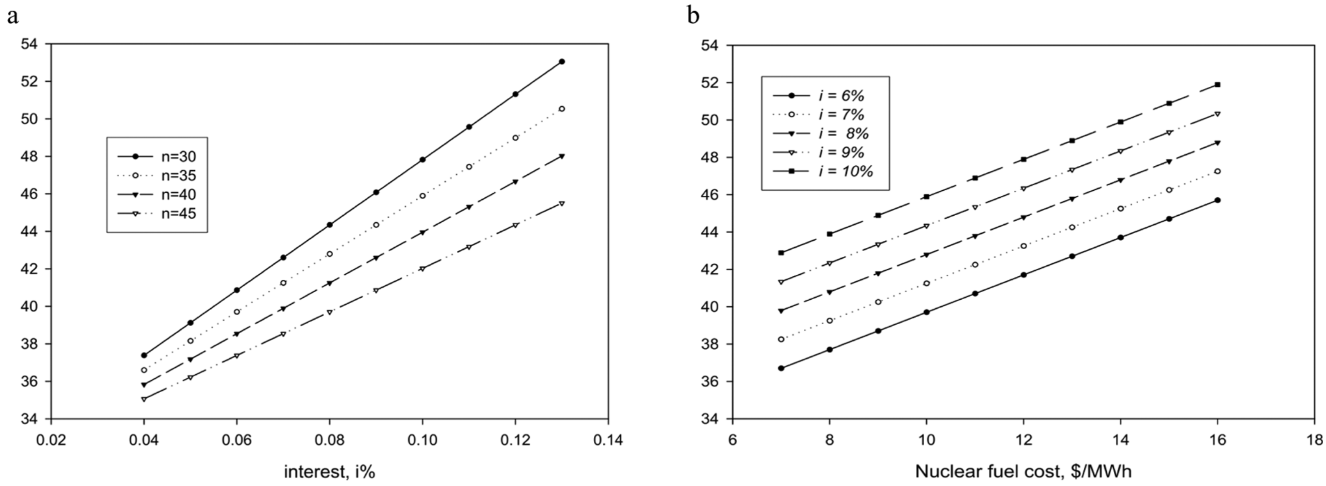

Fig. 15. (a) Effect of interest rate on the EP produced by NPP. (b) Effect of nuclear fuel cost on the EP produced by NPP

and viable RE option in Kuwait and other Arab Gulf Countries.

CSP systems can also be configured with auxiliary gas-fired equipment to supply thermal energy to achieve full power and remove intermittency from operation with insufficient sunlight. This is demonstrated by parabolic trough system performance at the Kramer Junction sites in California, which typifies the reliability of these systems.

A solar CSP parabolic trough PP of 100 MWe net power output is suggested in this study with 6 h thermal storage system to assure the plant capability to cover the peak load period and to raise the CF to 40%. As given before, the parabolic troughs consist of

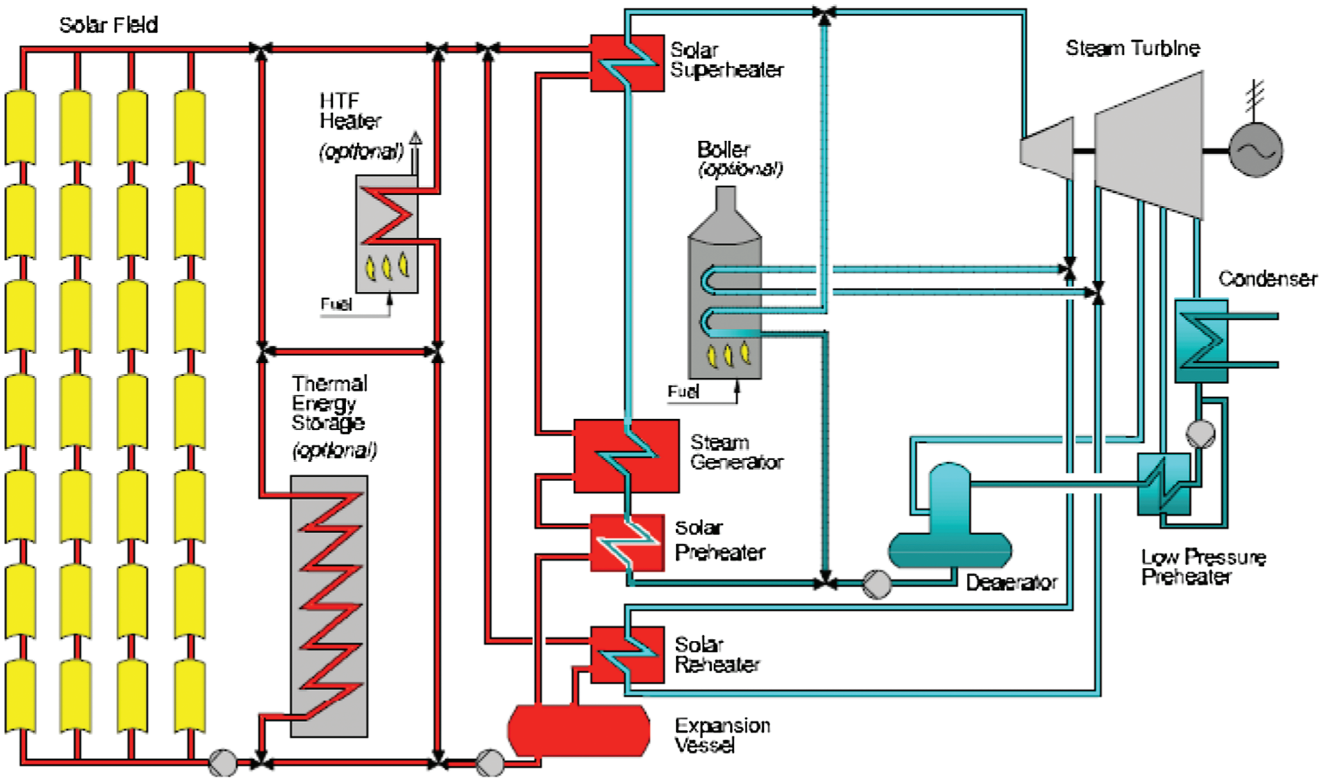

Fig. 16. Suggested solar parabolic trough power plant with thermal storage and supplementary natural gas fuel, [10].

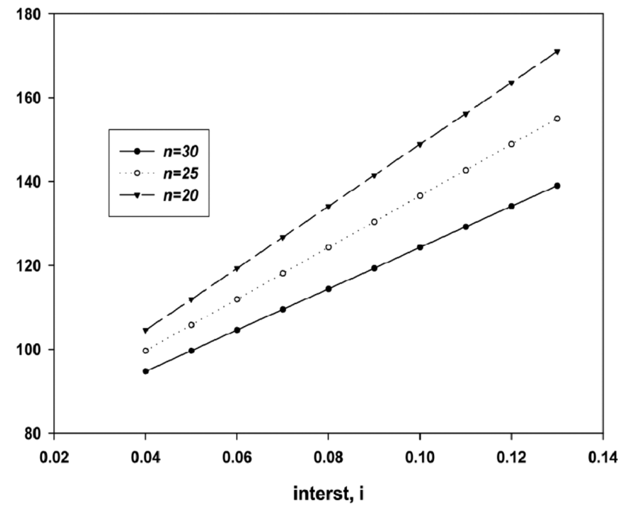

Fig. 17. The effect of the interest rate on the EP production cost.

long parallel rows of identical concentrator modules – typically glass mirrors – that are curved in only one dimension, forming troughs. Tracking the sun from east to west, while rotating on a north-south axis, the trough focuses the sun's energy on a pipe located along its focal line. Troughs can also rotate on an east-west axis only but yield less annual energy. A HTF, typically oil at temperatures up to 400°C, is circulated through the pipes and then pumped to a central power block area, where it passes through a heat exchanger. In this heat exchanger, called SG, the oil's heat is then passed to water to generate steam. The steam is used in turn to drive a conventional turbine generator. Several commercial units with sizes up to 80 MWe were put into operation with peak net electric efficiencies of 23%.

Since the parasitic power loss of this type of PP is about 9%, the gross power would be 110 MWe. The net efficiency of the power block plant (net EP out/ heat rate output of the SG) is 1/3. Thus, heat is to be generated at rate 300 MWt in the SG. The ratio of the SG heat output to the solar heat is in the range of 65–70%, and thus the required solar heat input is (300/0.65) 461.54 MWt. Assuming an average solar intensity received by the solar collector equal to 0.9 kW/m^2 aperture area, the solar collector area is 512.8×10^3 m^2. When this area is increased by 60% to account for 6 h energy storage, the total area is 820.5×10^3 m^2. The TES capacity for 6 h is 300 MWt $\times$ 6 = 1,800 MWht. The solar field area is almost 30% of the required land area; this gives 2,735,000 m^2 land area. When the solar collector cost/m^2 is taken equal to \$350/m^2, and the land preparation cost is taken equal to \$20/m^2, the total cost of the collector and land preparation is \$341.875 M. Other capital costs of the plant include:

SG of almost 0.86 Mm^2 at cost of \$50/m^2 gives \$43 M.
TES 1,800 MWh at cost of \$70/kWh gives \$126 M.
Power block 100 MW at cost of \$900/kW gives \$90 M.
Total investment cost \$600.875 M.
Operation and maintenance, fixed by capacity \$80/kW y.
Operation and maintenance cost, variable by generation \$3/MWh.
Data of similar plant but with 50 MW capacity are given in Appendix C [27].

Calculation of the levelized EP cost from solar thermal parabolic trough plant was performed as follows:

The capital cost (for \$600.875/kW) is \$600.875 M. For 25 years plant life, and 6%, 8% and 10% IR, the total principal and interest to be paid are \$1051.53 M, \$1201.75 M and \$13512.97 M with annual fixed payment of \$42.06 M, \$48.07 M, and \$54.08 M for 6%, 8% and 10% IR, respectively. The real value of the annual payment is decreased due to inflation, and by assuming 3% annual inflation rate, the levelized annual payments for the investment over the 25 years are \$30.176 M, \$34.487 M, and \$38.797 M for 6%, 8% and 10% IR, respectively.

The annual EP output for 40% CF is 350.4 GWh, and by assuming the fixed operation and maintenance (O&M) as \$80/kWy, variable O&M cost as \$3/MWh. The annual total cost is \$39.23 M, \$43.54 M and \$47.85 M for 6%, 8% and 10%, respectively. The EP cost in \$/MWh is \$111.95/MWh, \$124.25/MWh and \$136.55/MWh for 6%, 8% and 10%, respectively. Fig. 17 shows the change of the EP cost as function of both interest rate and life span of plant.

It is noticed here that the capacity chosen is 100 MW, while the required capacity is 1,000 MW. The required land for the 100 MW plant is almost 3 km^2, and then for 1,000 MW plant, 30 km^2 or piece of land with 1 km width and 30 km length. This cannot be taken from seashore as all PP in Kuwait. As a result, this plant should be inland and cooling water with cooling towers should be applied, which is another problem.

6. Conclusion

This study addresses the economics and capabilities of using NPP and RE in generating EP in Kuwait. It compares these options with the business as usual of using GTCC operated with NG or oil fuel. The results indicate that the PP using RE such as WE or solar cells (PV), cannot be considered as capacity addition but primarily as a fuel saver. The intermittency and the non-dispatchable nature of these plants do not generate consistent output as fuel-fired PPs production. Their output should be taken by the grid, and this decreases the load on the conventional PP and thus reduces their fuel consumptions.

Among the thermal solar concentrating PP, solar tower, solar dish with Stirling engine and parabolic trough mirrors, the later is the only PP that have reached commercial status with well-proven records of reliability and availability. This type of PP should be augmented with supplementary FF and/or thermal storage system to become a dispatchable plant.

Appendix A

Table A1. List of some of the largest PV PPs in the World [11]

World's largest PV power plant					
Name of PV power plant	Country	DC Peak Power (MW)	GW·h/year	Capacity factor	Notes
Olmedilla Photovoltaic Park	Spain	60	85	0.16	Completed September 2008
Strasskirchen Solar Park	Germany	54	57		
Lieberose Photovoltaic Park [67]	Germany	53	53[67]	0.11	2009
Puertollano Photovoltaic Park	Spain	50			2008
Moura photovoltaic power station [68]	Portugal	46	93	0.16	Completed December 2008
Kothen Solar Park	Germany	45			2009
Finsterwalde Solar Park	Germany	42			2009
Waldpolenz Solar Park[69][70]	Germany	40	40	0.11	550,000 First Solar thin-film CdTe modules. Completed December 2008

Appendix B

Table 1B. List of Some of Operating NPP around the world, [21]

	In operation		Under construction	
		Electric net output		
Country	Number	MW	Number	Electric net output MW
Belgium	7	5,902	–	–
Canada	18	12,569	–	–
China	11	8,438	21	20,920
Czech Republic	6	3,678	–	–
Finland	4	2,696	1	1,600
France	58	63,130	1	1,600
Germany	17	20,470	–	–
India	18	3,984	5	2,708
Iran	–	–	1	915
Japan	54	46,823	1	1,325
Korea, Republic	20	17,705	6	6,520
Pakistan	2	425	1	300
Russian Federation	32	22,693	8	5,944
Spain	8	7,450	–	–
Sweden	10	9,043	–	–
Switzerland	5	3,238	–	–
Taiwan	6	4,980	2	2,600
Ukraine	15	13,107	2	1,900
United Kingdom	19	10,097	–	–
USA	104	100,683	1	1,165

Appendix C

Andasol-1

Andasol-1 is solar power plant located in southern Spain, and cost 300 M Euros.Its construction started June 2006 and began operating in 2008. The nominal production capacity is 50 MWe. A two-tank indirect thermal storage system holds 28,500 tons of molten salt, and this reservoir can run the turbine for up to 7.5 h at full load.

Land area: 200 hectares
Solar resource: 2,136 kWh/m^2/yr
Electricity generation: 158,000 MWh/yr (Expected/Planned)

Plant Configuration
Solar Field
Solar-Field Aperture Area: 510,120 m^2
# of Solar Collector Assemblies (SCAs): 624
# of Loops: 156
# of SCAs per Loop: 4
SCA Aperture Area: 817 m^2
SCA Length: 144 m
# of Modules per SCA: 12
# of Heat Collector Elements (HCEs): 11,232
# of HCEs: 11,232
Heat-Transfer Fluid: Diphenyl/Biphenyl oxide
  Solar-Field Inlet Temp: 293°C
  Solar-Field Outlet Temp: 393°C
  Solar-Field Temp Difference: 100°C
Power Block: Rankine cycle
  Turbine capacity (Net): 49.9 MW
  Power cycle pressure: 100.0 bar
  Cooling method description: Cooling towers
  Turbine efficiency: 38.1% @ full load
  Annual solar-to-electricity efficiency 16%
  Fossil Backup Type: HTF heater
  Backup Percentage: 12%
Thermal Storage
  Storage capacity: 7.5 hour(s)
  Storage type: 2-tank indirect
  Storage capacity: 7.5 hour(s)
  Thermal storage Description: 28,500 tons of molten salt. 60% sodium nitrate, 40% potassium nitrate. 1,010 MWh. Tanks are 14 m high and 36 m in diameter.

Economic study showed that the cost of EP from plants of high capital cost, such as NPP or thermal solar PP strongly depend on the interest rates. The EP cost of the GTCC depends strongly on NG fuel cost. As this PP have low capital cost and high operating cost (due to high fuel cost). The economic study showed that the EP costs, when the interest rate is 8%, are as follows: $59.04, $74.04, $89.04, and $104.04 per MWh when the fuel costs are $6, $8, $10, and $12 per 10 GJ using GTCC. The EP cost from NPP is $42.79/Mwh; from thermal solar, PP is $124.25/MWh.

Nomenclature

A/C	air conditioning
bbl	barrels, usually for oil fuel
bbl-E	energy equivalent of one bbl of oil, 6.12 GJ
BTU	British Thermal Units
GTCC	combined gas/steam turbine cycle
CF	capacity factor
CPDP	cogeneration Power Desalting Plant
CSP	concentrating solar power
DW	desalted seawater
EP	electric power
FF	fossil fuel, e.g. fuel oil, natural gas, and coal
GJ	giga Joules
GT	gas Turbines
CTCC	combined gas-steam cycle power plant
GW	giga watt
GWe	giga watt electric

GWh	giga watt hours
LEC	levelized electric energy generating Cost
LW-PWR	light water pressurized water reactor
M	million
MEW	Ministry of Electricity and Water in Kuwait
MWh	mega watt hours
NE	nuclear energy
NG	natural gas
NPP	nuclear power plants
PP	power plant
PV	photovoltaic
kWh	kilo watt hours, 3,600 kJ
RE	renewable energy
TWh	trillion watt hours
SE	solar energy
SEC	equivalent specific energy consumption, kWh/m^3
SEGS	nine solar power plants (Solar Electric Generating Systems) in California
WE	wind energy
WTs	wind turbines
y	year

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