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Large Scale Grid Connected (20MW) Photovoltaic System for Peak Load Shaving in Sahab Industrial District

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Abstract

In the daily electrical load cycle, peak load that lasts for few hours is the most expensive electrical production. In the present paper, Sahab Industrial District (SID), as an example, has its peak load occurring during daylight hours. Therefore, it is suggested that a PV plant be installed to shave off the peak load. The location of the proposed large-scale grid-connected PV generation system will be in the Al-Risha area because of the land low cost, and of a link to the national grid. The proposed PV system is designed with 20 MW installed capacity. It is found that the generation cost for all power is US$ 0.170 per kWh, which is much lower than the electrical production cost of the peak load generation. In addition, a cost comparison is conducted between kWh generated from conventional units (gas turbine in this case) and that generated from PV system. It was found that the cost of kWh generated from the PV system for peak shaving can be very competitive compared to gas turbines after 6 years of operation; so the cost of PV compared to the cost of gas turbines after 25 years was found to be 0.170$/ WP, 0.375 $/ WP, respectively. Also, the overall CO_2 reduction in the life cycle of PV system is about 541,798 tons of CO_2. So, there is no doubt that PV can be an effective tool to replace the conventional power generation, fighting against climate change.

The results of the present study clearly illustrate that it is possible to use photovoltaic generation at large-scale for peak load shaving because it is a very cost-effective project and could be generalized to other industrial districts, and to other load types, such as Industrial, and economic loads. The results of this work should encourage governments to impose new legislations regarding modifying the peak time to coincide with the solar generation time, (at least one operating peak hour)..

Keywords: *: Peak Load Shaving, Photovoltaic System, Life Cycle Cost, Net Present Value, On Grid System*.

Nomenclature

A_C	Cable Cross Sectional Area (mm^2)
A	Annuity Payment
CF	Plant Capacity Factor Per Month
C_{PV}	Capital Costs
$D_{O/C}$	Directional Over-Current Relay
$D_{e/f}$	Directional Earth-Faulty Relay
E	Irradiation Level $(kW/m^2.^\circ C)$
F_{PV}	Fuel Costs ($)
F_V	Future Worth Value ($)
I	Current Through Cable (A_{DC})
I_{SC}	Short Circuit DC Current (A_{DC})
I_{mp}	Optimum Operating current
i	Interest Rate (%)
L	Total Length of Cable (m)
n	Number of Years
$NOCT$	Nominal Operating Cell Temperature (°C)
$O\&M_{PV}$	Operation & Maintenance costs
P_{max}	Maximum Rated Power of PV Module (W_p/m^2)
PV	Present Worth Value ($)
$PVIF$	Present Value Interest Factor
$PVIFA$	Present Value Interest Factor annually
$R_{e/f}$	Restricted Earth-Fault Relay
R_{PV}	Replacement Costs ($)

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$S_{e/f}$	Sensitive Earth Fault
S_{PV}	Salvage Costs ($)
UPW	Uniform Present Worth ($)
V	Operating Voltage (V_{DC})
V_{mp}	Optimum Operating Voltage (V_{DC})
V_{OC}	Open Circuit Voltage
V_d	Voltage drop in a cable (V_{DC})
X (m)	Distance Between Rows (m)
Y	Height of Tilted PV Panel (m)
T_X	Temperature derate factor per month
T_a	Ambient temperature (°C)
T_m	Module Operating temperature (°C)
α	Voltage Temperature Coefficient
β	Tilt Angle (Degrees)
γ	Azimuth Angle (Degrees)
ρ	The resistivity of copper wire (0.0183 mm/m^2)
ϕ	Latitude Angle (Degrees)
η	Efficiency
η_{PV}	Overall Efficiency of the PV Module

Abbreviations

DNI	Direct Normal Irradiation
ERC	Electricity Regulatory Commission
FV	Future Value
GW	Giga Watts
JD	Jordanian Dinar
JEPCO	Jordan Electric Power Company
kV	Kilo-Volt
kW	Kilo-Watt
LCA	Life Cycle Analysis
LCC	Life Cycle Cost
MMP	Maximum Power Point
MEMR	Ministry of Environment and Mineral Resources
NEPCO	National Electric Power Company
NPV	Net Present Value
PV	Photovoltaic
PVGC	Photovoltaic Grid Connected
PVIF	Present Value Interest Factor
PVIFA	Present Value Interest Factor Annually
SID	Sahab Industrial District
UPW	Uniform Present Value
VT	Voltage Transformer

1. Introduction

1.1. The Present Situation of the Jordanian Energy Sector

The Jordanian energy sector currently faces a number of significant challenges (Mason M. *et al.*) [1]. These challenges are the following:

- A high level of dependence on energy imports, with approximately 96% of Jordan energy demands being imported from outside the country. This is likely to continue in the near future given the modest endowment of commercially available fossil fuel resources.
- A heavy fiscal burden caused by a substantial energy import bill. This was estimated at 2.28 billion JD (US$3.21 billion) in 2012.
- Rapidly rising energy demand. According to JEMR, Jordan's primary energy requirements are projected to rise 5.5% annually from 7.6 million tons of oil equivalent (Mtoe) in 2007 to 15 Mtoe in 2020. Furthermore, demand for electric power is predicted to rise 7.4% annually from 2.1 GigaWatts (GW) in 2007 to 5.77 GW in 2020, requiring an additional power generation capacity of 4 GW (Arab Union of Producers, Transporters and Distributors of Electricity) .
- High energy consumption density in Jordan (where energy consumption density is defined as the amount of energy required to produce one unit of national production). In 2006, the energy consumption density for developing countries was 590 kg oil equivalent per $1,000, on average, and for the developed countries, it was 310 kg oil equivalent per $1,000. However, the energy consumption density in Jordan was 640 kg oil equivalent per $1,000.

1.2. Peak Loads in Jordan

Jordan's peak load of the electric power system is 2790 MW in the year 2012 compared with 2680 MW in 2011 with a 4.1% annual growth. The annual peak load for the interconnected system is 2770 MW in July 2012 compared with 2660 MW in August 2011. This represents an annual growth of (4.1 %) as shown in **Table 1** (National Electric Power Company (NEPCO) annual report) [2].

Table 1 System peak loads (MW) - NEPCO annual report, 2012

Year	Interconnected system (MW)			Interconnections(MW)		All Jordan (MW)		
	Generated	Sent-out	Growth (%)	Imported	Exported	Generated	Sent-out	Growth (%)
2008	2230	2120		282	____	2260	2150	
2009	2300	2200	3.8	223	132	2320	2220	3.3
2010	2650	2540	15.5	____	____	2670	2560	15.3
2011	2770	2660	4.7	49	____	2790	2680	4.7
2012	2880	2770	4.1	____	40	2900	2790	4.1

1.3. Electricity Consumption Pattern in Sahab Industrial District (SID)

1.3.1. Sahab Industrial District (SID)

SID represents the largest consumption district of the Jordanian Electric Power Company ltd. (JEPCO). The largest main distribution substation which receives power from NEPCO at 33 kV voltage to 11 kV step down voltage level was installed. Four step-down power transformers (33kV/11kV) were used. The rating power for transformers T1 and T4 is 25 MVA for each and 20 MVA for both T2 and T3. This resulted in 90MVA overall installed capacity.

1.3.2. Daily Load Curve for SID

Loads for all the months of the year for SID at 33 kV side are recorded each 60 minutes. The day with the largest load in each month is taken as the worst case to ensure that all days in the month can be covered by the generated energy. The daily load curve is a strong tool to analyze the load pattern, peak loads and the time they occurred. Data are collected from the Supervisory Control and Data Acquisition (SCADA) center in JEPCO, annual report, 2012, [3]. The daily load curve for September is shown in Figure 1 as a typical daily load. It is obvious that the peak load starts from 7:00 AM, which is the starting time for industrial loads, and reaches about 64 MW in midday, and then it decreases at night.

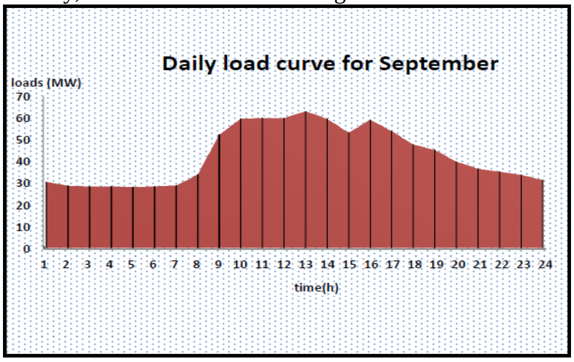

Figure 1. Daily load curve of SID, 2010, SCADA Center, JEPCO [3]

The photovoltaic generation period is considered to be from sunrise to sunset, 6:00 AM - 6:00 PM. This is shown in Figure 2. There is a degree of symmetry between the daily load curve and a PV output.

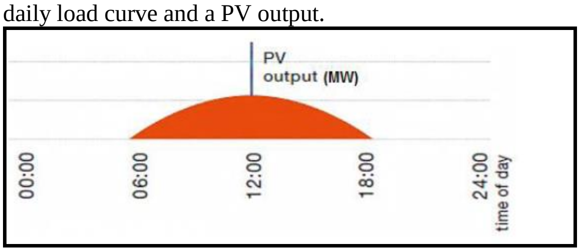

Figure 2. Photovoltaic generation output, JEPCO [3]

Peak loads for all months were recorded as shown in Figure 3, which represents the monthly peak loads for the year 2012.

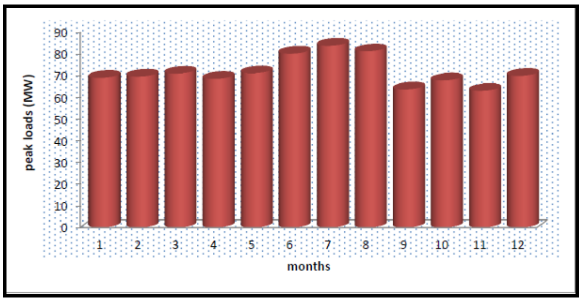

Figure 3. Peak loads for SID in year 2012

1.3.3. Load Types in SID

Any electrical consumption is usually divided into three main sectors, namely Industrial loads, residential loads and commercial loads. Unfortunately, there is no measured specific data that can specify the load types in SID, and this enforces an extra effort to distinguish loads. SID comprises 236 distribution substations (11 kV/0.415 kV) with 243 distribution transformers with power ratings varying from 250 kVA to 1500 kVA, with 224.75 MVA installed capacity. All SID distribution substations were visited as part of this work and loads were measured as shown in Table 2.

Table 2 Measured loads in SID distribution substations

Classification of Load Shares in SID	Measured Load Percentage	Installed Capacity (MVA)	Number of Transformers
Pure residential loads	100 %	163.94	173
Pure industrial loads	100 %	13.09	30
Industrial loads + Residential loads	80 % + 20 %	16.008 + 4.002	23
Industrial loads + Residential loads	70 % + 30 %	11.417 + 4.893	3
Commercial loads + Residential loads	80 % + 20 %	3.6 + 0.9	4
Commercial loads + Residential loads	70 % + 30 %	0.91 + 0.39	2
Commercial loads + Residential loads	50 % + 50 %	2 + 2	5
Commercial loads + Residential loads	50 % + 50 %	0.23 + 1.28	3
Total		224.75	243

Load types distribution, including losses, is shown in Figure 4.

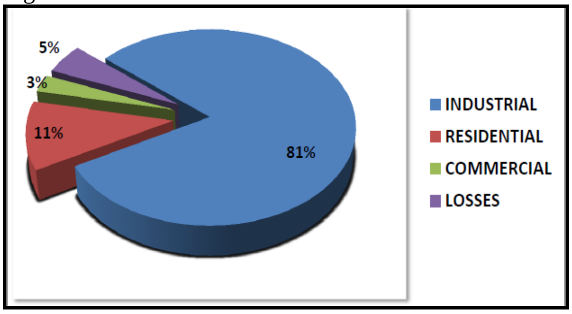

Figure 4. Load types distribution including losses in SID

1.4. Time of Peak Loads

Peak loads become more effective from 7:00 AM - 6:00 PM, as shown in Figure 1. The daily load curve of the Jordanian network has two peak periods, in midday and evening hours. A large sector of Jordanian electrical load can greatly benefit from the high irradiance and long sunny days whether these loads are connected to grid or stand alone as reported by Al Zou'bi [4]. However, Badran *et al.* [5] stated that the great importance of electricity from solar technologies is due to the considerable associated benefits namely, maximum power generation at peak load hours in hot climate countries like Jordan, reduction of greenhouse gas emissions, and others.

As mentioned previously, the major load type in SID is industrial, followed by residential and then commercial loads. Cost analysis is based on the fact that the peak load in SID will increase and a new generation power plant will be needed to be installed to overcome this incremental demand. So, a comparison between a kWh, generated by conventional unit and Photovoltaic system, is held. The peak period for medium industries, was decided to be modified by the Electricity Regulatory Commission (ERC).

1.5. Solar Radiation in Jordan

Jordan lies between Latitude 28.4° - 33.30° N and between Longitude 35° - 39° E and has an annual solar radiation average that ranges from 3.8kWh/m^2/day in winter up to 8.0 kWh/m^2/day in summer. This is classified as one of the solar belt countries according to the international classification Al-Salaymeh [6]. According to the solar atlas of Jordan, SID is characterized as part of the eastern region with an annual daily irradiance between 5.5-6 kWh/m^2.day.

1.6. Aim of the Work

A serious problem takes place, in all countries, including Jordan, when loads, especially industrial loads, reach the bottleneck situations or the peak due to hard overloading condition. Finding the best and cheapest solution for peak load shaving is a difficult challenge for the operation and control engineer, of course to avoid cascaded blackouts in the grid. The demand generated during the peak is too expensive. Power plants designed to provide emergency or opportunist power are called peak shaving plants. They are mostly gas turbine plants which can be brought on stream very quickly, in case there is a sudden unplanned demand. This is the main problem which needs a solution and finding alternative resources. Any available solution to supply the grid should enforce the reliability of the system. Reliability benefits reflect that the Jordanian national system should be stable during the peak periods with low cost, and to qualify better "electrical security" and less dependency on the neighboring countries through electrical interconnection during peak load times.

1.7. Proposed Solution

The photovoltaic system has shown that it could be one of the most appropriate options for peak load shaving and can generate electricity in large-scales during the day peak period. This is of course besides the challenges regarding the present situation of the energy sector in Jordan; the challenges which reflect an urgent need for large-scale photovoltaic generation. Therefore, photovoltaic system can generate both energy value (the system’s ability to save energy) and capacity value (in the form of coincident peak demand reduction) as well as its environmental benefits. In the present paper, a large-scale grid-connected photovoltaic system is designed with 20 MW installed capacity. The generated output power from the PV system is at 0.4 kV voltage level and steps up through two steps to 132 kV. In addition, a cost comparison is conducted between kWh generated from conventional units (gas turbine in this case) and that generated from PV system.

2. Previous Studies

Research on photovoltaic power generation has gained momentum for the past few years in the world due to the rapid rise of oil prices. PV generators range from small scale to large ones as reported by Hammad and Ebaid [7]. Also, PV resources [8], which state that more than 750 large-scale PV power plants are located in Spain, more than 500 are in Germany and a little more than 370 in USA.

The literature review in this paper is divided into the following two sections:

2.1. Photovoltaic Power Generation

Abdallat *et al.* [9] showed that the main driver behind the increase in the energy demand, between years 1998 and 2005, was the rapid increase in industrial production output. They believed that their work could be considered as a milestone for improving and restructuring the Jordanian industrial sector then for the purposes of reducing its energy use.

Hussain *et al.* [10] determined the potential of grid-connected solar PV system in Bangladesh utilizing GeoSpatial toolkit, NASA SSE solar radiation data and HOMER optimization software. Financial viability of solar PV, as an electricity generation source for Bangladesh, was assessed utilizing a proposed 1 MW grid-connected solar PV system using RETScreen simulation software for 14 widespread locations in Bangladesh. Results showed a favorable condition for developing the proposed solar PV system for all the sites considered in Bangladesh.

EL-Shimy [11] investigated, from techno-economic and environment, the feasible sites in Egypt to build a 10 MW grid-connected PV power plant using RETScreen software. Also, Khresat [12] analyzed the viability of 5 MW grid-connected solar PV power plant as an electricity generation source for Jordan. The annual electricity production of the plant, the specific yield and the economic indicators were performed using RETScreen software. EL-Shimy's study concluded that a pilot 5 MW grid-connected solar PV power plants should be installed at each of Karak and Tafila. A similar 5 MW PV power plant system was installed in Saudi Arabia, as reported by Rehman *et al.* [13]. The study utilized RetScreen software for energy production and economical assessment. Denholm and Margolis [14] analyzed the potential of large scale PV generator to provide a large fraction of a system's electricity and they found that the system will have excess PV generation during certain periods of the year. Hardran [15] described a centralized PV power system and its operation in grid connection mode in a small village situated in Aleppo.

AI-Hasan *et al.* [16] discussed the optimization of electrical load pattern in Kuwait using grid connected PV system as the electric load demand can be satisfied from both the PV array and the utility grid. They found during the performance evaluation that the peak load matches the maximum incident solar radiation in Kuwait. This emphasized the role of using the PV plants to minimize the electrical load demand, and that the significant reduction in peak load can be achieved by grid connected PV systems. The work of Sechilariu *et al.* [17] focused on the design and implementation applied to building-integrated microgrid system with energy storage and smart grid communication aiming at reducing grid peak consumption, avoiding undesirable grid power injection, making full use of local PV production. Their results showed that the system maintains stability and confirms the relevance of the proposed local energy management giving perspectives on better integration of small urban PV plant in power grid. Chow *et al.* [18] investigated the short-term load forecasts of the power generated by PV systems using artificial neural networks modelling. Their results showed that forecasting plays a critical role in power system management in saving on peak load energy generation for PV plants.

Ito *et al.* [19] and Kurokawa *et al.* [20] studied the economic and environmental potential of a 100MW PV power generation system in the Gobi and Sahara desert. Issues such as generation cost, payback, life cycle cost, and CO_2 emission were analyzed. They concluded that very large scale PV systems are economically feasible on sufficient irradiation sites.

Muneer *et al.* [21] explored the long term prospects of large scale PV generation in rid/semi- arid locations, around the globe and the transmission of PV generation using hydrogen as the energy vector. Cunow and Giesler [22] described a1 MW rooftop PV plant at the new Munich Trade Fair Centre. They mainly studied the system technology, the components employed, the operational control and the costs. Alajlan [23] studied a 6 kWp PV grid-connected system at the solar Village in Riyadh. Issues such as PV array output per year for different tilt-angles, the effect of dust, and the degree of agreement between the predictions from simulation, and the experimental data were investigated and analyzed. Oha *et al.* [24] suggested a cost-effective method for the integration of existing grids with new and renewable energy sources in public buildings in Korea. Numerical calculations based on the hourly energy demand pattern data, obtained from field studies for buildings, showed that the additional cost by installing the energy systems can be minimized.

2.2. CO_2 Emission Reduction Due to Photovoltaic System

Harder and Gibson [25] studied the potential for a 10 MW photovoltaic power plant in Abu Dhabi using RetScreen modeling software to predict energy production, the financial feasibility and the reductions of Green House Gas (GHG) emissions. The benefits of reducing GHG and air pollution emissions by replacing natural gas with PV generation were calculated to have a net present value of USA $47million in the life cycle cost analysis.

A study of the operational performance for a grid-connected building integrated PV system in Hong Kong was conducted by Li *et al.* [26]. The output energy ranged from 10 to 360 kWh with an average value of 116.3 kWh. They found that the emissions of CO_2, SO_2, NO_x and particulates could be reduced, respectively, by 32 tons, 43.3 kg, 41.8 kg and 2.07 kg, and GHG payback period was estimated at 5.5 years.

Tezuka *et al.* [27] proposed a new method for estimating the amount of CO_2-emission reduction in the case where the carbon-tax revenue is used as the subsidy to promote PV-system installations. They concluded that the amount of CO_2-emission reduction increases by advertising the PV system with subsidy policy even under the same tax-rate and the CO_2-payback time of the PV system reduces by half if the Gross Domestic Product is assumed not to change after the introduction of carbon taxation.

Krauter *et al.* [28] examined a CO_2 comprehensive balance within the life-cycle of a photovoltaic energy system and found that the actual effect of the PV system in terms of net reduction of carbon dioxide is the difference between the sum of electrical yield related to the local grid and the value for recycling and the sum of the production requirements and the transport emissions. Hondo H. [29] presented the results of a life cycle analysis of greenhouse gas emissions from power generation systems in order to understand the characteristics of nine different types of power generation systems that included PV from the perspective of global warming and life cycle GHG emission per kWh of electricity generated.

Based on previous studies, it can be noted that the potential for grid connected PV systems is quite high. However, no work on the use of a photovoltaic solar electrical generator for peak load shaving is found in open literature; this is what motivated the present study, where the main objective is to use a photovoltaic solar electrical generator for peak load shaving in SID of 20 MW demand capacity of peak value.

3. Design Procedure

3.1. The Generated Power by the Photovoltaic System

In the present study, a large-scale grid-connected photovoltaic system is designed with 20 MW installed capacity. This work will address two situations: (a) photovoltaic power generation of 20 MW at Al-Risha city at the eastern part of Jordan, and (b) grid-connected photovoltaic system as a peak-shaving tool in SID. The present study also combines these two situations to gain the benefits of power generation and to make use of the benefits of peak-shaving in SID and any other industrial district.

3.2. System Design

In the present study, the main system design is undertaken based on the amount of generated power (20MW). The generated output power from the PV system is at 0.4 kV voltage level. It stepped up through two stages:

- First stage: voltage step-up from 0.4 kV to 11 kV by 10 step-up distribution transformers with 2 MVA rating each.
- Second stage: voltage step-up from 11 kV to 132 kV by one step-up power transformer with 20 MVA rating.

The output of the power transformer is synchronized to the national grid at Al- Risha main substation at 120 km east of the supply point, SID in this case. To achieve the power ratings, 10 arrays with 2 MW for each array resulting at 20 MW generated power were adopted.

3.3. Al-Risha Power Station

3.3.1. Selection and Description of the Site

Al-Risha is located in the eastern part of Jordan, near the Iraqi borders, at (31.33 North) latitude and 35.35 East) longitude). It was selected as a site for the photovoltaic generation system. Al-Risha has high solar radiations. Also, the national grid is located in Al-Risha, which makes the cost of connection to the grid low. On the other hand, the cost of the land is very low, which encourages investing there. Al-Risha gas power station is one of the major Jordanian generation centers which are used for local peak demand (Halasa) [30]. There are four gas turbines of 40 MW each and one unit of 45 MW generation capacities, AL-Risha station comprises the national grid at 132 kV voltage level which connects Al-Risha with Sahab substation, and also 11kV busbar with six feeders.

3.3.2. Radiation Potential in Al-Risha Station

Calculations of the monthly mean solar radiation on the tilted surface at Al-Risha are conducted for each month of the year. Calculations are based on different inclination angles from the horizontal surface,

($\beta = 0^\circ$) to vertical surface ($\beta = 90^\circ$) with 6 degrees difference each time passing through the approximately latitude value of the site W·= 30°. The average yearly values of the solar irradiance at AI-Risha range from 5.12 kWh/m^2 day to 7.22 kWh/m^2 day and the average tilt angle throughout the year was found to be $\beta = 30^\circ$.

3.3.3. Specifications of Al-Risha Transmission Line

The specifications of the transmission line of the national grid are shown below in Table 3:

Table 3. Specifications of the transmission line of Al-Risha power station

Voltage level	132 kV
Number of circuits	Double circuits
Maximum capacity / circuit	629 Ampere
Maximum resistance	0.06908 Ω/km

The transmission line from Al-Risha power station is not directly connected to Sahab substation, but it passes via Al-Rewishid (80km), Al-Safawi (108km), Al-Azraq (50km) and Al-Kharaneh broadcasting (47km) to finally reach Sahab substation. The overall distance is about 320 Km.

3.4. Design of Large scale PV System

3.4.1. Design and Selection of PV modules

The main factors affecting the selection of a PV module for grid connected systems are the efficiency of the module and the product warranty because the grid connected systems are designed to last for a long time. To decide whether to use poly-crystalline or mono-crystalline modules is not easy; it requires weighing costs against efficiencies. And since the cost has a higher importance due to the large number of modules expected to be needed, poly-crystalline modules are more likely to be selected, bearing in mind that its efficiency has also to be considerably high.

For the intended system, a large variety of PV panel options were studied in terms of type, power, cost and warranty. The Canadian Solar Power (CS6P) [31] of 250 Wp production is selected and adopted in the present work. CS6P is a robust solar module and can be used for grid-connected applications and solar power stations. Typical electrical characteristics of the PV module CS6P are measured under standard test conditions, irradiance of 1000W/m^2, air mass of 1.5 solar spectrum and an effective cell temperature of 25°C).

3.4.2. Design and Selection of Inverter

In the present study,, two designs of the PV system are conducted. The first design is based on using a central inverter system, while the other design is based on using multi-string inverter. Although the multi-string inverter has many advantages over the central one, the very high cost of the multi-string inverter compared with the central inverter leads to the selection of the central inverter. Another reason is that the central inverter is used widely all over the world in large-scale applications. In this work, the design of the central inverter will be described, and the other design is not included for brevity.

3.4.2.1. Design Considerations of Central Inverter

The aim of the present study is to design a large scale grid connected PV generator which has a size of 20 MW at Al-Risha district, and then to use this amount of power for peak load shaving in SID. The arrays and the inverters will be sized simultaneously. Maximum modules in the array for a large scale inverter size and the restrictions of the inverter input voltage and current are considered. The overall PV modules of 20 MW are divided into 10 arrays with 2 MW for each array. The design for one array of 2MW is conducted and then the design is generalized to all arrays in a similar way, and again the peak power for the selected PV module is 250 Wp. Based on that, two central inverters, each of 1000kW rated power, are considered for each array. Sinvert 1000 MS (Master-Slave from Siemens) central inverter is accordingly selected at rated input power 1119 kW, MPP voltage ($V_{MPP} = 450 - 750 V_{DC}$), $V_{Max} = 820 V_{DC}$, and maximum efficiency 96.5%.

1. Design Calculations for the Central Inverter

The number of the estimated modules for each array = $\frac{2000kW}{250W} = 8000$ PV module.

The operating voltage V_{mp}, and the open circuit voltage V_{OC} at $T_{\min} = -10^{\circ}C$ and $T_{\max} = 70^{\circ}C$ were obtained, respectively, by using Eq. (1), and the required input values were taken from Krauter and Ruther [28]

$$V(T) = V_{@25C} \times (1 + \alpha \Delta T) \quad (1)$$

Where: $(1 + \alpha \Delta T)$ = temperature derate factor

It is found that $V_{mp@-10C} = 33.68V$ and $V_{mp@70C} = 25.49V$ Also , $V_{OC@-10C} = 41.63V$ and $V_{OC@70C} = 31.51V$

It should be noted that both values of V_{mp} and V_{OC} were maximum at the lowest temperature $T = -10^{\circ}C$ and minimum at the maximum temperature $T = 70^{\circ}C$ that the module could reach.

The next step was calculating the number of modules per string (Eqs. 2 & 3), according to the maximum values of both operating voltage $V_{mp@-10C} = 33.68V$ and open voltage $V_{OC@-10C} = 41.63V$ as shown below:

No. of modules/string

$$= \frac{(V_{MPP})_{inverter}}{(V_{mp})_{@-10C}} = \frac{750}{33.68} = 22.27 \cong 23 \quad (2)$$

module/string

No. of modules/string

$$= \frac{(V_{\max})_{inverter}}{(V_{OC})_{@-10C}} = \frac{820}{41.62} = 19.70 \cong 20 \quad (3)$$

module/string

For safety conditions, 20 modules / string were selected. Now, the maximum number of strings in parallel can be found using Eq. (4) based on the selected inverter Sinvert 1000 MS, we have;

Maximum No. of strings in paralle

$$= \frac{(P_{output,kW})_{inveter} / \eta_{\max}}{[(20\, module / string) \times (P_{\max})_{module}]} \quad (4)$$

$$= \frac{1000,000 / 0.965}{20 \times 250} = 207.25 \cong 207$$

string

For each inverter, the total number of PV modules required can be found from Eq. (5)

No. of modules/string X No. of parallel strings

$$= 20 \times 207 = 4140 \quad (5)$$

modules

2. Layout of Grid-Connected PV System with the Central Inverters

Since the distribution transformer rating is 2 MVA, each array will accordingly contain 2 inverters. Each inverter is connected with 207 parallel strings, and 20 modules per string in a series, as shown in Figure 5.

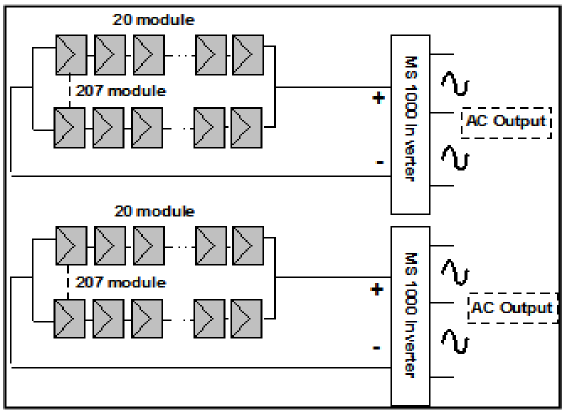

Figure 5 The array configuration of the central inverter

The wiring diagram connection of the inverters output to the main combiner box is shown in Figure 6. It must be mentioned here that the output of the main combiner box was connected to a step-up distribution transformer. This transformer is selected to be (0.4/11) k V, since it receives the voltage from the inverter at 0.4 kV level, and the 11 kV voltage level is selected because in Al-Risha station there is an 11 kV busbar.

3.4.3. Sizing of Cables

As much as the design/sizing of the grid connected PV system is important, the accurate selection of system wiring cables is vital so that the system will be safe. The wiring must not reduce the performance of any of the components of the system. The cables in a grid connected system must be sized correctly to reduce the voltage drop in the cable and to make sure that the safe current handling capacity of the cable is not exceeded. In the present work, a maximum cable voltage drop of 5% was used and this is the maximum allowable drop in PV grid connected systems. Calculations were carried out for sizing the required cables of the system and the results are shown in Table 4. It should be noted here that any DC cable of cross sectional area above the given value in Table 4 can be used.

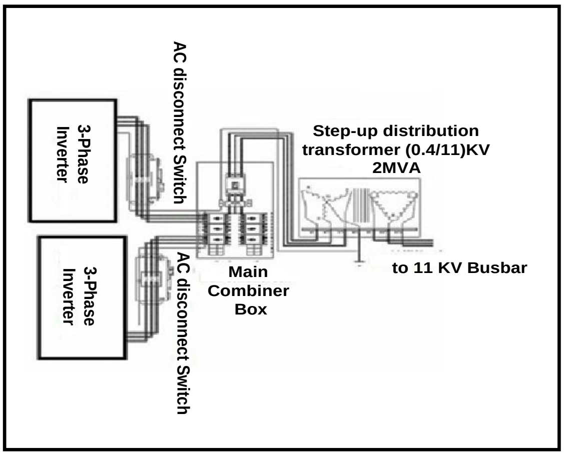

Figure 6. Wiring diagram of connection of inverters output to main combiner box

Table 4. Cable sizing for the PV system

Cable	**Cable Length (m)**	**Minimum DC Cable Rating (Cross-sectional area, mm^2)**
Sizing cables between PV modules	1.5	0.41
Sizing of DC cable from PV array bus-bar (from array collection point) to inverter	20	44.80
Sizing of AC cables from inverter to main combiner box	20	99.90
Sizing of AC cables from main combiner box and transformer.	20	199.80

A summary of wiring ratings of the system is shown in Figure 7:

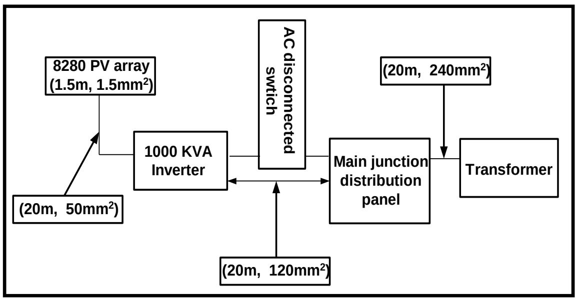

Figure 7. Summary of wiring ratings and lengths of the system

3.4.4. Sizing of System Circuit Breakers

Circuit breakers are installed in the system to operate for over current protection and sized below 125% of the current flowing through the wiring. Calculations were made and the results are shown in Table 5.

Table 5. Circuit breaker rating for the PV system

Circuit breaker position	Minimum DC current rating (A_{DC})
Circuit protection between PV array and inverter	13.98
Circuit protection on every phase output of inverter	1942.5
Inverter AC output disconnect	2000

3.4.5. *Synchronization with the System*

For this design, synchronization must be assured in two places, upon the interconnection with the national grid since there is another source of power supply to the grid from another source, and when connecting the $(0.4/11)\ kV$ transformer with the $11kV$ busbar since there is outgoing feeders. In other words, synchronization must be achieved when there is a closed loop system; this is implemented by using Synchro-check relay. Two voltage transformers (VTs) on yellow phase measure the voltages, one on the circuit side and the second on the busbar. The synchro-check relay compares the line voltage and the bus-voltage, and then a closing pulse command comes from the SCADA center, and closes a normally open contactor if the synchronization conditions are achieved, then the circuit breaker closes.

3.5. PV System Output Generation

The PV system considered in this study is a fixed axis system with an array slope of $\beta = 30^\circ$ (maximum annual energy production) and array azimuth angle $\gamma = 0^\circ$.

3.5.1. PV system Losses

There are many factors that affect the output of a PV system. These factors are quantified as losses and are listed in Table 6. Temperature loss, mismatch and wiring losses, and DC to AC inversion loss values are given by German Energy Society [32]. Normally, for design purposes, 2 to 6% of the PV panel output can be subtracted to compensate for the losses caused by dirt and dust on panels (Hussein *et al.*) [33].

Table 6. Type of losses of PV system

Type of Losses	**Loss value (%)**
Temperature loss	4% per $^\circ C$ above $25^\circ C$
Mismatch and wiring losses	5%
DC to AC inversion losses	5%
Dust losses	5%

3.5.2. Overall efficiency of the PV system per month (η_{PV})

The overall efficiency of the proposed system for each month is calculated according to Eq. (6).

(η_{PV}) = *[(Temperature derate factor X inverter efficiency) X (mismatch and wiring losses factor) X (dust factor)]* (6)

For Al-Risha, the temperature derate factor T_X per month is calculated based on the data measured by the Jordanian Meteorological Department as shown in Table 7 below**,** and by using Eqs. (7) and (8), given by Pate and Foster [34]

$$T_m = 20.4 + 1.2 \times T_{avg} \quad (^\circ C) \tag{7}$$

$$T_X = 1 + \alpha (T_m - T_a) \qquad (\alpha = -0.43\% \ ^\circ C) \tag{8}$$

Table 7 Al-Risha solar radiation and average daily maximum temperature (Jordanian Meteorological Department)

Month	Solar irradiance (KW/m^2.day)	Avg. Daily Max. Temp °C (T_a)
January	7.24	20.00
February	8.05	21.00
March	7.51	23.00
April	6.64	29.00
May	7.10	34.00
June	7.08	38.00
July	7.08	41.00
August	6.56	39.00
September	7.08	34.00
October	7.40	32.00
November	8.04	26.00
December	6.55	28.00

T_X for January can be estimated as follows:

$T_a = 25^\circ C$, and $T_{avg} = 20\ ^\circ C$ (January)

$$T_m = 20.4 + 1.2 \times 20 = 44.4\ ^\circ C$$

$$(T_X)_{Jan} = 1 - 0.0043(44.4 - 25) = 0.916 \tag{9}$$

Similarly, T_X can be estimated for all months of the year (see Table 8). By using Eqn. (6) and the value of $T_X = 0.916$ Eqn. (9), the overall efficiency $(\eta_{PV})_{Jan}$ can be calculated. For January as an example,

$$(\eta_{PV})_{Jan} = (0.916 \times 0.95) \times (0.95) \times (0.95) = 0.781 \tag{10}$$

Similarly, η_{PV} can be estimated for all months of the year, (see Table 8)**.** However, solutions can be adopted to reduce the losses due to PV module temperature which reduces efficiency and power output of the module such as

- Include Aluminum fins at the rear of the module for cooling which reduces the thermal resistance and increases the surface area for convection.
- Another proposed solution is to mount the PV modules above the ground at 1.5 m to enhance heat transfer by convection.
- Installing water tanks at the bottom of the PV panels or flowing cold water.

3.5.3. Calculation of Generated kWh of the system per month

Full nameplate capacity for each month (kWh) = [installed modules (kW)] x [24 (hour/day)] X [number of days of month (day)] (11)

CF = [solar irradiance in (kWh/m^2.day)] x [PV system efficiency] / [24 (hour/day] x [1 (kW/m^2)] (12)

So, the plant capacity factor [35] for an average day of January is calculated as follows :

$$(CF)_{avg.\,day of\ Jan} = \frac{7.24 \times 0.718}{24 \times 1} = 0.2370$$

(Solar irradiance in (kWh/m^2.day) = 7.24 from Table 7).

Similarly, CF can be estimated for all months of the year, (see Table 8). Combining Eq. 11 and Eq. 12 to get the generated kWh of the system yields to

The generated kWh of the system = Full nameplate capacity X Capacity factor CF (13)

So, the full nameplate capacity for January = (20000kW x 24 hour/day) x 31 = 14.88 MWh

Similarly, full nameplate capacity can be estimated for all months of the year, (see Table 8)

So, the generated MWh of the system (Eq. 13) for January = (14.88×10^6) x 0.237=3.528 MWh

Similarly, this is calculated for all months, the average generated MWh for all months in the first year is 3.236 MWh. Finally, the total generated kWh of the system for the first year is the summation of all months, which equal 38.829 MWh. The overall results are shown in Table 8.

3.5.4. Required Land

According to the mechanical data of the PV module, the length of the selected PV module is $L = 1638mm$, and the width is $W = 982mm$. The needed spacing between the rows of modules has to be taken into consideration. The spacing needed depends on the length L of the modules, the tilt angle $\beta = 30^\circ$ and altitude angle ϕ , which corresponds to the elevation of the sun at which shadows are undesirable. The geometrical relationship between the angles and module is shown in Figure 8

Table 8. Al-Risha 20 MW PV system plant performance summary

Month	Avg. Daily Max. Temp. (°C)	Avg. Module Temp. (°C)	Temp. Derate (%)	PV system efficiency (%)	Plant Capacity Factor (%)	Energy KWh produced (MWh)	Full nameplate Capacity (MWh)
January	20.00	44.40	91.658	0.786	23.707	3.528	14.880
February	21.00	45.60	91.142	0.781	25.210	3.523	13.440
March	23.00	48.00	90.110	0.773	24.175	3.597	14.880
April	29.00	55.20	87.104	0.746	20.640	2.972	14.400
May	34.00	61.20	84.434	0.724	21.416	3.186	14.880
June	38.00	66.00	82.370	0.706	20.686	2.978	14.400
July	41.00	69.60	80.822	0.693	20.442	3.041	14.880
August	39.00	67.20	81.854	0.702	19.182	2.854	14.880
September	34.00	61.20	84.434	0.724	21.356	3.075	14.400
October	32.00	58.80	85.466	0.733	22.594	3.362	14.880
November	26.00	51.60	88.562	0.759	25.437	3.663	14.400
December	28.00	54.00	87.530	0.750	20.481	3.048	14.880
AVG.	30.42	56.90	86.283	0.740	22.194	3.236	
					Annual Total	38.829	

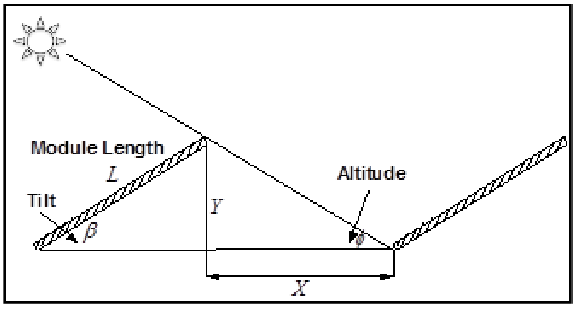

Figure 8. Illustration of values in Eq. (11) for the shading distance

The minimum module spacing between rows

$$X = \frac{L\sin\beta}{\tan\phi}$$

Where: $L\sin\beta = 1638 \times \sin 30 = 819\,mm = 0.819\,m$

Since the module in this design is south facing, i.e., the azimuth angle equals zero, the tilt angle $\beta = 30^\circ$, and values of the altitude angles ϕ from 10° - 80° are taken, and the average value of the corresponding X is calculated according to Eq. (12) above, and tabulated in Table 9.

Table 9. The minimum spacing between rows for different altitude angles

Altitude angle	X (m)	Altitude angle	X (m)
10°	4.65	50°	0.69
20°	2.25	60°	0.48
30°	1.42	70°	0.30
40°	0.98	80°	0.15
Average X value		1.37	

For this design, there are 10 arrays, each of which consists of two zones;

The life-cycle cost methodology is a useful tool used to conduct financial analysis of large-scale PV power system as compared to conventional alternatives. PV modules are guaranteed by manufacturers up to 25 years of 80% of rated wattage at standard test conditions (25°C and 1,000 W/m^2). The only way to make a fair economic assessment of the equipment is to look at a levelized life-cycle cost analysis over reasonable time frame. There is a variety of methods used for calculating the financial feasibility of solar energy projects. For life-cycle cost comparison considered here, the Net Present Value (NPV) method of comparison is most easily applied and commonly used for this type of analysis. The NPV can be calculated as follows [34]:

$$NPV = Annual\ \ return - Investment\ \ costs + Liquidation\ \ yield \tag{14}$$

3.6. Life-Cycle Costing Methodology (LCC)

It is reasonable to use a life-cycle cost approach, particularly when dealing with renewable energy technologies which typically have high initial capital costs. Costs of electrical generation can be broken down into five main categories: capital costs, operation and maintenance costs, fuel costs, and replacement parts costs. However, viable economic decisions cannot be made only on the basis of one type of costs (e.g., capital cost), but rather must consider all the costs incurred over the lifetime of the system. Levelized LCC analysis method makes it possible to compare different alternatives by adding up the project costs over its lifetime. The LCC can be calculated as follows [34]:

$$LCC = (C)_{PV} + (O\,\&\,M)_{PV} + (F)_{PV} + (R)_{PV} - (S)_{PV} \tag{15}$$

Where the salvage value $(S)_{PV}$ after 25 years are assumed to be zero in this design.

In order to accurately estimate the average incremental economic cost of the project alternatives, a project life time must be selected. The project life time is taken to be 25 years since it is the warranty period of the solar panel which is the most costly part of the system.

3.6.1. AI-Risha PV System Economic Assumptions

Economic assumptions for Al-Risha PV system is summarized in Table10.

Table 10. AI-Risha PV System Economic Assumptions

Parameter	Solar system
Project Lifetime	25 years
Salvage Value	None
Fuel Cost	None
Demand Cost	None
Fuel (Grid) Escalation Rate	4% Per year
O&M Costs	$0.012/Wp installed per year
General Inflation	6% per year
Discount Rate	5% per year
Real Discount Rate	1% per year

The LCC analysis was conducted to bring all costs into their present worth. This information is included in Table 11. In these calculations, the total installation cost is 124,070,000 $, dividing this value by 20 MWp yielding to 6.20 $/Wp installation cost. Again, this analysis optimistically assumes no PV system downtime during daylight hours. Obviously, the PV system will not be available for night-time usage. If energy storage was added, the system cost would approximately double. To the best of our knowledge, there are no MW sized PV systems in the world using energy storage due to the high cost.

Table 11. Al-Risha 20 MWp PV system estimated Component Costs

$ Approximation		Costs	Total Costs
$/Wp	$2.000	PV modules	$40,000,000,00
$/Wp	$1.000	Mounting structure	$20,000,000,00
$/Wp	$0.750	Switch gear and interconnect	$15,000,000,00
$/Wp	$0.038	One power transformer	$750,000,00
$/Wp	$0.010	10 distribution transformer	$200,000,00
$/Wp	$0.800	20 Inverters	$16,000,000,00
$/Wp	$0.400	Monitoring	$8,000,000,00
$/Wp	$0.800	Design and installation	$16,000,000,00
$/Wp	$0.006	Land costs	$120,000,00
$/Wp	$0.400	Miscellaneous (contingency)	$8,000,000,00
Total	$6.000		$124,070,000,00
		Installation cost ($/W$_P$)	$ 6.2035

To calculate present worth value, the following Eq. is used [34]:

$$PV = \frac{FV}{(1+i)^n} \qquad (16)$$

To calculate the present worth value where annual payments are known and the total present worth of all payments needs to be determined, the following Eq. can be used [34]:

$$PV = A \times UPW \qquad (17)$$

Where: $$UPW = \frac{(1+i)^n - 1}{i \times (1+i)^n} \qquad (18)$$

Operation and maintenance cost (O&M) is considered as labor cost (0.012 $/Wp/year), which is equal to (0.012 x 20,000,000 = 240,000 $/Year). This annual value must be converted to the present value using Eq. (18) as follows:

$$UPW = \frac{(1+0.01)^{25} - 1}{0.01 \times (1+0.01)^{25}} = 22.02$$

$$PV = 22.02 \times 240{,}000 = 5{,}284{,}800\,\$$$

Now, the replacement cost of the inverters is 16,000,000 $. For operation purposes, these inverters should be replaced after the half life-cycle (say 12 years). The present value is calculated using Eq. (16) as follows:

$$PV = \frac{160{,}000{,}000}{(1+0.01)^{12}} = 18{,}032{,}000\,\$$$

The NPV total LCC of Al-Risha 20 MWp PV system with O&M cost is calculated and found to be equal to 147,387,557 $, yielding to 7.37 $/Wp; these results are summarized in Table 12.

It must be noted that PV modules degrade slightly each year. For this analysis, the PV array was considered to degrade at an average rate of 0.8% each year. After 25 years, the total array degradation is expected to be 20% below nameplate rating. This is typical of the warranty offered by several manufacturers (i.e., Sharp). Actual PV array degradation will vary according to climate and module manufacturing methods.

The annual expected energy production, the electricity value saved and the NPV at Al-Risha 20 MWp solar system for the load types of SID, which are industrial loads (80.89 %), residential load (11.22%) and commercial load (2.90%), of each load type are calculated for the operation period of 25 years and listed in Table 13.

The PV LCC generation cost for all the system is calculated as follows:

PV LCC generation cost = NPV total life cycle cost ($) / Total PV Energy production (kWh) = $ (147,387,557.0 / 857,937,559.0) = 0.170 $ / kWh (19)

3.7. Cost Comparison between kWh Generated from Conventional Units and PV System

It is possible to evaluate the total cost of the kWh production at Al-Risha from conventional unit (gas turbine generation units in this case) if it is used during peak hours and compare this with the kWh generated from PV system. The assumption, based on that, is that the peak happens 6 months in a year, 3 hours in a day, the discount rate is 5%. This calculation is based on an annual value method; the cost of kWh production from gas turbine is shown in Table 14.

Table 12. Net Present Value of Al-Risha 20 MWp PV system with O&M

Item	Year	Cost $	PVIF, PVIFA	Net present value $
1-Price				
PV modules	0	$40,000,000	(1)	$40,000,000
Mounting structure	0	$20,000,000	(1)	$20,000,000
Switch gear and Interconnect	0	$15,000,000	(1)	$15,000,000
One Power Transformer	0	$750,000	(1)	$750,000
10 distribution transformer	0	$200,000	(1)	$200,000
20 Inverters	0	$16,000,000	(1)	$16,000,000
Monitoring	0	$8,000,000	(1)	$8,000,000
Design and Installation	0	$16,000,000	(1)	$16,000,000
Land costs	0	$120,000	(1)	$120,000
Miscellaneous (contingency)	0	$8,000,000	(1)	$8,000,000
2- O&M				
Labour 0.012/W_P	Per year	$240,000	$22.023	$5,285,557.37
3-Replacement				
20 inverters	12	$160,000,000	$ 1.127	$18,032,000
NPV Total Life Cost Cycle		**$/ W_P**	**$ 7.37**	**$ 147,387,557**

3.7.1. Gas Turbine Cost

The operating peak hour = (6 months/year) x (30 day/month) x (3 hours/day) = 540

Annual cost for gas turbine = 400 x $(1+ 0.05)^{25}$ x (0.05 / [$(1+0.05)^{25}$ -1]) = 28.83 $

Cost of kWh = 28.83 /540 = 0.053 $/kWh

Total cost = 0.053+ 0.009+0.0707 = 0.133 $/kWh

This value is calculated for the first year; but to calculate the total cost for the generated kWh from gas turbine for all life-cycle, the increase of fuel cost must be considered. The fuel escalation rate is considered to be 4%.

3.7.2. PV System Cost

The total cost of PV system is calculated previously and equals 0.170 $/kWh. In PV system, the capital cost per installed Wp peak is 7.37 $/Wp (Table 12), and the total generated energy is 857,937,559.0 kWh

From the above analysis, it can be seen that the cost of kWh generated from the PV system for peak shaving can be very competitive compared to gas turbines after 6 years of operation. This cost comparison between PV and gas turbine is shown in Figure 9.

Table 13. Annual expected energy production, electricity value saved and NPV at Al-Risha 20 MWp solar system

Load type	Annual expected energy production (25 years) (kWh)	Electricity value saved (USA $)	Net present energy value (USA $)
Industrial loads	730,434,367.0	80,944,260.0	100,084,193.0
Residential loads	101,316,276.0	18,272,248.0	20,757,273.0
Commercial loads	26,186,916.0	5,383,699.0	6,115,882.0
Total	857,937,559	104,600,207	126,957,348

Table 14. Cost of kWh production from gas turbine

Type of cost	Gas turbine
Capital cost	400 $/kW
Operating and Maintenance	0.009 $/kWh
Fuel cost	0.0707 $/kWh
Life cycle	25 years

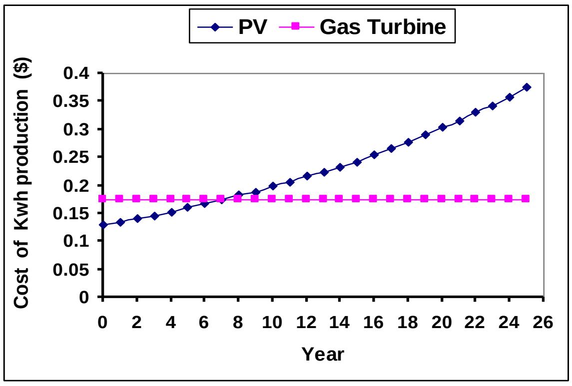

Figure 9. Cost comparison between PV system and gas turbine

4. Discussion

4.1. PV System

The present study clearly illustrate that it is possible to use PV generation at large-scale (20MW) for peak load shaving in Sahab Industrial District. In preparation for this study, peak loads for SID were recorded. Also, the daily load curve for each month was plotted and it was a typical curve for industrial peak load. Another preparation for this study was the load types in SID, which were classified as industrial loads, sharing 80.89%, residential loads, sharing 11.22%, and, finally, commercial loads, sharing 2.90%.

The design of the PV system is based on two different inverters, a central inverter and a multi-string inverter. Despite of the advantages of the multi-string inverter, the very high price of this type leads to opting for the conventional inverter (i.e., the central inverter). PV system is selected to be fixed structure, the array slope is $\beta = 30^{\circ}$, and the array azimuth is $\gamma = 0^{\circ}$ (due south). PV generation yield, the temperature derate factor, and the overall PV system efficiency (η_{PV}) are all calculated for each month. The average η_{PV} for all months in the first year is 0.74.

The plant capacity factor is calculated for each month, it is a very important factor, and the average capacity factor for all months in the first year is 0.22, which is a typical value. The full nameplate capacity (installed capacity) for each month is calculated and finally, the total generated kWh of the system for the first year is equal to 8,828,975.19 kWh.

4.2. Economic Viability

The LCC analysis was conducted to bring all the costs into their present worth. In these calculations, the total installation cost was 124,070,000 $, dividing this value by 20 MWp yielding to 6.20 $/Wp installation cost. Also, the NPV total LCC of Al-Risha 20 MWp PV system with O&M cost was calculated, and it was equal to 147,387,557 $, yielding to 7.37 $/Wp. For this analysis, the PV array was considered to degrade at an average rate of 0.8% each year. After 25 years, total array degradation is expected to be 20% below nameplate rating.

For the load types of SID considered in this work, the total expected energy production, total electricity value saved, and the Net Present Value for the 25 years operation period were equal to 857,937,559.0 kWh, $104,600,207, and $126,957,348.0 (6.35$/Wp), respectively.

A cost comparison between PV and gas turbine is held. The assumption is based on that the peak occurs at 6 months in the year, 3 hours in a day, with a discount rate of 5%. It is based on an annual value method, and it was found that the cost of kWh generated from the PV system for peak shaving can be very competitive under the assumptions mentioned and that after 6 years of operation of gas turbine from now.

4.3. Environmental Analysis

The amount of CO_2, saved by grid-connected PV systems, depends on the existing energy mix for power generation in various countries. It has been assumed that PV installations will save, on average, 0.6 kg of CO_2 equivalent per kilowatt-hour. This takes into account emissions during the life-cycle of the PV system of between 12 and 25 g of CO_2 equivalent per kWh (European Photovoltaic Industry Association (EPIA)) [36].

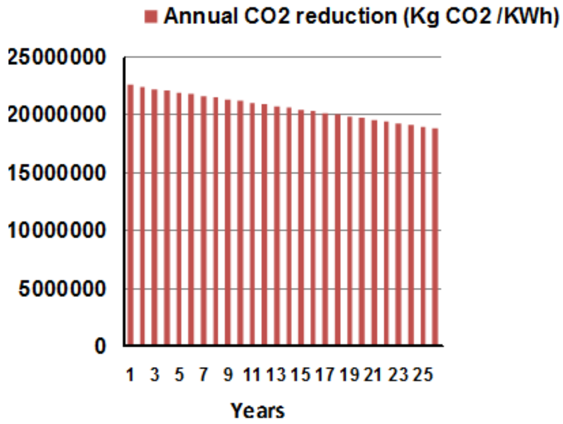

Figure 10. Annual CO_2 reduction by using PV system

The overall CO_2 reduction in the life-cycle of PV system is about 541,798 tons of CO_2. So, there is no doubt that PV can be an effective tool to replace the conventional power generation and can fight against climate change.

4.4. Dust Effect

The accumulation of dust particles on the surface of PV panel greatly affects its performance, especially in desert areas. But desert countries are of course best suited to PV power generation due to the abundant availability of sunlight throughout the year. Nowadays, the idea for setting up vast solar arrays in desert countries and exporting the power to other countries is being discussed. In bigger PV solar power plants, more work force and machines will be needed to keep making rounds and cleaning the panels, especially after a sand storm. Dust accumulation on the PV panel surface depends on different parameters, like PV panel inclination, kind of installation (stand alone or on tracker), humidity, etc. Many research results discussed the performance of panels with dust concentration on the surface in g/m^2. But for a common PV user, it is important to know how frequent the panel has to be cleaned. There are several techniques to clean the modules, such as manual or semi-manual cleaning if labor is cheap. If water is restricted, brushes are used for cleaning, and in places where water is available, trucks or hosing systems spraying off surfaces, or installs sprinkler-like systems that spray off panel surfaces. New technologies such as using automated robotic cleaning devices or a new technology using transparent, electrically sensitive material is deposited on a transparent plastic panel cover. Embedded sensors detect dust and activate an electric, dust-repelling charge. The technology requires little electricity and removes about 90 percent of deposited dust [37]. However, in case if the frequent cleaning is not feasible, it is important to know the performance loss due to dust for additional estimation to compensate for the loss. An average of 5% dust losses is considered for this design (Hussein *et al.*) [33].

5. Conclusion

Large-scale grid-connected PV generation system of 20MW power output is suggested to be installed in Al-Risha area to shave off the peak load in Sahab Industrial area in Amman. Such systems can generate both energy value (the system's ability to save energy) and the capacity value (in the form of coincident peak demand reduction). However, if the PV system is generated to save energy only, it is not a cost effective project, since the Net Present Value with the O&M for the LCC is $147,387,557 (7.37$/ $W_{P)}$ and the Net Present Value of the energy saved is $126,957,348 (6.35$/ $W_{P)}$. So, the difference does not make this project cost effective. Unfortunately, this is because the times of peak loads used are based on the book of the Electricity Regulatory Commission (ERC), which does not include peak times during solar generation time (6:00 AM- 6:00 PM), in both winter and summer seasons. It is found that the generation cost for all power is US$ 0.170 per kWh which is much lower than the electrical production cost of the peak load generation. It must be mentioned that the peak load according to ERC is 4.26 ($/kW/Month), while the daily energy cost is 6.7 (cent/kWh). If it is assumed that there is at least one peak hour during solar generation time, it is a very cost-effective project.

Also, this study shows that the cost of kWh generated from the PV system for peak shaving can be very competitive compared to gas turbines after 6 years of operation, so the cost of PV compared to the cost of gas turbines after 25 years was found to be 0.170$/ $W_{P,}$ 0.375 $/ W_P, respectively. Moreover, the overall CO_2 reduction in the life cycle of PV system is about 541,798 tons of CO_2. So, there is no doubt that PV can be an effective tool to replace the conventional power generation and to fight against climate change.

This project could be generalized to other industrial districts as well as other load types (i.e., industrial, economic, etc.). The results of this work should encourage governments to impose new legislations regarding modifying the peak time to coincide with the solar generation time, at least one operating peak hour.

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