

## Software Design of Photovoltaic Grid-Connected Power Plants

A. H. Almasoud & Hatim M. Gandayh

Electrical and Computer Engineering Department King Abdulaziz University, Jeddah, Saudi Arabia

Email: [amasoud@kau.edu.sa](mailto:amasoud@kau.edu.sa)

**Abstract:** It is aimed to construct software to aid the design of photovoltaic grid-connected (PVGC) power plants at suitable locations in Saudi Arabia with high solar radiation that are not in the area of sand dunes or shifting sands. These power plants should cover 15% of the expected load by 2020 and support conventional power generation during peak loads. PVGC software was built with Microsoft Visual Basic to assist in the design. The results show that adding 11273.25 MW of solar energy in the Saudi Arabia grid would save 3581151 ton of CO<sub>2</sub>, 62869 ton of SO<sub>2</sub>, and 42375 ton of NO<sub>x</sub> emissions. The tariff of PVGC power plants in this design varied between 0.45 and 0.72 Saudi riyal/kWh. Solar radiation is the most significant factor in the design of PVGC plants. Accordingly, Saudi Arabia should be ready to add PVGC to its network by 2020 to support conventional generation and meet increasing power demands.

[A. H. Almasoud & Hatim M. Gandayh. **Software Design of Photovoltaic Grid-Connected Power Plants.** *J Am Sci* 2014;10(8):155-162]. (ISSN: 1545-1003). <http://www.jofamericanscience.org>. 21

**Keywords:** PVGC software, solar energy, conventional generation, solar radiation, Saudi Arabia.

### 1. Introduction

The construction of photovoltaic (PV) power plants for generating electricity chiefly depends on issues such as finance, environment and health, geography, and meteorology. All these factors must be taken into account when designing a PV grid-connected (PVGC) system.

In a grid-connected system, the PV system is connected to the utility grid. This means that during the daytime, the electricity generated by the PV system can either be used directly or transferred to the utility network. The PVGC power plant reduces the power taken from the utility power grid during the daytime and integrates the power demand of the load. At nighttime, the PVGC power plant is unable to provide the electricity required, and therefore during this time, the power is generated from conventional power plants. The PVGC system is able to use the utility grid as a store because the system does not require storage batteries. By 2010, transmission networks in Saudi Arabia were almost completely connected, and therefore installing PVGC would help to feed the loads to customers connected to the national grid.

The use of PVGC has been growing internationally since 2000 [1] and has a large advantage over PV stand-alone systems in that initial costs are reduced by approximately 40% [2]. The initial capital costs of a PV power plant are 2000–4000 \$/kW [3], and these costs are falling with new developments coming onto the market.

### 2. Grid-Connected Systems

The PV generator is a number of strings connected in parallel, and a string is a number of series-connected PV modules. This configuration of parallel/series connections determines the current and voltage of the system. The PV generator is connected to the utility grid through inverters in the case of the grid-connected system. These inverters convert the DC power from the PV arrays into AC power at a voltage and frequency that can be accepted by the utility grid. PVGC systems may have a centralized inverter layout (plant-oriented), string inverter layout (module-oriented), or individual inverter layout (module-integrated) (summarized in Table1)[4].

**Table 1. Comparison of PVGC Layouts**

Plant-oriented	Module-oriented	Module-integrated
Connection in parallel and/or in series on DC side	Several modules connected in series on DC side, and parallel connection on AC side	Connection in parallel and/or in series on AC side
One inverter for the entire PV power plant	One inverter for each string	Individual inverter per PV module
Nominal inverter power of up to several MW	Inverter power of up to 2 kW	Inverter power of 50–400 W

### 3. Sizing of PVGC Power Plants

Normally, for PVGC, the installed power is not of great importance [5], and an array size is suggested by the designer. Accordingly, in the present paper, the suggested sizing of PVGC power plants is based on a fraction of the total electrical loads. The suggested DC/AC inverter power is equal to the nominal array power. In grid-connected plants, the inverters reproduce the exact network voltage. The sizing of power transformers depends on the PV plant peak power [6]. These transformers are required to boost the inverter output voltage to the voltage of the utility network.

Simple calculations are normally conducted to determine the number of PV solar panels needed to meet the required demand. The number of series PV modules per string,  $M_s$ , can be determined via Eq.1. The total required number of PV modules,  $M$ , is given by Eq.2, and the number of strings of modules in the PV array,  $M_p$ , can be calculated via Eq.3. The number of modules  $M_s$  is determined by the selected voltage, and  $M_p$  is given by the current required from the plant. The current  $I_m$  and voltage  $V_m$  at the maximum power point (MPP) are needed to calculate the number of panels required to cover a given load. Operational MPP can be considered in the design via Eq.6. The values of PV parameters change for other conditions of irradiance and temperature, and for this a sizing factor is introduced to oversize the amount of current available from the array according to Eq.4 [7].

$$M_s = \frac{V_{in}}{V_m} \quad (1)$$

where  $V_{in}$  is the required input voltage.

$$M = \frac{\text{Nominal capacity of PV power plant}}{MPP} \quad (2)$$

$$M_p = \frac{M}{M_s} \quad (3)$$

$$I^A = \frac{\text{Nominal capacity of PV power plant}}{V^A} \quad (4)$$

where  $I^A$  is the total current of the PV array, and  $V^A$  is the output voltage of the PV array.

The land area required for the PV power plant can be calculated according to solar radiation  $h$ , nominal capacity of the PV plant, and efficiency of the solar module [5], as shown in Eq.7. This equation can be derived via Eq.2 and Eq.6.

$$A = M \times A_{\text{module}} \quad (5)$$

$$MPP = \eta_{PV} \times h \times A_{\text{module}} \quad (6)$$

By substituting Eq.6 and Eq.2 into Eq.5,

$$A = \frac{\text{Nominal capacity of PV power plant}}{\eta_{PV} \times h} \quad (7)$$

The yearly energy delivery  $E_y$  in kWh/year is defined as the following [3]:

$$E_y = H_y \cdot K_p \cdot P_{\text{max}} \quad (8)$$

where  $K_p$  is the performance ratio of the system, indicating loss accumulation;  $H_y$  is yearly solar radiation in kWh/m<sup>2</sup>/year divided by 1000 W/m<sup>2</sup> [8]; and  $P_{\text{max}}$  is the installed peak power under STC.

Typical values of  $K_p$  for well-designed grid-connected systems are 0.7 to 0.8 [3]. For sizing a PVGC system, a safety (sizing) factor must be considered as well as factors such as reduction of module efficiency due to dust accumulation on the solar modules, changes to the load profile, and variations in weather conditions.

The fill factor  $FF$  is a measure of sharpness of the knee in an I-V curve [9] and indicates the quality of the PV module. The I-V curve indicates the electrical characteristics of the PV cell. Typical values of  $FF$  are between 0.7 and 0.8, with the maximum value of 1. It can be represented by the following formula:

$$FF = \frac{I_m \times V_m}{V_{oc} \times I_{sc}} \quad (9)$$

where  $I_{sc}$  and  $V_{oc}$  are the short-circuit current and the open-circuit voltage of the PV module, respectively, and  $I_m$  and  $V_m$  are maximum current and maximum voltage of the PV module, respectively. The short-circuit current is the higher value of the current generated by the PV and is obtained under short-circuit conditions. The open-circuit voltage is the PV voltage during the nighttime.

A PV module would attain maximum efficiency if the angle of incidence of solar radiation was always 90° [10]. Most PV modules are supported at fixed positions. The advantages of this design are simplicity, no moving parts, and low cost. The tilt angle ( ) of the PV array is usually set at the annual optimum tilt angle. The annual optimum tilt angle depends mainly on the latitude of the location [11], and the array faces due south for the northern hemisphere or due north for the southern hemisphere in order to face the sun [12]. Sun-tracker systems increase the solar energy collected by up to 40% [3, 7] compared with fixed-tilt systems,

but the disadvantages of sun-tracker systems include complexity and high cost because of the maintenance required. Tracking systems are important and recommended only when concentrated PV cells are used. As discussed above, the optimum fixed orientation is usually suggested to be south-facing in the northern hemisphere, and thus a fixed-tilt angle toward the south with flat panels is used for PVGC systems in Saudi Arabia (Figure 1) according to the latitude of the selected location.



Figure.1 Tilt Angle of Photovoltaic Module

#### 4. Design Procedures

To design PVGC power plants, many elements must be specified, which include, but are not limited to, specifications of the

- Grid
- Solar PV power plant
- Inverter
- Transformer
- PV module

The design of a PVGC power plant requires the following steps, which must be input into suitable computer software for calculation:

- 1 Determination of overall forecasted electrical loads
- 2 Determination of the required percentage and the equivalent value in MW to be covered by solar power plants during peak load period
- 3 Determination of PVGC location with associated average solar irradiance in  $\text{W/m}^2$
- 4 Determination of PV module specifications
- 5 Determination of capacity for each solar power plant
- 6 Determination of essential land area in  $\text{m}^2$  to construct the PV system
- 7 Determination of number of PV modules to provide the required power
- 8 Determination of parallel and series branches for PV arrays to obtain suitable values of voltage and current
- 9 Selection of tilt angle for the PV array according to the latitude of the power plant location
- 10 Selection of suitable inverter to convert the DC output of the solar array to AC system
- 11 Selection of appropriate power transformers to boost output voltage from the inverter

12 Calculation of total cost for each solar power plant

13 Calculation of the reduction in greenhouse gas emissions

#### 5. PVGC Software Analysis

We constructed a PVGC program via Microsoft Visual Basic 2010. This visual PVGC software is intended to be a tool for designing solar PVGC power plants according to user-input data and required specifications. The results are displayed in specific windows of the PVGC software and can be printed at the end as a report form. The PVGC software consists of a Home window, Project Information, Introduction window, Main window, Design Parameters, Conditioning System, Tilt Angle, Cost of PVGC Plants, Reduction of GHG (greenhouse gas) Emissions, and Report.

PVGC power plant design in Saudi Arabia is expected to be implemented via PVGC software. PV-generated electricity in Saudi Arabia should be ready for action by 2020 [13]. The proposed design of PV power plants in Saudi Arabia should cover 15% of the expected load by 2020, which is estimated to be 75155 MW. Consequently, the capacity of PVGC power plants will be approximately 11273.25 MW. The first step to designing PV power plants via PVGC software is to register the project's information. The Project Information window contains five icons (Figure 2).

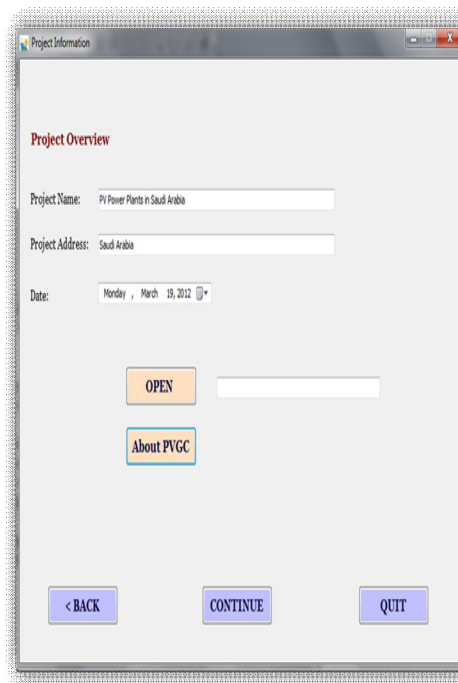


Figure.2 Project Information Window

The Introduction window (Figure 3) contains the main parameters of the network and PV power plants. Total expected load by 2020 in Saudi Arabia (75155 MW) and percentage required from solar power (15%) were input as system parameters. The parameters of PV power plants, required modules, and suitable location were selected at the same stage. A monocrystalline module with a maximum power of 300 W and efficiency of 15.4% was chosen in the design for all PV power plants. The ambient temperature was set to the nominal value of 25°C. The pollution factor is required as a percentage, and its default value in the program is 0% because until now there was no representation of the effect of pollution, e.g., dust as a ready value to be deducted from the efficiency of the PV module. Many practical studies are needed to measure the effect of pollutants on the efficiency of PV modules.

Figure.3 Main Parameters of Photovoltaic Power Plants

The plant locations are ranked according to solar radiation, with the highest solar radiation at the top. The PVGC program is sufficiently flexible to enable a new location to be added by selecting "other" from a dropdown list by *Plant Location*; the user is then asked to enter location name, solar radiation, latitude, and longitude of this new location (Figure 4).

The same applies when the user needs to change the PV module data: Selecting "other" from the dropdown list by *Module Efficiency* brings up a dialog box (Figure 5) for the user to enter the necessary data on the new PV module.

Figure.4 New Location Data

Figure.5 Data of New Photovoltaic Module Dialog Box

In the Main window, the user is required to enter the capacity of the PV power plant or to determine the land area in  $m^2$ . A sizing factor of 0%, 5%, or 10% may be chosen according to the design requirements of the user. The results (Figure 6) comprise location, module type, solar radiation, PV plant capacity, latitude, longitude, required area, and the fill factor of the PV module.

The Design Parameters window displays the number of series modules, number of parallel modules, total number of modules, array current, array DC voltage, and MPP of PV modules at the ambient temperature (Figure 7).



Location	Module Type	Solar Radiation	PV Plant Capacity	Latitude	Longitude	Required Area	Fill Factor
Al-Jah	M 3000, Efficiency 15.4%	243 W/m²	500 MW	18.22°N	42.48°E	1.402918E+07 m²	0.754
Al-Ahaj	M 3000, Efficiency 15.4%	250 W/m²	500 MW	22.28°N	46.73°E	1.363636E+07 m²	0.754
Al-Hufuf	M 3000, Efficiency 15.4%	236 W/m²	500 MW	25.50°N	49.57°E	1.44453E+07 m²	0.754
Al-Humay	M 3000, Efficiency 15.4%	252 W/m²	500 MW	19.10°N	42.15°E	1.353814E+07 m²	0.754
Al-Ula	M 3000, Efficiency 15.4%	242 W/m²	500 MW	26.62°N	37.85°E	1.408713E+07 m²	0.754
Baha	M 3000, Efficiency 15.4%	292 W/m²	500 MW	20.02°N	42.60°E	1.167497E+07 m²	0.754
Daoudam	M 3000, Efficiency 15.4%	240 W/m²	500 MW	24.40°N	44.37°E	1.374633E+07 m²	0.754
Derab	M 3000, Efficiency 15.4%	258 W/m²	500 MW	24.42°N	46.57°E	1.321333E+07 m²	0.754
Harakiya	M 3000, Efficiency 15.4%	252 W/m²	500 MW	24.85°N	40.50°E	1.353814E+07 m²	0.754
Heifa	M 3000, Efficiency 15.4%	254 W/m²	500 MW	19.87°N	42.53°E	1.342166E+07 m²	0.754
Hutut-Sudar	M 3000, Efficiency 15.4%	245 W/m²	500 MW	25.53°N	45.62°E	1.391466E+07 m²	0.754
Khulays	M 3000, Efficiency 15.4%	249 W/m²	500 MW	22.13°N	39.43°E	1.369113E+07 m²	0.754
Madina	M 3000, Efficiency 15.4%	265 W/m²	500 MW	24.52°N	39.58°E	1.288449E+07 m²	0.754
Najran	M 3000, Efficiency 15.4%	289 W/m²	500 MW	17.55°N	44.23°E	1.179616E+07 m²	0.754
Qutairat	M 3000, Efficiency 15.4%	232 W/m²	273.25 MW	15.53°N	37.33°E	1.469436E+07 m²	0.754
Sayf Kabir	M 3000, Efficiency 15.4%	240 W/m²	500 MW	21.62°N	40.42°E	1.420456E+07 m²	0.754
Shaqra	M 3000, Efficiency 15.4%	252 W/m²	500 MW	25.25°N	45.25°E	1.353814E+07 m²	0.754
Sulayyil	M 3000, Efficiency 15.4%	274 W/m²	500 MW	22.47°N	45.57°E	1.244194E+07 m²	0.754
Tayma	M 3000, Efficiency 15.4%	233 W/m²	500 MW	27.63°N	38.48°E	1.463129E+07 m²	0.754

Figure.6 Main Data of Photovoltaic Power Plants

Location	Modules in series (No)	Modules in parallel (No)	No. of Modules (No)	Array current (A)	Array DC voltage (V)
Al-Jah	279	25865	6993125	51376.75 A	10218.63 V
Al-Ahaj	279	26551	7407729	51376.75 A	10218.63 V
Al-Hufuf	279	24866	6937614	51376.75 A	10218.63 V
Al-Humay	279	25893	7224147	51376.75 A	10218.63 V
Al-Ula	279	21499	5987061	51376.75 A	10218.63 V
Baha	279	25267	7049493	51376.75 A	10218.63 V
Daoudam	279	24267	6776073	51376.75 A	10218.63 V
Derab	279	24866	6937614	51376.75 A	10218.63 V
Harakiya	279	24670	6882930	51376.75 A	10218.63 V
Heifa	279	25576	7125794	51376.75 A	10218.63 V
Hutut-Sudar	279	25185	7021035	51376.75 A	10218.63 V
Khulays	279	23646	6597224	51376.75 A	10218.63 V
Madina	279	21682	6049278	51376.75 A	10218.63 V
Najran	279	27005	7535511	51376.75 A	10218.63 V
Qutairat	279	26109	7284411	51376.75 A	10218.63 V
Sayf Kabir	279	24866	6937614	51376.75 A	10218.63 V
Shaqra	279	22869	6380451	51376.75 A	10218.63 V
Sulayyil	279	26893	7382147	51376.75 A	10218.63 V
Tayma	279	26128	7214822	51376.75 A	10218.63 V

Figure.7 Design Parameters of Photovoltaic Power Plants

In this step, the power conditioning system is considered, such as using inverters to convert the system from DC to AC and power transformers to boost the output voltage of the solar power system. The rating of step-up transformers may be changed to any

value as per the user's requirements. The same applies for determining the efficiency of the inverter. The inverter input voltage, output voltage, rating, and type, and the number of transformers, power transformer rating, and transformer ratio may be determined by selecting one of the listed PV plant layouts (Figure 8).

Location	Type of Inverter	Inverter (ip) voltage	Inverter (op) voltage	Inverter VA	No. of T/F	T/F Ratio	T/F Ratio
Al-Jah	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Al-Ahaj	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Al-Hufuf	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Al-Humay	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Al-Ula	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Baha	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Daoudam	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Derab	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Harakiya	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Heifa	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Hutut-Sudar	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Khulays	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Madina	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Najran	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Qutairat	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Sayf Kabir	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Shaqra	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Sulayyil	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA
Tayma	Module-integrated	36.59 DC V	13800 AC V	294.3154	2	13.8/380 kV	220 MVA

Figure.8 Conditioning Systems of Photovoltaic Power Plants

The tilt angle of the PV module is determined in this step according to the latitude of the selected location. The PV modules are mounted in the design at a fixed angle from the horizontal. In addition, the suggested direction of the PV module is described for each location (Figure 9).

Costs of PV power plants are categorized as cost of PV modules, cost of inverters, cost of transformers, and total cost of the plant. Three questions are asked at this stage if cost changing of the PV module, solar inverter, or power transformer is required (Figure 10 and Figure 11), otherwise programmable costs are used. The user can obtain these costs for each plant in either US\$ or Saudi riyals (Figure 12). The tariff of solar energy for a specific PV power plant also is also calculated.

The final step is related to reducing greenhouse gases, which is given in terms of annual reductions in the amounts of CO<sub>2</sub>, SO<sub>2</sub>, and NO<sub>x</sub> emissions. To calculate these reductions, the amount of annual energy in MWh from each PVGC power plant is calculated via Eq.8. Accordingly, CO<sub>2</sub> reduction, SO<sub>2</sub> reduction, and NO<sub>x</sub> reduction values are obtained for each PVGC

plant (Figure 13). The total reduction in greenhouse gases for all required PVGC power plants is calculated via Eqs.10–12 [13].

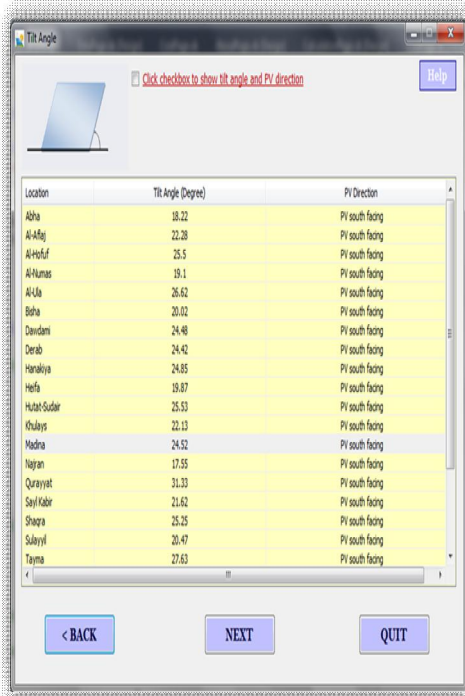


Figure.9 Tilt Angles of Photovoltaic Power Plants

Location	Cost of PV Module	Cost of Inverters	Cost of Transformers	Total Cost of PVGC	Tariff
Alpha	78757.15946.66 SR	5557205.85 SR	4000000 SR	12472821025.66 SR	0.62 SR/kWh
Al-Ahag	8142634401.97 SR	5886562627.05 SR	4000000 SR	14269197329.02 SR	0.7 SR/kWh
Al-Hafuf	7813187715.69 SR	5512885338.32 SR	4000000 SR	13366173055.01 SR	0.61 SR/kWh
Al-Humas	8135883114.39 SR	5740679216.25 SR	4000000 SR	13916562330.64 SR	0.66 SR/kWh
Bahra	674268510.86 SR	4757626976.43 SR	4000000 SR	11540295487.29 SR	0.45 SR/kWh
Dandani	7939186600.67 SR	5601890153.96 SR	4000000 SR	13581076754.63 SR	0.63 SR/kWh
Derab	7631259151.09 SR	5384616542.09 SR	4000000 SR	1355875693.18 SR	0.58 SR/kWh
Hanakiya	7813187715.69 SR	5512885338.32 SR	4000000 SR	13366173055.01 SR	0.61 SR/kWh
Heifa	7751602225.77 SR	5468530636.93 SR	4000000 SR	13261132842.7 SR	0.6 SR/kWh
Hufat-Sudar	8036278010.8 SR	5670307854.03 SR	4000000 SR	13746475864.83 SR	0.65 SR/kWh
Khulays	7907137008.98 SR	5579279961.7 SR	4000000 SR	13526412970.68 SR	0.62 SR/kWh
Madina	7426949462.12 SR	5243501863.33 SR	4000000 SR	12712351325.45 SR	0.55 SR/kWh
Najran	6812727716.22 SR	480767868.52 SR	4000000 SR	11659895524.74 SR	0.46 SR/kWh
Qararyat	8140543332.89 SR	5888152094.45 SR	4000000 SR	14114640437.34 SR	0.72 SR/kWh
Sayl Kabir	820752837.97 SR	578856893.96 SR	4000000 SR	1403202931.93 SR	0.67 SR/kWh
Shaqra	7813187715.69 SR	5512885338.32 SR	4000000 SR	13366173055.01 SR	0.61 SR/kWh
Subayil	7185706984.24 SR	5070214038.1 SR	4000000 SR	12359419312.44 SR	0.52 SR/kWh
Tayma	845094977.64 SR	596286893.43 SR	4000000 SR	14452481781.07 SR	0.71 SR/kWh
Turbath	8228001911.44 SR	5812754240.6 SR	4000000 SR	14909736152.04 SR	0.68 SR/kWh

Figure.12 Costs of Photovoltaic Power Plants

$$\text{CO}_2 \text{ reduction} = \text{CO}_2 \text{ emission (180 g/kWh)} \times E_y \quad (10)$$

$$\text{SO}_2 \text{ reduction} = \text{SO}_2 \text{ emission (3.16 g/kWh)} \times E_y \quad (11)$$

$$\text{NO}_x \text{ reduction} = \text{NO}_x \text{ emission (2.13 g/kWh)} \times E_y \quad (12)$$

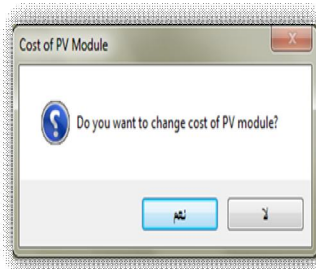


Figure.10 Dialog Box for Cost of Photovoltaic Module

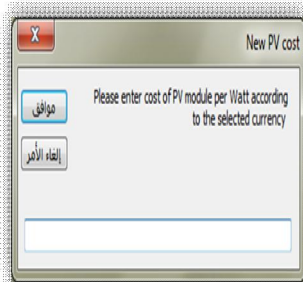


Figure.11 Dialog Box for New Photovoltaic Module Cost

Location	Total Annual Energy	CO2 Reduction	SO2 Reduction	NOx Reduction
Alpha	838167.75 MWh	150870.19 tonne	2648.61 tonne	1785.29 tonne
Al-Ahag	862312.5 MWh	155216.25 tonne	2724.9 tonne	1836.72 tonne
Al-Hafuf	8140231 MWh	146524.14 tonne	2572.31 tonne	1733.86 tonne
Al-Humas	869211 MWh	156457.88 tonne	2746.7 tonne	1851.41 tonne
Al-Ula	834718.5 MWh	150248.32 tonne	2637.71 tonne	1777.95 tonne
Bahra	100718.1 MWh	181292.58 tonne	3182.69 tonne	2145.29 tonne
Dandani	855414 MWh	153974.51 tonne	2703.1 tonne	1822.03 tonne
Derab	889906.5 MWh	161083.17 tonne	2812.1 tonne	1895.5 tonne
Hanakiya	869211 MWh	156457.88 tonne	2746.7 tonne	1851.41 tonne
Heifa	876109.5 MWh	157889.71 tonne	2788.5 tonne	1866.11 tonne
Hufat-Sudar	845066.25 MWh	152111.92 tonne	2670.4 tonne	1799.99 tonne
Khulays	858863.25 MWh	154595.38 tonne	2714 tonne	1828.37 tonne
Madina	914051.25 MWh	164528.22 tonne	2880.4 tonne	1946.92 tonne
Najran	996833.25 MWh	179429.58 tonne	3149.99 tonne	2123.25 tonne
Qararyat	800226 MWh	144046.68 tonne	2528.71 tonne	1704.46 tonne
Sayl Kabir	827820 MWh	149007.6 tonne	2615.91 tonne	1763.25 tonne
Shaqra	869211 MWh	156457.88 tonne	2746.7 tonne	1851.41 tonne
Subayil	945094.5 MWh	170117.01 tonne	2886.49 tonne	2013.05 tonne
Tayma	803675.25 MWh	144661.54 tonne	2539.61 tonne	1711.82 tonne

Figure.13 Reduction of Greenhouse Gases by Photovoltaic Power Plants

The Help window (Figure 14) offers a guide to using the PVGC software. It can be accessed from any window from the Introduction window to the Reduction of GHG Emissions window.

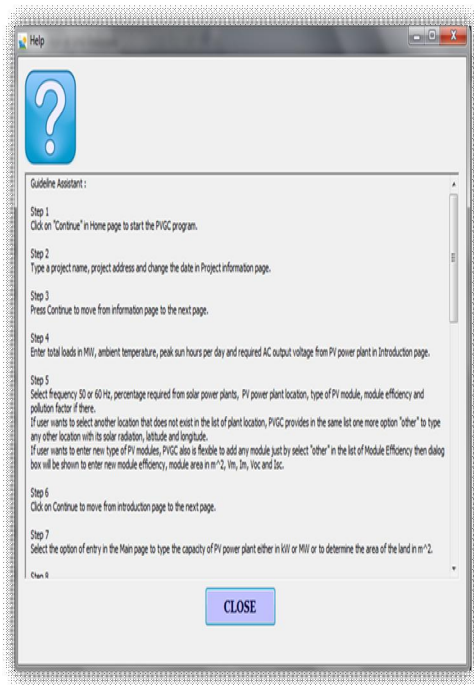


Figure.14 Help Window

Finally, all data inputs and results are shown as a simple report. This report can be printed by selecting *Report* (Figure 15), and each page of the report may be printed individually upon the user's request. The full project can be saved by selecting *Save*.

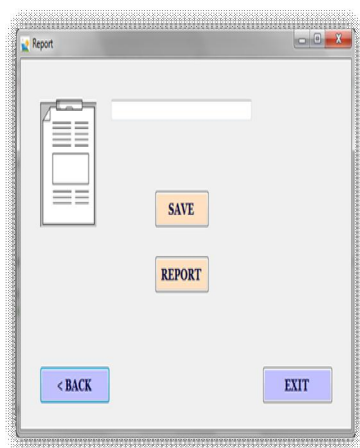


Figure.15 Report and Printout Window

## 6. Conclusion

The total size of PVGC power plants in Saudi Arabia is based on the fraction of the expected total electrical loads in 2020. This fraction is considered to

be 15% of total loads, which is approximately 11273 MW. This would reduce environmental pollution and save emissions of 3581151 ton of CO<sub>2</sub>, 62869 ton of SO<sub>2</sub>, and 42375 ton of NO<sub>x</sub>, as shown in the results obtained from the PVGC software. The tariff cost of PVGC power plants in this design varies between 0.45 and 0.72 Saudi riyal/kWh, and the average tariff cost is 0.62 Saudi riyal/kWh.

The nominal capacity of individual PVGC power plants was set to 500 MW to match that of projects currently under construction around the world. The PV modules are 300 W monocrystalline type because these are of suitable efficiency compared with other types. The major parameter for sizing PV arrays is solar radiation, where locations with the highest solar radiation should have the lowest number of PV modules. The values of PV parameters should be changed according to variation in solar radiation and ambient temperature, and accordingly, a sizing factor should be introduced.

Our analysis of PVGC software shows that the most significant factor in the design of PVGC power plants is solar radiation. The total number of PV modules, land area of PVGC power plants, cost of PVGC power plants, and tariff are inversely proportional to the intensity of solar radiation at the same capacity, whereas MPP, total annual amount of energy, and reduction of greenhouse gases are directly proportional to solar radiation. It was found that the efficiency of PV modules changes inversely with ambient temperature, and that the performance of PV modules is affected by the accumulation of dust on PV module surfaces.

## References

1. Al-Nuaim, Abdulaziz A., Al-Ismael, Fahad, and Shwehdi, M.H. (2010) Photovoltaic (PV) Stations Major Components and Design; an Overview (Lecture), Damascus (Syria): International Conference on Renewable Energies, 5–8 April 2010.
2. Alajlan, Saleh A. (1999) Photovoltaic grid-connection system as load-shaving tool in Riyadh, Saudi Arabia, *Applied Energy*, vol. 63: 91–99.
3. Patel, Mukund R. (2006) *Wind and Solar Power Systems*, 2nd edition, Boca Raton (Florida, USA): CRC Press.
4. Meinhardt, Mike, and Cramer, Günter (2000) Past, Present and Future of Grid Connected Photovoltaic- and Hybrid-Power Systems (Lecture), Seattle (USA): IEEE Power Engineering Society Summer Meeting, 16–20 July 2000.
5. Kalogirou, Soteris (2009) *Solar Energy Engineering: Processes and Systems*, USA: Elsevier Inc.



6. Testa, A., Caro, S. De, Torre, R. La, and Scimone, T. (2010) Optimal Size Selection of Step-Up Transformers in PV Plants (Lecture), Rome (Italy): International Conference on Electrical Machines, 6–8 September 2010.
7. Markvart, Tomas (2000) Solar Electricity, 2nd edition, Chichester (UK): John Wiley & Sons Ltd.
8. Solar Frontier (2011) Farasan 500kV PV Workshop (Lecture), Farasan (Saudi Arabia): Solar Frontier K.K., 19 November 2011.
9. Tiwari, G.N., and Dubey, Swapnil (2010) Fundamentals of Photovoltaic Modules and Their Applications, Cambridge (UK): RSC Publishing.
10. ABB Company (2010) Technical Application Papers No.10, Bergamo (Italy): ABB.
11. Benghanem, M. (2011) Optimization of tilt angle for solar panel: Case study for Madinah, Saudi Arabia, *Applied Energy*, vol. 88: 1427–1433.
12. Yang, Hongxing, and Lu, Lin (2007) The optimum tilt angles and orientations of PV claddings for building-integrated photovoltaic (BIPV) applications, *Journal of Solar Energy Engineering*, vol. 129: 253–255.
13. Gandayh, Hatim (2012) Appraisal of Prospective Schemes in Solar Energy Applications (Masters thesis), King Abdulaziz University, Jeddah, Saudi Arabia.

5/29/2014