INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 9, Issue 2, 2018 pp.153-168
Journal homepage: www.IJEE.IEEFoundation.org

Modeling and simulation of 1mw grid connected photovoltaic system in Karbala city

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Received 6 May. 2017; Received in revised form 1 Oct. 2017; Accepted 20 Oct. 2017; Available online 1 Mar. 2018

Abstract
The increment of electricity demand in last few years and the wide difference between generation and load, led to support the national grid with additional generations, solar power is becoming most popular in generation sector because it is clean, inexhaustible, dependable and available in all sizes in addition of its capital cost is continuously decreases. It has also become more efficient since the power conversion efficiency of converters devices and photovoltaic solar cells has increased. This work proposes a design of 1MW grid connected Photovoltaic system under Iraq climate condition. The work contains a studying the solar radiation estimations, system technical design, system losses estimations, environmental impact, performance and economic evaluations for this system. From the obtained results, it was found that the city has good solar radiation to build PV systems in large scales, the estimated energy produced about (1757.8 MWh) produced in the first year and reach to 40,445 MWh for the total life cycle with performance ratio varied between 86.4% to 73 % and average capacity factor 19.83%. The system the system will save about 27794 tons of CO2 emission during total life. The financial analysis shows that the levelized cost of energy is around 0.0289 $/kWh which is economically feasible.

Keywords: Solar Radiation; PV System design; On Grid system; Performance analysis; Financial Analysis.

1. Introduction

Renewable energy (RE) sources are very good solution to provide alternative energy to overcome the global energy problem, and it's believed to be able to meet the energy challenges that are unable to be solved by traditional centralized power plants [1]. Grid connected PV systems in the world account for about 99% of the installed capacity of solar energy compared to stand alone systems, which use batteries. Battery-less grid connected PV are cost effective and require less maintenance [2].
The solar PV technology has now reached to its commercial acceptance and requires a minimal attention of manpower for its operation [12]. Grid-connected PV systems have many technical advantages such as flexibility, non-polluting, emitting no noise, requiring little maintenance and simplicity to install in any area where the solar irradiation is available, therefore, many countries are encouraging customers to install PV systems in order to support the traditional energy sources and to increase the contribution of renewable energy to limit carbon dioxide (CO_2) emissions.

Typical megawatt scale grid-connected solar PV power plant main components are: solar PV modules, module mounting (or tracking) systems, Inverters, Step-up transformers and grid connection interface, [1] and the net useful energy output of any solar energy conversion system depends on various environmental factors such as ambient temperature, solar irradiation intensity, the rate of dust settlement on the solar system upper surface and wind speed at installation sites [3].
The PV farms are easy to build and require a relatively shorter time for its realization. the only requirement for PV farm development is the proper and accurate solar resource assessment by conducting the meteorological measurements [12], but it's still suffer from some weaknesses that make it weakly competitive with fossil fuels energy markets such as high capital cost, modest panel conversion efficiency and cleaning cost in dusty areas [3].
Today, all the world begins use the on grid PV system in very large scales as non-fossil energy source, numerous publications regarding deals with design and performance evaluations of PV projects are found in this research. An investigation of the energy performance, environmental impact, and cost assessments of 1MWp plant using the main 2017 market available PV technologies under hot climatic conditions for the state of Kuwait is carried out in [3], a study of design a large scale grid connected (20MW) PV system for peak load shaving in industrial district is studied in [6], while in [7], a comparative study using new approach for optimum design of rooftop grid connected PV system. A various performance parameter for grid connected 1MW SPV plant is carried out using three different methods is presented in [8]. A new method for the calculation of the optimal configuration of large PV plants is presented in [9], while [12] presents technical, environmental and economic aspects for the selection of viable sites for constructing 10 MW installed capacity grid connected PV power plants in Saudi Arabia and in [20] a study aims to numerically discover the optimal configuration for a 1 MW GCPV plant in Oman.
In this work a design of 1MW grid connected PV system in Karbala city (105 Km in south-west of the capital Baghdad) is proposed, the structure of this paper is as follows: section 2 presents a mathematical model for solar radiation estimation on horizontal and tilted surfaces, section 3 includes the selection criterion of solar panel type, section 4 includes PV system design and layout, section 5 estimates the PV system Losses, section 6 explained the financial analysis, in section 7 the environmental Impact of this project is presented. Section 8&9 study the system performance and calculating system yield, section 10 contains the result & discussion and finally the conclusions in section 11.

2. Mathematical model for solar radiation

Solar radiation is the rate at which radiant energy of the sun is incident on a surface per unit area, [4] neglecting the reflection component, the hourly global solar radiation in clear sky on a horizontal surface, R_h (W/m^2) is given by [10]:

$$R_h = R_a 0.7^{m^{0.678}} \quad (1)$$

Where; m is the air mass which the ratio of the mass of atmosphere through which beam radiation passes to the mass it would pass through if the sun were at the zenith (i.e., directly overhead) [4], given by [10]:

$$m = \sqrt{[1229 + (614cos\theta_z)^2]} - 614cos\theta_z \quad (2)$$

And R_a is the extraterrestrial irradiance on a horizontal surface given by [10]:

$$R_a = R_{sc}\left[1 + 0.033\cos\frac{2\pi J}{365}\right]\cos\theta_z \quad (3)$$

where; R_{sc} is the solar constant=1.367 kJ/m^2. s, J is the day number starting from 1-Janaury, θ_z is the angle of incident on a horizontal surface (zenith angle) obtained from; [4, 10]

$$cos\theta_z = (cos\emptyset cos\delta cos\omega + sin\emptyset sin\delta) \quad (4)$$

where φ is the geographical latitude and δ is the solar declination angle given by: [4, 10, 11]:

$$\delta = 23.5\,sin\left[\frac{360}{365}(J + 284)\right] \quad (5)$$

And ω is the hour angle calculated from; [4, 10]

$$\omega = 15(12 - ST) \quad (6)$$

where ST is the local solar time which calculated from the local standard time (LT) and the equation of time (ET) as follow; [10]

$$ST = LT + \frac{ET}{60} + \frac{4}{60}(L_S - L_L) \quad (7)$$

where LS is the standard meridian for the local time zone, LL is the longitude of the location in degree & ET is the equation of time given by: [10]

$$ET = 9.87 sin2B - 7.53 cosB - 1.5 sinB \quad (8)$$

Where;

$$B = \frac{360\,(J-81)}{365} \quad (9)$$

Usually, solar energy applications (panels, collectors…) are not installed horizontally but at an angle to increase the amount of radiation intercepted and reduce reflection and cosine losses [4]. Therefore, there is a need to convert these data to radiation on tilted surfaces. Figure 1 shows the ratio of beam radiation on the tilted surface to that on a horizontal surface at any time.

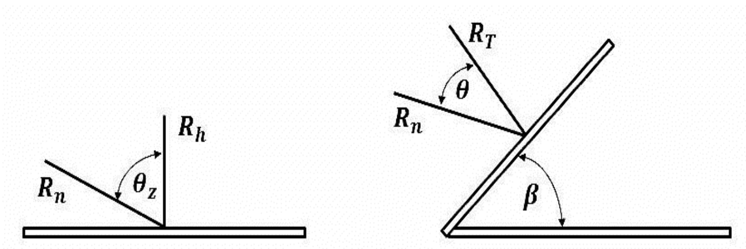


Figure 1. Beam radiation on horizontal and tilted surfaces [4].

The geometric factor R_b, which represents the ratio of beam radiation on the tilted surface to that on a horizontal surface at any time, can be calculated as follows [4, 10]:

$$R_b = \frac{R_T}{R_h} = \frac{R_n cos\theta}{R_n cos\theta_z} = \frac{cos\theta}{cos\theta_z} \quad (10)$$

Where; R_T is solar radiation on a tilted surface, R_n is solar radiation on a surface normal to the direction of propagation and θ is angle of incident on a tilted surface obtained from [10, 11]:

$$cos\theta = sin\delta\, sin\emptyset\, cos\beta - sin\delta\, cos\emptyset\, sin\beta\, cos\gamma + cos\delta\, cos\emptyset\, cos\beta\, cos\omega + cos\delta\, sin\emptyset\, sin\beta\, cos\gamma\, cos\omega + cos\delta\, sin\beta\, sin\gamma\, sin\omega \quad (11)$$

where; β is the tilt angle, γ is the azimuth angle. Using equation (12) the daily or monthly optimal tilt angle ($\beta_{optimal}$) can been obtained by substitute the respective δ for that day or the average δ for that month respectively [11].

$$\beta_{optimal} = \emptyset - \delta \quad (12)$$

MATLAB software has been developed to calculate the best tilt angles and solar radiation on a tilted surface in Karbala city, the flowchart of the proposed program is shown in Figure 2 with input parameters as in Table 1 and the results are in section 11.

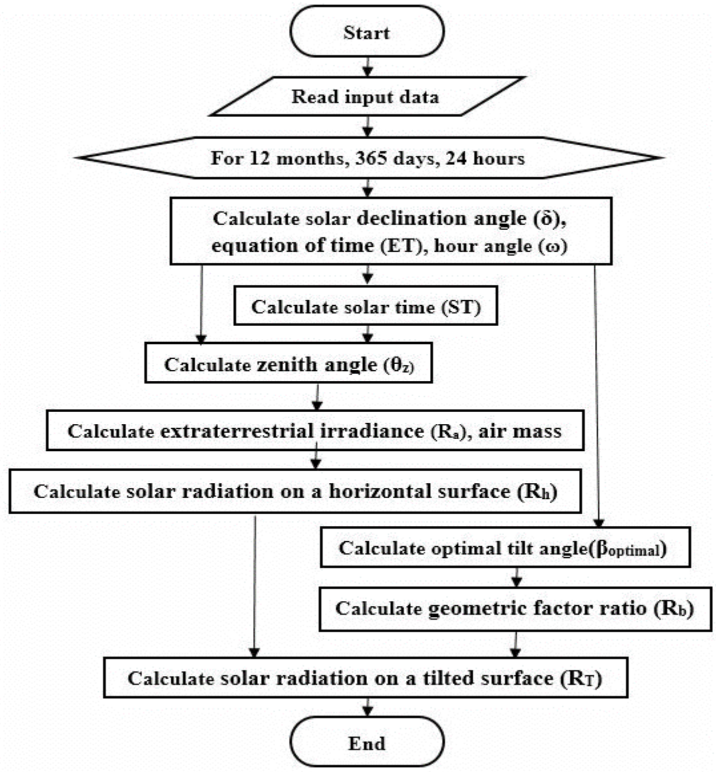


Figure 2. Flow chart for solar radiation estimation program.

Table 1. Inputs of the MATLAB program.

Latitude of Karbala (φ)	32.34°
Longitude of Karbala (LL)	44.11°
Standard meridian (Ls)	45°
Local standard time (LT)	1-24 hours
Day number (J)	1-365 days
Solar constant (R_{sc})	1.367
Azimuth angle (γ)	0°
Tilt setting	Fixed

3. Selection of PV modules

Choosing and ordering the appropriate modules is very important. They are usually the most expensive part of the system and it can be a costly error if the incorrect product is chosen, this choice should not only be governed by the performance, efficiency and cost of the module but also by the conditions under which it will operate [14].

The most common PV panel types that used in the design of large PV power plants are Mono-crystalline, Poly-crystalline and Thin-film, many constraints that effect on the decision in which type of panel will be used, such as the available space, type of surface, the nature of climate, capital cost. Consequently, it is important that selection criteria are used to select PV module to suit the climatic conditions in Iraq, these criteria include improved efficiency at high temperature with low cost.

Poly-crystalline modules are more likely to be selected, since it has slightly low power temperature coefficient bearing in mind that its efficiency has also to be considerably high with slightly low cost, (suntech_STP275-20/Wfw) panel has been chosen in this study which has good specifications in terms of type, power, cost and warranty, typical electrical characteristics of this PV module that measured under standard test conditions (STC) are shown in Table 2.

4. PV system design and layout

The connection of PV inverters with PV panels (Figure 3) in large PV power plants considers four basic topologies: [1, 5]

1. Central plant inverter
2. Multistring plant inverter
3. String plant inverter
4. AC module technology

The correct choice of the topology is according to the power output, location, reliability, cost and efficiency, a brief detail for all characteristics for these topologies are presented in [5]. The central configuration remains the first choice for many medium and large-scale solar PV plants which was selected in this paper. Central inverters offer high reliability and simplicity of installation, however, they have disadvantages: Increased mismatch losses and absence of maximum power point tracking for each string [1].

Table 2. Panel specifications at STC.

Maximum Power at STC (P_{max})	275 W
Optimum Operating Voltage (V_{mp})	31.2 V
Optimum Operating Current (I_{mp})	8.82 A
Open Circuit Voltage (V_{oc})	38.1 V
Short Circuit Current (I_{sc})	9.27 A
Module Efficiency	16.8%
Operating temperature	-40 °C to+85 °C
Maximum System Voltage	1000 V DC
Power Tolerance	0/+5 %
Nominal Operating Cell Temperature	45±2°C
Temperature Coefficient of P_{max}	-0.41 %/°C
Temperature Coefficient of V_{oc}	-0.33 %/°C
Temperature Coefficient of I_{sc}	0.067 %/°C
No. of Cells	60
Weight	18.2 Kg

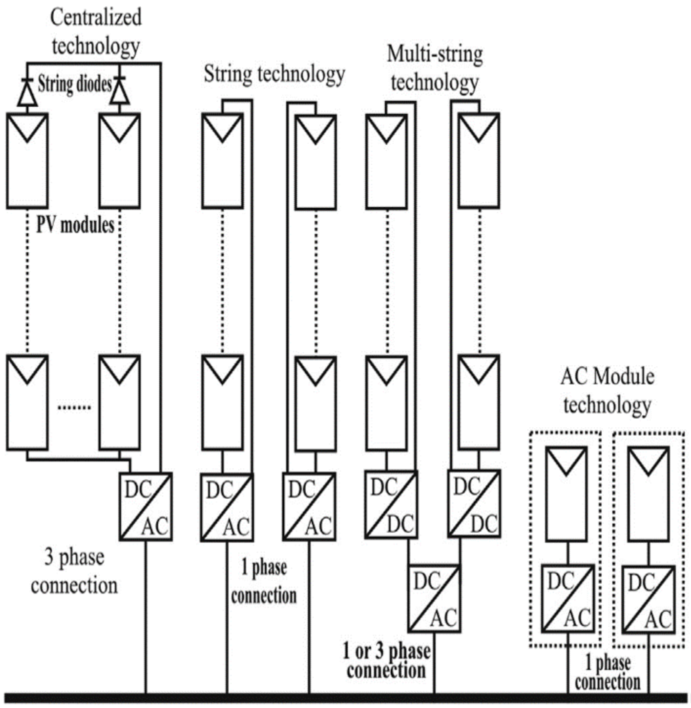


Figure 3. Topologies of PV system inverters [1].

The choice of inverter may depend on price, availability, weight, physical dimensions, reputation, or any number of other considerations [13]. Ingeteam company manufacturer was selected for the design of this system the specifications of (1000TL M400 DCAC Indoor) central inverter are shown in Table 3.

Table 3. Central inverter specification.

Type	Central inverter
Continuous output power	(1,108.5 / 1,019.8) kVA
Nominal AC voltage	400 V
Max input power	1,325.7 kWp
DC voltage range, mpp (U_{DC})	481 to 820 V
Number of independent MPPT	4
Maximum DC voltage(U_{max}))	1050 V
Maximum DC current ($I_{max\ (DC)}$)	1800 A
Maximum efficiency	99.1%
Euro efficiency	98.7%
Nominal frequency	50/60 Hz
Current distortion AC	< 3%
Nominal line current AC	1,472 A
Range of ambient temperatures	-20 ºC to +65 °C

4.1 System design

The main system design is undertaken based on the amount of generated power (1MW), the generated output power from the PV system is at 0.4 kV AC voltage level. It stepped up from 0.4 kV to 11 kV by one step-up distribution transformer with 50Hz, 1250 MVA rating, the output of the power transformer is synchronized with the national grid.

4.1.1 Number of modules in series per string

The maximum number of modules in a string is defined by the maximum DC input voltage of the inverter to which the string will be connected, this design can be made in the coldest daytime temperatures at the site location, the different operating voltages at the maximum and minimum site temperatures can be calculated using the following relation: [6, 14]

$$V(t) = V_{@25^\circ} \times (1 + \alpha(T_X - T_{STC})) \quad (13)$$

where; V(t) is module voltage at any temperature; α is temperature Coefficient of Voc, TX is cell temperature in °C and TSTC is temperature at standard test conditions. The temperature range for modules in Iraqi climate is chosen for worst case to be from (-10°C) to (80°C), so the operating voltages at this range is:

$V_{mpp(-10^\circ)} = 31.2\big(1 + (-0.0033) \times (-10 - 25)\big) = 34.8\,V$

$V_{oc(-10^\circ)} = 38.1\big(1 + (-0.0033) \times (-10 - 25)\big) = 42.5\,V$

$V_{mpp(+80^\circ)} = 31.2\big(1 + (-0.0033) \times (+80 - 25)\big) = 25.537\,V$

$V_{oc(+80^\circ)} = 38.1\big(1 + (-0.0033) \times (+80 - 25)\big) = 31.184\,V$

Now, using Eq. (13) the maximum number of modules per string is calculated [6, 7, 13]:

$$Maximum\ No.of\ modules/string = \frac{(V_{max})_{inverter}}{(V_{OC})_{(-10^\circ)}} \quad (14)$$

$$Maximum\ No.of\ modules/string = \frac{1050}{42.5} = 24.7$$

Which must down to 24 modules/string for safety. And also the minimum number of module per string can be found using the following relation: [6, 7, 13]

$$Minimum\ No.of\ modules/string = \frac{(V_{mpp})_{inv_{min}}}{(V_{mpp})_{(+85^\circ)}} \quad (15)$$

$$Minimum\ No.of\ modules/string = \frac{581}{25.537} = 22.75$$

Also, for safety conditions 23 modules/string were selected, thus the 24 modules/string choice is not available because the maximum system voltage which equal to (24 ×42.05=1009.2 V) which exceeds the module maximum voltage (1000 V DC).

4.1.2 Total number of strings

The number of strings in parallel can be found according the power generated needed (1 MW) using the following relation: [6]

$$No.of\ strings\ in\ parallel = \frac{(P_{output\ kW})inverter/\eta_{max}}{[(No.Modules/string)\times(P_{max})_{module}} \quad (16)$$

$$No.of\ strings\ in\ parallel = \frac{1000000/99.1\%}{23\times 275} = 159.5 \cong 160$$

Thus, the total number of solar modules required is (23×160=3680 modules) connected in best available method as shown in Figure 4. With solar inverter contain 16 separately DC inputs grouped into four maximum power point tracker (MPPT) each has four inputs, so each MPPT contain 40 string distributed among its four inputs by 10 circuit combiner boxes, since there is a single inverter used, there is no need for synchronization between the serval inverter and just the synchronization to the grid is needed.

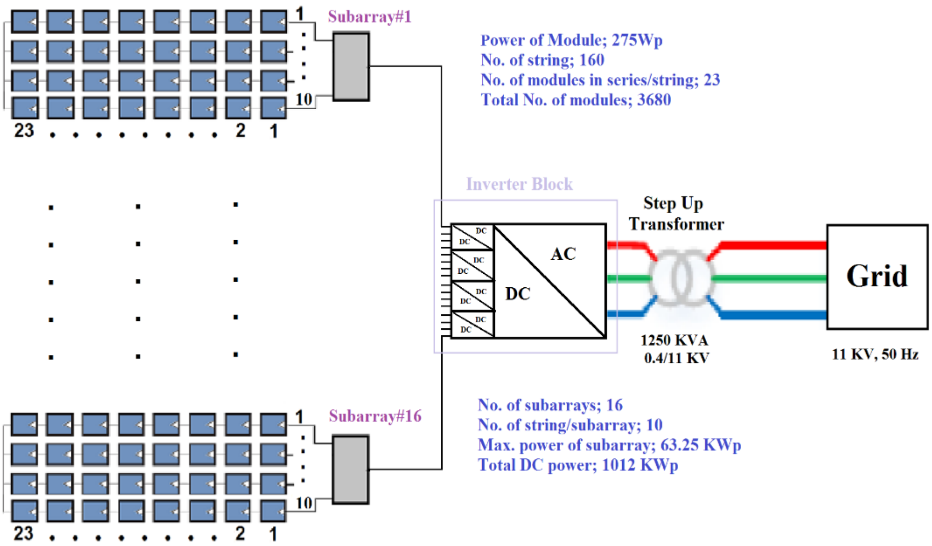


Figure 4. 1 MW grid connected PV system single line diagram.

5. PV system losses estimation

Theoretical systems may have 100 % efficiency, but this is not the case when installing a real physical system. A PV array has several factors that prevent PV systems from working at maximum efficiency and reaching their rated output. There are many factors that affect the output of a PV system such as: temperature losses, voltage drop losses, dirt and soil losses, shading losses, mismatch losses, inverter & Transformer losses [6, 14].

The temperature at which the PV module operates has a large effect on its power output and high operating temperatures lead to power losses [14]. The effect of temperature on output varies from module to module and can be calculated using the temperature coefficients provided on the manufacturer's data sheets using the following relations: [6]

$$T_x = 1 + \alpha(T_m - T_a) \quad (17)$$

$$T_m = 20.4 + 1.2 \times T_{avg} \quad (18)$$

where; T_X temperature de-rating factor , α power temperature coefficient for module selected (-0.41% ˚C), T_m is module temperature (˚C), T_a is reference temperature (25˚C), T_{avg} is the average daytime temperature

(˚C), the ambient temperature (T_{avg}) for each month in Karbala city is used [15], and all calculations are illustrated in Table 4.
The voltage drop equals the total resistance times current. The total resistance is dependent of the cross-sectional area of the conductor, the wire length and resistivity. The voltage drop in the DC cable can be calculated using the relation: [13, 14]

$$V_{Drop\_DC} = 2 \times L_{DC} \times I_{DC} \times R_{DC(\frac{\Omega}{m})} \tag{19}$$

Also, the AC cables side drop can be calculated using the relation: [13]

$$V_{Drob_{AC}}(\%) = 100 \times \left(\frac{\sqrt{3} \times I_{AC} \times R_{AC(\frac{\Omega}{m})} \times L_{AC(m)}}{V_L} \right) \tag{20}$$

where; L_{DC},L_{AC} are DC and AC cables lengths (m), I_{DC},I_{AC} are DC and AC cables currents (A), R_{DC}, R_{AC} are DC/AC cables resistance (Ω/m) and V_L is line-to-line voltage.

Table 4. Monthly Temperature losses in PV system.

Month	Avg. daytime Temp. for Karbala city [15]	Avg. module Temp. (˚C)	de-rating factor T_X	Percentage of losses (%)
January	7.0	28.8	0.984	1.558
February	12.6	35.52	0.956	4.3
March	20.2	44.64	0.919	8
April	26.3	51.96	0.889	11.05
May	30.2	56.64	0.870	12.9
June	35.1	62.52	0.846	15.3
July	37.0	64.8	0.836	16.4
August	37.9	65.88	0.832	16.7
September	33.8	60.96	0.852	14.7
October	25.9	51.48	0.891	10.8
November	17.7	41.64	0.931	6.8
December	11.5	34.2	0.962	3.7
average	24.6	49.92	0.897	10.18

Table 5, summarizes all system wiring with supposed length and voltage drop calculations, the total voltage drops percentage losses equal to 0.8847%, this will be increase to 1% adding the effect of resistances in terminations, fuses and disconnect/isolator devices.
The dirt & mismatch losses are assumed to be 2% and 1% respectively, the inverter losses equal to 1.3 % according to Euro efficiency of the chosen inverter, transformer losses equal to 0.94% according to efficiency of the transformer used with load 100% at 75°C) and shading losses is Location dependent and it assumed that the system is arranged in which there is no shading losses in proposed system, thus, the annual average losses in this system 16.42%.

6. Econamic analysis of grid connected PV system

In order to assess the benefits of investment in PV power plant establishments, the economic aspects must also be taken into account [19], among different measures of the economic value of an investment, an appropriate economic analysis such as life-cycle cost (LCC), net present value (NPV), Internal rate of return (IRR), payback period (PBP) and levelized cost of energy (LCOE) can guarantee the profitability of the investment in the PV systems.

6.1 The life-cycle cost (LCC)

The life-cycle cost (LCC) of a solar PV system is given by; [16]

$$LCC = C_0 + O\&M_{PV} + R_{PV} \tag{21}$$

where; C_0: capital cost, $O\&M_{PV}$: operation & maintenance cost and R_{PV}: replacement cost.

Table 5. System cable sizing and voltage drop.

Cable location	Cable material	Cable length (m)	cross-sectional area(mm^2)	Max DC/AC Resistance (Ohm/Km)@70˚C	Voltage drop (V)	Relative power loss refer to Max power
DC side (string to combiner box)	Copper	20	2×4	5.09	1.8	0.2508%
DC Side Cables (Com. box to inverter)	Copper	45	2×50	0.393	3.12	0.4347%
LT Cables (Inverters to Tr.)	Copper	20	3×500/phase	0.0459	0.76	0.1912%
HT Cables (Tr. to feed-in point)	Aluminum	50	1×185/phase	0.197	0.887	0.008%
Total						0.8847%

6.1.1 Initial capital cost

Table 6 contains PV system initial capital cost., solar PV modules is the most expensive part with price with (0.38$/Wp) which represent 51% of the total capital cost, solar cetral inverter also represent 11% of this cost, panals mounting structure from Grace Solar Company (AL-Ground Mounting System IV) type which represents 16% of total cost, Evacuation Cost from Bluesun Solar Energy Tech. Co**.** which include cost of transformer, DC and AC cables within the solar farm, breakers, junction boxes, LT & HT switchgear, isolators, protection and metering components ..etc. these component represent 10% of total cost knowing that this prices is obtain from company's distributors.

Other system costs are very difficult to calculated from solar markets, which are estimated from CERC [17], these costs are civil & general work which include levelling and mounting, building control room to house inverter, boundary wall, cable trenching, etc. Preliminary/pre operating expenses and Financing Costs include transportation of equipment, storage of equipment, contingency & finance charges. Thus, and with free land, the total initial cost will be 760,540$.

Table 6. PV power plant initial capital cost.

Particulars	Total price ($)	% of Total cost
SPV module	384,560	51%
inverter	81,800	11%
Mounting structure	120,000	16%
Evacuation cost	78,500	10%
Civil & General works	53,470	7%
Preliminary/Pre-operating expenses costs	42,210	5%
Land	free	----
total	760,540	100%

6.1.2 Operation and maintenance cost

It is very difficult to predict the O&M cost over the 25-year design life as there are very few large PV plants that have been generating for sufficient time to have reached the end of their design life. The need for O&M can be very different depending on the system size, installation site, and PV technology type. [3] Generally, it was assumed to be of (22.7 $/kWp. year), [3] thus, (1012×22.7$ = 22,972$/year) including the cost of spare parts, this is regular annual payments at specified intervals, thus it must be converted to the present value by the following relation; [6]

$$Present\ value = UPW \times \frac{(1+i)^n - 1}{i \times (1+i)^n} \quad (22)$$

where: UPW; Uniform Present Worth, i interest rate: this provides the information about the amount of profit that is obtainable from saving a sum of money (4% according to Central Bank of Iraq in 31-5-2017), n number of year. Thus;

$$(O\&M)cost = 22972.4 \times \frac{(1+0.04)^{25} - 1}{0.04 \times (1+0.04)^{25}} = 358876\$$$

6.1.3 Replacement cost

Normally, inverter have shorter lifetimes than the PV modules and other system components and their lifetime depends on their operating conditions, especially in the hot climate [18]. Thereby, if the inverter replaced after 12 years, with replacement cost of 81800$; the present value of this cost is calculated by the following relation: [6]

$$Present\ value = \frac{Future\ value}{(1+i)^n} \tag{23}$$

$$\text{Total replacement cost} = \frac{81800}{(1+0.04)^{12}} = 51092\$$$

Thus; with these three costs the life-cycle cost (LCC) of 1 MW grid connected PV system in present time is 1170508$.

6.2 Net Present Value (NPV)

The net present value is the value of all future cash flows in today's currency, which is a measure of a project's economic feasibility [19]. NPV presents the summation of total net cash flows of the investment project reduced to the present value by discounting. [3]. when a positive NPV indicates an economically feasible project, and a negative NPV indicates an economically infeasible project, NPV is calculated by the relation: [19]

$$NPV = \sum_{n=0}^{N} \frac{CF_n}{(1+d)^n} \tag{24}$$

where; CF_n is the net cash flow related to the conventional n^{th} year, N is number of years (25) and d (%) is the discount rate (used to determine the present value of future cash flows).

6.3 Internal Rate of Return (IRR)

The internal rate of return is the nominal discount rate that corresponds to a net present value of zero for projects, [19] the rate in question is the maximally acceptable profitability rate, the largest rate the investment project can accept, it can be calculated by the relation: [19]

$$NPV = \sum_{n=0}^{N} \frac{CF_n}{(1+IRR)^n} = 0 \tag{25}$$

6.4 Levelized Cost of Energy (LCOE)

For making fair comparisons with electricity prices and the cost of other power generation technologies, the concept LCOE is widely used [3]. LCOE is a reliable and practical criterion to compare alternative technologies for producing energy when different scales of operation, different investment and/or operating time periods exist, LCOE is calculate by the relation: [19].

$$LCOE\ \left(\$/_{kWh}\right) = \frac{Total\ life\ cycle\ cost(\$/W_P)}{Total\ lifetime\ energy\ yield(kWh/W_p)} \tag{26}$$

6.5 The payback period

A common and simple way to evaluate the economic merit of an investment is to calculate its payback period [16]. The payback period is the number of years of energy-cost saving it takes to recover an investment's initial cost, which is given by: [16]

$$PBP = \frac{C_{tot}}{(Q_D \times e)} \tag{27}$$

where; C_{tot} is total system costs, Q_D is the annual energy production (kWh/year), e is the cost of electricity per energy unit ($/kWh).

7. Environmental impact of PV system

PV is recognised as one of the cleanest technologies for energy production [3]. During PV system operations, there are zero (or negligible) releases of CO_2, CO, NO_X, and SO_2 gases and it does not contribute to global warming. While a special study estimated that the Greenhouse gas (GHG) emissions is range from 60.1 to 87.3 g-CO2,eq/kWh depending on the installation methods, with 84% or even more of the total energy consumption and total GHG emission occupied during the PV manufacturing process. [23], the saving amount of CO_2 emission can be calculated using equation (24) [7].

$$CO_{2(emission)} = F_E \times AEP \times N \quad (28)$$

where; AEP, annual energy production of system, N, number of years F_E, emission factor, F_E is set to be 0. 699 kg CO_2-eq/kWh [7].

8. System performance analysis

The performance of solar PV system is a function of climatic conditions, equipment used and system design [21]. The main parameters for evaluation of PV system performance are as follows. [8, 21, 22].

8.1 Final Yield (Y_F)

The final yield is the annually, monthly or daily net AC energy output of the system divided by the rated output power generated ($P_{PV,\ Rated}$) of the installed PV system at STC.

$$Y_F = \frac{E}{P_{PV(rated)}} \quad (29)$$

8.2 Reference Yield (Y_R)

Reference yield is defined as the ratio of total in plane solar insulation (H_t) (kWh/m^2) to the reference irradiance (G) (1kW/m^2).

$$Y_R = \frac{H_t}{G} \quad (30)$$

8.3 Performance Ratio (PR)

Performance ratio is defined as the ratio of the final yield (Y_F) to the reference yield (Y_R). Performance ratio is dimensionless quantity and it is normalized to performance parameter w.r.t incident solar radiation. It shows the overall effect of losses.

$$PR = \frac{Y_F}{Y_R} \quad (31)$$

8.4 Capacity Factor (CF)

Capacity factor (CF) implies a relation of the real annual electrical energy generation and electrical energy which could be generated if the PV solar plant operated with its total installed (nominal) power 24 h a day over a year, Solar PV plant capacity for one year is calculated by equation (28) [22].

$$CF = \frac{Y_F}{8760(h)} = \frac{E_{AC\,out}}{P_{max.STC} \times 8760} = \frac{G_{OPT} \times PR}{P_{max.STC} \times 8760} \quad (32)$$

Also, the capacity factor (CF) for any month can be calculated using the relation [6]:

$$CF_{month} = \frac{Solar\ irradiance(kWh/m^2.month) \times \eta_{sys.month}}{24(hour/day) \times No.of\ days\ in\ that\ month \times 1kW/m^2} \quad (33)$$

9. Calculating system yield

The net AC energy (kWh) produced for any month can be estimated using equation (34), [6] PV system efficiency for any month can be calculated using the de-rating factor (T_X) combinations for all losses, taking in the account the Industry-leading Warranty based on nominal power of the selected solar panel which 97.5% in the first year, thereafter, form the second year through twenty-five, 0.7% maximum decrease from module's nominal power output per year. Also, because not all year days are sunshiny, taking the effect of cloudy days, a factor of (350/365) is added to the calculations meaning that there are 15 days off work in every year.

$$E_{month(kWh)} = Full\ nameplate\ capacity\ X\ CF_{month} \quad (34)$$

The full nameplate capacity for any month (kWh) is calculated by the relation: [6]

$$Full\ name\ plate\ capacity = [Plant\ capacity\ (kW)]\ x\ [24\ (hour/day) \times (No.of\ days\ in\ that\ month) \quad (35)$$

MATLAB software is used to calculate the plant generated energy, performance, environmental impact & economic evaluations for the proposed system according to the flow chart shown in Figure 5 with the input data of average solar radiation from the output of the first program, 1012 kWp plant and the estimated system losses in section 5.

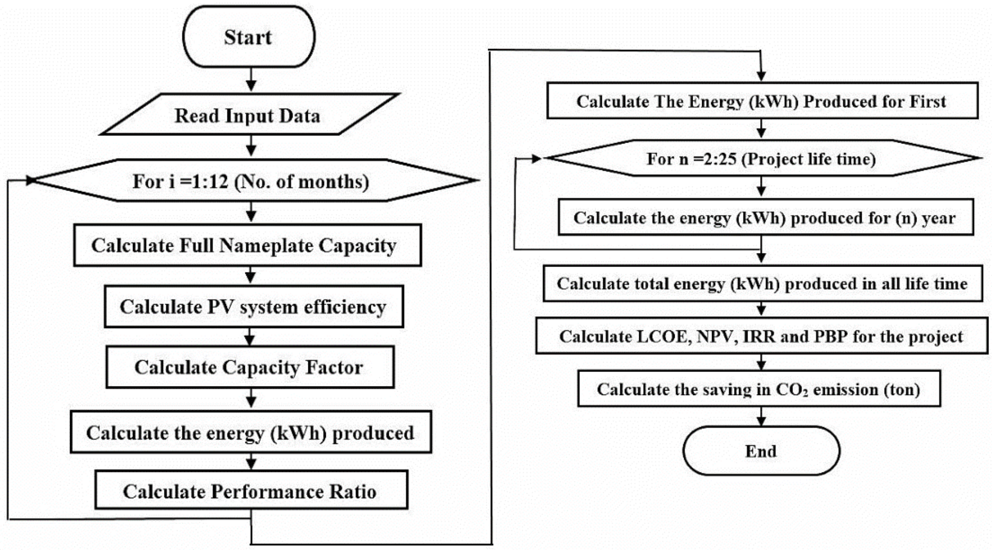


Figure 5. Flow chart of the MATLAB program used for system parameters estimation.

10. Results and discussion

Two MATLAB programs were used to get the complete study for installing large scales PV system in Karbala. First, the solar radiation estimation and its' results are used as input for the second program to get System performance, generated energy, environmental impact and economic evaluations as follows.

10.1 Solar radiation

Table 7 shows the optimal tilt angles settings for Karbala city with their respective annually average solar radiation in (kWh/m^2.day), the fixed tilt angle is calculated by finding the average value of the tilt angles for the all months of the year which it is found to be equal to latitude of the location (32°), while the seasonal adjustment for solar collectors was achieved by taking the mathematical average of each six months to represent one season which was equal to (latitude + 15°) for winter months whilst in summer months equal (latitude -15°).

Table 7. Tilt angle setting for Karbala city.

Month / Setting	Jan	Fab	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	annual Avg. radiation kWh/m^2.day
Monthly tilt angle	53	46	35	23	13	9	11	19	30	42	51	55	6.524334
Seasonally tilt angle	47	47	47	17	17	17	17	17	17	47	47	47	6.439888
yearly tilt angle	32	32	32	32	32	32	32	32	32	32	32	32	6.0725

Figure 6 shows the variation of average solar radiation in (kWh/m^2.day) with different tilt angle settings, as it clear monthly type give best performance with annually average of 6.524 (kWh/m^2.day). Yearly tilt type gives less annually average radiation of 6.075 (kWh/m^2.day). It is worth mentioning that in order to reduce the initial investment cost (simple panels mounted stricture) and periodic operation and maintenance cost, the fixed tracking system preferred for large scale as well as the yearly optimum tilt angle for installing PV modules which is dependent in this study.

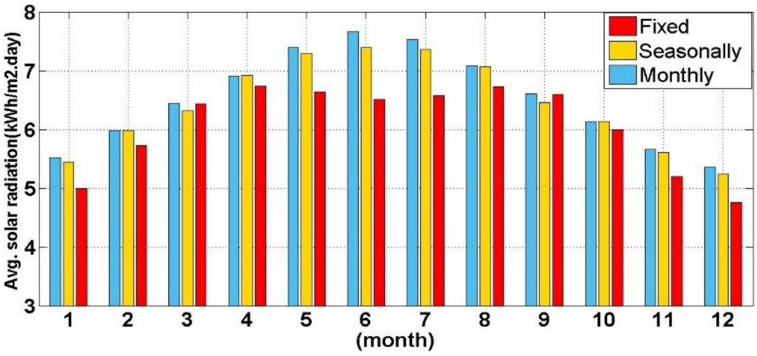
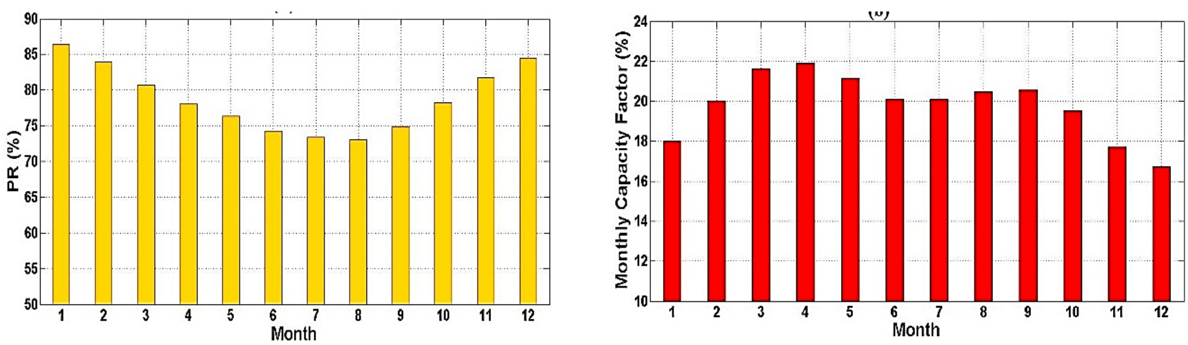


Figure 6. Monthly average solar radiation (kWh/m^2.day) with different tilt angle settings.

10.2 System performance

Performance Ratio (PR) is widely used to access the quality of PV system installations that are commonly reported on a daily, monthly or yearly basis, the PR for every month for first year of generation plotted is shown in Figure 7-a. Performance Ratio is varied between 86.4% in January month to 73 % August, evidently, the PR is low in the summer months compared with the winter months, this due to profoundly effect of temperature in system performance. The annually average PR is about 78.78% which is acceptable in case of large scale PV system. The capacity factor in each month for the first year is varied between 16.73% in December to 21.9% in April with annually average of 19.83%, (Figure 7-b) which is mainly depending on the amount of solar radiation fulling on the panels, so the variation of its values distributed as the same as the solar radiation for fixed tilt type that shown in Figure 6, the capacity factor percentages is acceptable compare with that for real PV power plant installed in different countries in Asia.



(a) (b)

Figure 7. (a) Monthly PR for first year of generation, (b) Monthly CF for first year of generation.

10.3 Energy yield

The most important part of any type of PV system is the amount of generated energy. The result show that about (1757.8 MWh) produced in the first year with average of (4.817MWh/day) distributed among the months as shown in Figure 8. Spring and autumn months gives higher production than the other because of the type of tilt angle setting which is suitable for this months which give maximum generation of 162.86 MWh in March while the wintery months give less amount of generation reach to 126 MWh in December. Also, the expected generated energy for 25 years (after taking the effect of module degradation of 0.7% maximum decrease from nominal power output per year) of the plant life time the result is plotted in Figure (9-a). The degradation effect is clearly shows in future years ended to 80.7% of the nominal power in the 25th year of life. The total MWh produced for twenty-five years is estimated to be 40,445 MWh.

10.4 Environmental impact

The environmental impacts of PV system with regard to reductions in emission are estimated for one of the four atmospheric emission constituents (i.e. CO_2) which has the greatest amount from others. After taking into consideration the small amount of CO_2 emission during the PV system operation, the saving value of CO_2 emission result by installed a 1MW PV plant in first year is 1208 tons. Figure 9-b shows the amount of CO_2 emission reduction for twenty-five years of life time of the project which is estimated to be 27794 tons of CO_2 can be avoided from entering the local atmosphere in during 25 years.

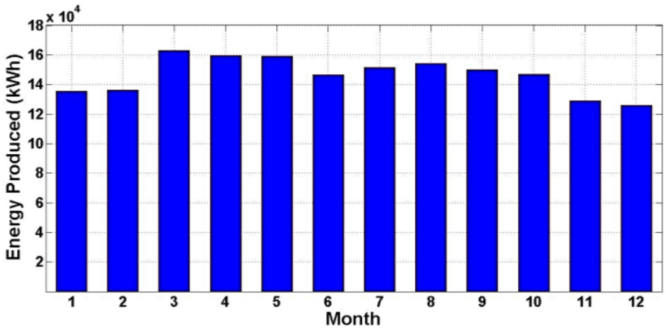
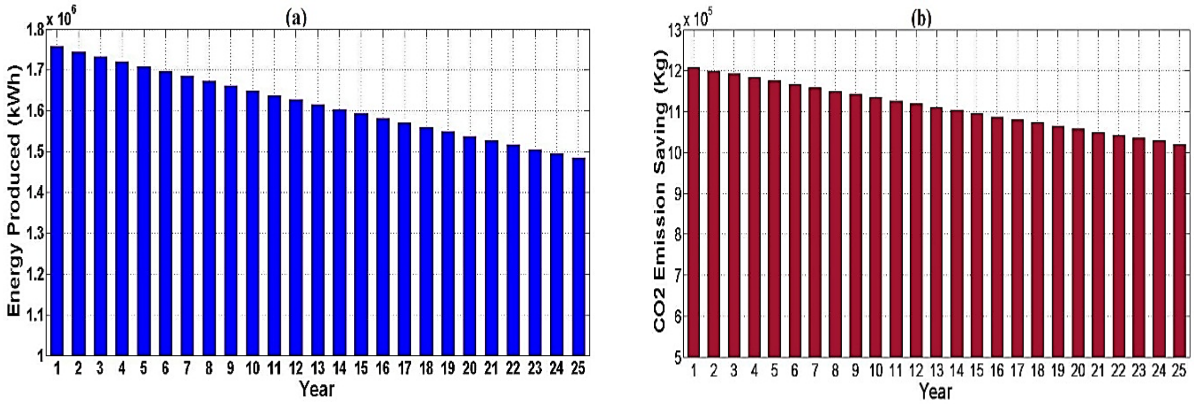


Figure 8. Monthly kWh produced for 1MW capacity PV power plant in first year.



(a) (b)

Figure 9. (a) Annually energy expected, (b) Greenhouse gas emissions saving.

10.5 Financial analysis

The economic analysis of 1MW PV plant with 1170508$ total life cycle cost and 40,445 MWh life cycle generated energy, the levelized cost of energy (LCOE) is 0.0289 $/kWh with installation cost of 0.7515 $/Wp. The relationship between the electricity selling price ($/kWh) and NPV, IRR and PBP has been investigated in Table 8 with 5% discount rate, obviously, the NPV & IRR are increased considerably with an increase in the electricity selling escalation and the NPV has positive value and the IRR is higher than the discount rate, then the project is economically profitable.

The PBP is important to know for an investor to get his investment back, Figure 10 shows the cumulative cash flow and the expected equity payback period with three selling prices, the payback period, in the present case are found to vary between minimum of 6.8 years for 0.1$/kWh selling price and maximum of 11.5 years for 0.06$/kWh selling price and the other is shown in the table according to the unit price that chosen since the price value is depend on demand sector and the amount of energy consumed.

Table 8. The relationship between the electricity selling price and NPV, IRR and PBP.

Price($/kWh)	NPV ($)	IRR (%)	PBP(Year)
0.06	221,410	6.88	11.5
0.07	453,400	8.72	9.6
0.08	685,390	10.4	8.5
0.09	917370	12.17	7.4
0.1	1,149,400	13.82	6.8

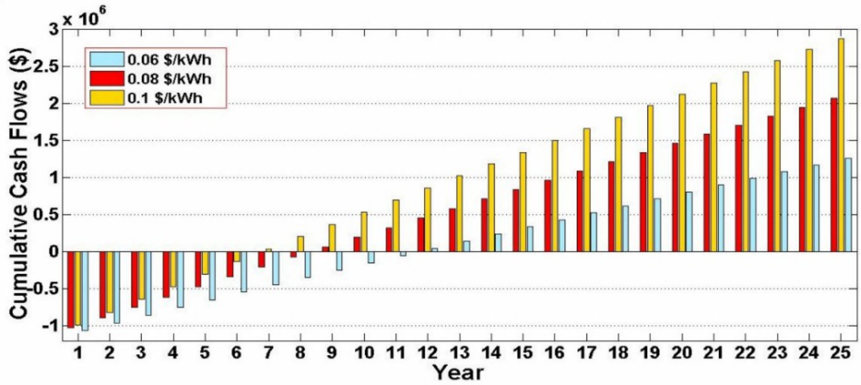


Figure 10. The cumulative cash flow and the expected equity PBP with different selling price.

11. Conclusion

On grid PV system type is widely increased nowadays especially in medium and large scales power plants, this work proposed a design of 1 MW grid connected PV plant in Karbala city. The results obtain from MATLAB programs including the estimation of solar radiation and the PV system performance parameters, clarified that the energy generated form PV system dependable for supporting the national grid in generation and management sector in addition the system has a high environmental impact by reducing the very high amount of greenhouse gas emissions. Also the project has good economic returns. The results obtained from this work would encourage the government to exploit this type of project in future.

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