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# Performance and Optimization of Commercial Solar PV and PTC Plants

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***Abstract:** Installation of solar PV arrays at utility scale is gaining popularity nowadays because of the significant reduction in the cost of components as well as the global push towards clean energy. Solar PV plants along with Parabolic Trough Collector Solar thermal plants has the highest potential among the available Renewable Energy (RE) technologies existing in the world. The objective of this paper is to optimize the performance of commercial Solar PV and PTC power plant for a potential location and hence to arrive on a most feasible configuration for the site. A representative site located in the Abudhabi region of UAE considered for the study. This paper also details on the annual performance of the proposed plant along with its technical aspects. PVSYST 6.7.7 and SAM software is used to design the optimal size and its specifications of a 100MW PV grid connected system at Abu Dhabi (UAE) region. The design and arrangements of the system verified using simulation results. The annual energy generated from the designed utility-scale solar PV plant from PVSYST 6.7.7 calculated as 161198MWh/year with a performance ratio (PR) of 74.8% per year where as for PTC it has calculated as 157152MWh/year by using SAM. The STC (Standard Testing Condition) for the specification of PV modules are normalized operating conditions when testing the module. Design parameters such as module orientation, array yield, reference yield, final yield, global horizontal irradiation (GHI), and ambient temperature and loss factors evaluated. To evaluate the economic feasibility of proposed plant, the levelized cost of electricity (LCOE) is determined as $0.04404/kwh for Solar PV and as $0.01533/kwh for PTC, which is used to calculate lifecycle cost and energy production.*

***Keywords:** Solar PV power plants, grid connected system, PVSYST, SAM, GHI, annual plants electricity generation.*

## I. INTRODUCTION

Utility-scale solar power generation using Photovoltaic technology is gaining popularity due to the rapid advancement towards renewable energy (RE) sources for reducing $CO_2$ emissions. Among the different RE sources, solar energy is the main source with lot of potential to generate power, which is pollution free and sustainable. Abu Dhabi (UAE) region has very huge solar potential with almost 300 to 350 clear sunny days in a year[1].

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The average annual solar hours for the region is nearly 3568h (i.e., 9.7hrs per day) [2]. The energy demand of the region has to be accurately estimated prior to the installation of PV system so as to estimate the benefits of the proposed plant after its installation [3]. Grid-connected Solar PV systems connected to LV side most commonly used in Abu Dhabi. The solar PV arrays have got the great potential to generate power with significantly higher GSR value [4]. For sizing a PV system, system designers and installers are adopting various tools such as PVSYST and SAM software. PVSYST is a specialized software package developed by University of Geneva [5]. SAM developed by the National Renewable Energy Laboratory (NREL) with the grants funded by U.S. Department of Energy. SAM collaborates with Sandia National Laboratories for the PV models, and with the University of Wisconsin's Solar Energy Laboratory for the concentrating solar power models [6]. The technological demands for small-scale and utility-scale PV systems performance are fast increasing along with economic aspects. The price of PV panels came down significantly due to the rising demands and corresponding bulk production. The electricity demand peaks during hot weather conditions and is essential to meet the additional power requirement of the grid from RE sources. A rooftop solar-powered home linked to the regional electricity grid has expanded adequately.

The ambient temperature differs in the range of 5°C to 50°C max, for unshaded areas in Abu Dhabi region. There will be an impact on the output voltage and output current of PV Modules when the temperature rises $10^0$C above ambient temperature. For performing system design calculations in the desired location, the variations in the temperature are considered.

A string inverter is considered to be reliable, cheap, compatible and highly sensitive towards shading issues[7]. Inverters should be choose based on the system and site conditions. Solar PV inverters can configured in many ways as detailed. The most common arrangements used in Abu Dhabi are:

1. Single String connected to a single Inverter and
2. Multiple Strings connected to a single Inverter with multiple MPPT [3].

## II. LITERATURE REVIEW

The extensive research and development activities for harnessing maximum energy from RE sources have increased the renewable energy targets. A detailed review of the existing research work concentrated on the constructive analysis and methodologies of solar PV and PTC system using PVSYST and SAM software discussed below.

S. Rehman et. al (2016) carried out a feasibility study of the grid-connected 10 MW installed capacity PV power plants in Saudi Arabia. The grid-tied PV system considered in the study supplied power to the grid instantly without resorting to high-power back-up batteries [9]. Nallapaneni M K et.al (2018) carried out a case study of a 95 $kW_p$ grid connected PV system located at Coimbatore compromising 312 PV modules and four 25 kVA inverters and the performance of the system was analyzed [10]. Sundaram et.al (2015) presented the performance of $5MW_p$ GCPVS situated at Sivagangai, Tamilnadu in India has estimated theoretically annual energy yield. The measured annual average generated energy found to be 24,116.61 kWh/day. Alam Hossain and Sadrul Islam (2011) estimated the potential of a 1 MW utility system capacity grid for 14 regions in Bangladesh was recorded as 50,174 MW [11]. Manasseh Obi and Robert (2016) presented a literature review of the recent developments and trends pertaining to GCPVS. The authors also highlighted the various challenges to improve the efficiency of GCPVS [12]. Ammar.M et.al showed the design and performance evaluation of GCPVS in hot weather conditions by installing a 36 kWp pilot Grid-connected PV system linked at 0.4 kV balanced at Abu-Dhabi distribution lattice [13]. Under the geographical weather conditions, the performance of a system including growth efficiency, voltage flexibility, the effect of dust, energy yield, and the effect of ambient temperature is calculated. The performance of a 1MWp photovoltaic system linked at distribution network for Aïnmelh M'sila region analyzed by Tallab.R and Malek.A (2015). The performance of the system evaluated by PVSYST software for both fixed tilt and seasonal tilt arrangements. The authors analyzed that there is a production of 1805 MWh/year injected into the grid with a performance ratio of 77.8% at a fixed tilt and annual production of 1893 MWh/year injected into the grid with a performance ratio of 77.8% at seasonal tilt [14]. The performance of the standalone photovoltaic system using PVSYST simulation tool was investigated by Irwan Y.M. et.al (2015). The analysis shows the generated energy on yearly basis is 841.31 kWh and energy supply to the user is 735.84 kWh [15]. The same software used by K.Matiyali and A.Ashok for designing a grid-connected 400-kWp solar PV power plant at Dhalipur. The performance analysis of the proposed system was also analyzed and the performance ratio was found to be 78.1% [16].

The design and performance analysis of 3.6 $kW_p$ GCPVS with rooftop installation presented by Vjollca komoni et.al (2016). The system was monitored for a period of two years and the parameters were measured and analyzed [17]. Khalid.M. Hamid et.al (2018) studied on an optimal design of connectivity of electric current by installing a stand-alone system by using solar cells. The authors determined the load calculations and sizing the PV system array configuration [18]. Al-Refai studied the design and analysis of 100MW grid-connected system at Tripoli by using the PVSYST software. The annual generated electrical energy was found to be 181614MWh and LCOE is $ 0.0321/kwh [19]. Islam M.D. et.al presented the actual measurement of direct Global Solar Radiation (GSR) has the highest annual mean in U.A.E among Arab state capitals. The highest daily mean value was recorded as 730 $w/m^2$ and monthly mean as 493.5 $w/m^2$ [20].

A report prepared by MASDAR Institute for IRENA states that the 10 plus MW rooftop PV further distributed through over country. The solar PV progressively identified as one of the most compromising technology in U.A.E and desire to endure the prominence because of its low price and enough resource in the country (IRENA, 2015) [21]. Shukla. A.K evaluated the technical performance of 110kWp grid-connected rooftop solar PV system to determine the performance ratio and Energy yield. The performance ratio recorded as 70-88% for various modules used by the PV system. Their Energy yield range from 2.67kWh/Wp to 3.36 kWh/Wp.[22]. C. Meriem et. al (2014) used PVSYST simulation tool to design the grid connected 9.9 kWp to study the photo-voltaic system network. The design is enhanced by surveying the direction and inclination of the PV generator the parameters such as performance ratio, energy generated and losses were also calculated [23]. After a thorough review on parabolic trough collector the Price et al [24] claimed that solar power generation using these collectors was the most reliable and robust technology.

For the proposed design of a 100MW utility-scale grid-connected solar PV system at Abu Dhabi ($24.43^0$ N $54.65^0$ E), the various performance parameters such as annual energy output, PR, energy injected to the grid in kWh/day and global incidence in collector plane $kWh/m^2/day$ are calculated. The performance of the plant parameters of this commercial solar PV plant will be discussed with that of the Parabolic Trough Collector plant design proposed by the authors in the paper [8]. The final selection criterion for zeroing in on the ideal configuration of the plant also detailed. A detailed analysis and performance aspects of the proposed plant discussed in the later part of the paper.

A typical arrangement of a PV system shown in Figure. 1. The grid-connected solar PV system considered in this design includes the following components:
The solar PV array consisting of various modules connected in series and parallel.
Grid-connected AC/DC inverter, which can supply AC power to the utility grid.
Safety equipment such as AC/DC circuit breakers, fuses, filter, safety switches, cabling, electric kWh meter and Isolation switch etc.,

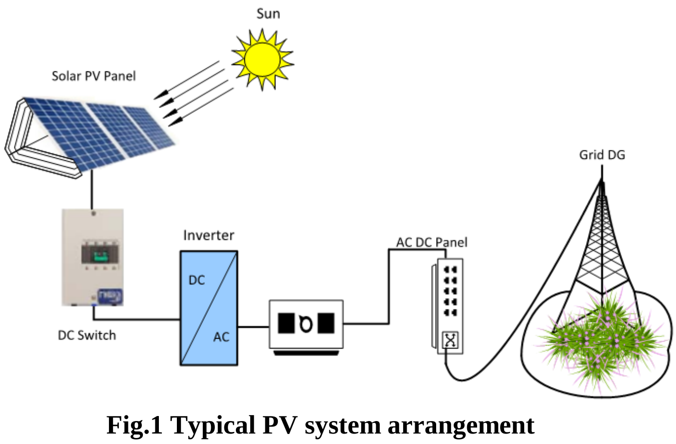



**Fig.1 Typical PV system arrangement**

In this system, the solar modules are directly fed to an inverter and the inverter connected to an electricity grid.

The system can draw the grids reserve capacity whenever it is needed and feed power back into the grid during times of excess production. The grid-connected PV system is simple and reliable with low maintenance requirements as it avoids the use of batteries for storage purposes.

Figure.2 shows the arrangement of parabolic trough collector (PTC) with thermal storage system selected for the design. PTC are usually use for steam generation where the temperature rises up to 300$^0$C. The solar energy from the sun is focused by the PTC surface on an absorber pipe then is transmitted to thermal fluid [25]**.** The absorber tube consists of a metal tube with a glass envelope covering it. The region between the glass envelope and metal tube is filled with either air or vacuum so as to allow for thermal expansion and reduction of convective heat losses. Parabolic Trough collectors can only use the dirct component of solar radiation, i.e Direct Normal Irradiance (DNI) [8].

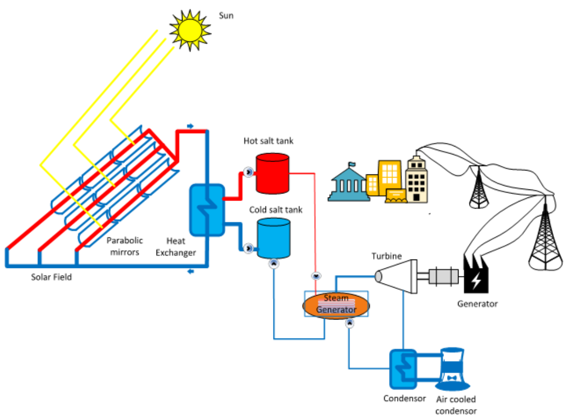



**Fig.2 Schematic diagram of PTC**

**Description of the solar photovoltaic grid system**

The design of utility-scale PV plants requires a few thousands of PV panels, with a range of 100Watts each. For the design of a PV plants, it is important to identify the preferred location, ideal value of design parameters, size of the inverter, type of modules, installation area and so on. The geographical site selected for the installation of a 100MW proposed plant with coordinates 24.43$^0$ N 54.65$^0$ E Meteonorm 7.2 Synthetic in Abu Dhabi region. Si-poly PV module with poly 110 $W_P$ 72 cells model and 4.2 kWac Inverter model with operating voltage of 125-500V is used to design the PV plant. Figure 3 shows the proposed model of the grid-connected PV system.

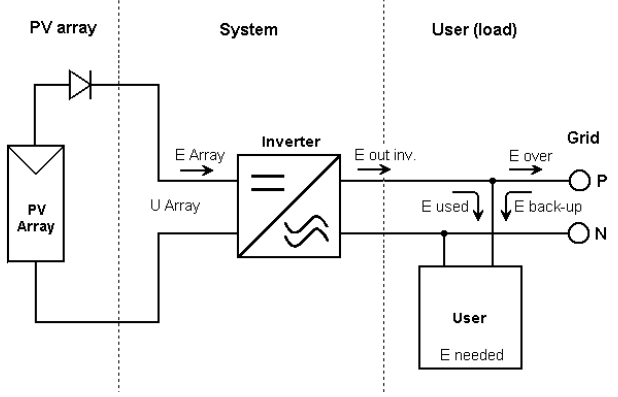



**Fig.3 Grid-connected a PV system**

The wiring layout of Low Voltage distribution system for Solar PV systems that connected in parallel shown in Figure 4 and, Figure 5 with 69930 parallel strings on 18316 inverters.

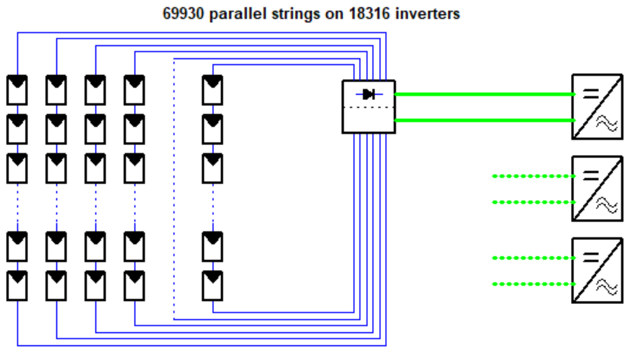



**Fig.4 wiring layout for parallel strings on inverters**

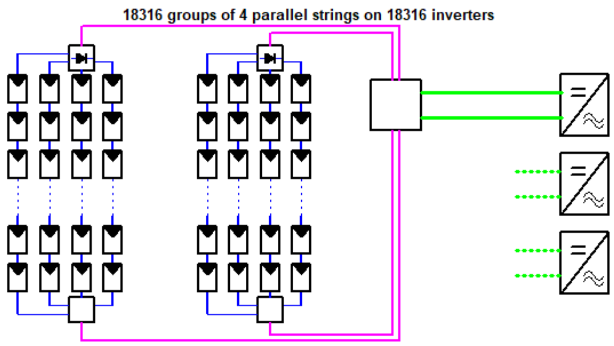



**Fig.5 wiring layout for a group of parallel strings on inverters**

Modules are made of solar cells to form arrays and strings and they are link by using connectors and cables. These Arrays and Strings are linked to Inverters to convert the DC output into AC current, which can be use within the premises to meet the demand for electricity. These modules are placed at mechanical structures to point them towards the sun. Grid-connected Inverters regulates the amount of voltage and the current that is receive from DC Strings and Arrays and then converts it into an alternating current by ensuring that the power will be in phase or synchronized with the grid-power. This will allow the transmission of any excess power generated by the PV system to the utility grid.

In this paper, the generating station is design to operate with a PV field orientated at an optimized tilt angle of 30$^0$ and azimuth 0$^0$, shown in Figure.6. The produced energy, specific production and performance ratio is calculated. The optimum tilt angle is 30$^0$ corresponding the location to get maximum solar irradiation for a solar panel at Abu Dhabi region [22].

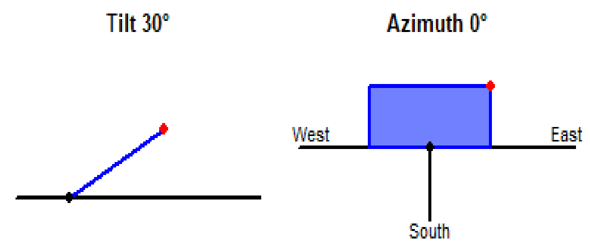



**Fig.6 Orientation**

A PV panel contains the grid-connected solar PV systems, which distribute the majority part of the prescribed power throughout the day. The grid links with the system to draw the power overnight. During sunny days, the PV panels produce more power and supplied to the grids. During cloudy periods or at nights the storage systems such as batteries are use as independent power systems to supply electricity. The grid acts as batteries to supply electricity when the PV array unable to do so [27]. These grids linked PV systems are quite effortless and have rather minimal performance and maintenance price.

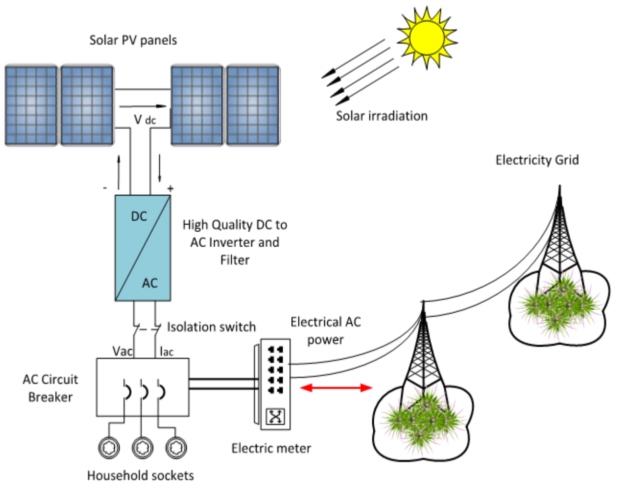



**Fig.7 Configuration of a grid-connected solar PV system**

The power generated from the solar PV panel fed to an inverter, which converts the DC power into AC power as shown in Figure 7. Semiconductor materials used to produce electricity from sunrays through PV cells. The electrical energy then flows from the inverter to the electrical service board that supplies energy. An inverter is a more efficient component of any grid-connected PV system. The energy meters or kilowatt-hour used to indicate the current of electrical energy from the grid. Dual type energy meters can use for inward energy and the other for departing energy. The tracking meter installed to know the consumption of electricity as well as the output obtained from the solar installation system. During peak productivity times, the excess energy generated from the system fed back to the grid. At times when power drawn from the grid to meet the load demand the electrical meter spins backward and records the same. This scheme of bi-directional power transfer will offer significant benefit to the firms as most of the local government will offer attractive subsidies in return to the excess energy been supplied to the grid.

In this system, all generated power connected to the grid and reduce the electric bill that pays back the cost of investment for the PV system and eventually turns a profit. The PV panels must choose for large cell efficiency and high operating temperature to make it easier for better power of PV array. Shading in PV modules must avoided otherwise; shading will reduce the output.

## III. METHODOLOGY FOR THE PERFORMANCE OF A SOLAR PV SYSTEM

The performance of the solar PV and PTC system divided into three levels.

1. Extract the site-dependent designed parameters of power generation through Meteo database from PVSYST and SAM.
2. Evaluate the parameters for the performance with PVSYST and SAM software.
3. Simulation using PV SYST and SAM.

The simulation software's is establishing to measure the performance of a solar PV plant. PVSYST-software used for predicting annual output energy for 100MW grid-connected solar PV plant. This software can calculate the performance of stand-alone, grid-connected and pumping arrangements built on the stated module option. Schedule precisely concludes the system yields gauge using specific simulation data (hourly).

To evaluate the performance of grid-connected PV system, the design standards have proposed by International energy agency (IEA). These parameters can be used as a general guideline to evaluate "final system yield, system losses, array capture losses, inverter efficiency, reference yield, array yield, performance ratios, capacity utilization factor, energy injected to the grid, system efficiency, etc." [24-29].

### IV.1. Parameters for the performance analysis of the PV system

#### IV.1.1. Array yield

Array yield is denoted by $Y_A$ measured in kWh/kWp/day Array yield is the time where solar PV system must utilize at minimal solar power generator $P_0$ is to generate array dc output energy $E_{dc}$.

$$Y_A = \frac{E_{dc}}{P_0} \qquad (1)$$

The DC output energy $E_{dc}$ measured in kWh given by the equation

$$E_{dc} = I_{dc} * V_{dc} * t \qquad (2)$$

#### *IV.1.2. **Reference yield***

The Reference yield denoted by $Y_R$ measured in $(\mathbf{kW\,h}/m^2\,/\,\mathbf{kW}/m^2)$, it is the ratio of $H_t$ (absolute irradiance in the plane) to $G_0$ (Reference irradiance of PV). It constitutes under ideal condition's obtainable energy. If G=1 kW/m$^2$, then $Y_R$ is the figure for top sun hours or the solar radiation in kW h/m$^2$. The $Y_R$ defines the solar radiation resource for the PV system.

$$Y_R = \frac{H_t}{G_0} \qquad (3)$$

#### IV.1.3. Final Yield

The final yield $Y_F$ measured in $(\mathbf{kWh/kWp\,/day})$ is the ratio of net AC output energy (Annual, monthly and daily) of the system to the extreme power of the installed PV array at standard test conditions (STC) of 1KW/m$^2$ solar irradiance and 25 °C cell temperature.

$$Y_F = \frac{E_{AC}}{P_{E,STC}} \quad (4)$$

### IV.1.4. Performance ratio

Performance ratio is the ratio of final yield to the reference yield. PR also specifies as differentiation of plant output to the output of the plant that could have reached by considering into archive irradiation, size of the aperture area, panel temperature, availability of grid, minimal power o/p, temperature correction values.

$$PF = \frac{Y_F}{Y_R} = \frac{E_{GRID}}{GlobInc} \quad (5)$$

### IV.1.5. Capacity Utilization Factor

CUF is determined as a real output of the system related to analytical maximum output to the system.

$$CUF = \frac{Energy\ measured\ (kWh)}{365 * 24 * installaed\ capacity\ of\ the\ plant} \quad (6)$$

### IV.1.6. Inverter Efficiency

Inverter efficiency also known as conversion efficiency. It is the ratio of generated AC power of inverter to generated DC power by the PV system. The formula for inverter efficiency is

$$\eta_{Inv} = \frac{P_{AC}}{P_{DC}} \quad (7)$$

### IV.1.7. System efficiency

System efficiency is a product of inverter efficiency to PV module efficiency. The performance of a system evaluated by these factors.

$$\eta_{sys} = \eta_{pv} * \eta_{inv} \quad (8)$$

### IV.1.8. Energy fed to the utility grid or Energy output

Energy fed to utility grid depends on energy generated across inverter output which is daily monitored [30].

There will be losses for any system during their performance. These losses are feasible when designing the grid-connected PV system. The losses parameter is generally of two types:

a. system losses and
b. array capture losses.

### IV.1.9. Array Capture Losses

Array Capture Losses is the difference of reference yield to the array yield. $L_C$ denotes array capture losses. These losses primarily appear in PV array similar rise in temperature at PV cell, dust collection on a PV system, errors, mismatching and incomplete shade.

$$L_C = Y_R - Y_A \quad (9)$$

### IV.1.10. System losses (LS)

A system loss consists of conduction, inverter, and losses of passive elements. System losses are the difference of array yield to the final yield.

$$L_S = Y_A - Y_F \quad (10)$$

### *IV.1.11.* ***Levelized Cost of Electricity (LCOE)***

The funder is interested in a PV system, which gives a reasonable profit or advantage while invested in a PV system. The cost-effectiveness estimation must be made by the investor to analyze the benefit for the system[35]. One of the economic terms is considered as levelized Cost of Electricity. LCOE is used to evaluate the economic feasibility of an electricity generation ($MWh) to correlate the lifetime cost of different energy-producing technologies (wind, solar-natural gas, etc.). The general equation for LCOE is given by[36]

$$LCOE = \frac{Life\ cycle\ cost\ (\$)}{Lifetime\ energy\ production\ kWh} \quad (11)$$

The LCOE calculated for the designed solar PV grid connected system is as follows [19]:

| Designed capacity | Initial capital | Maintenance cost | Estimated early production | Project life |
|---|---|---|---|---|
| 100MW | $\$142*10^6$ | $\$142*10^4$/Yr | 161198 MWh/Yr | 25 Years |

*Lifetime output* = *161198*$*10^2$kWh/year *25 years* = *4029950*$*10^2$kWh* (12)

The total cost of ownership can calculated by considering the Initial capital and maintenance cost is

*The total cost of ownership* = *$\$142*10^6 + \$142*10^4$/Year * 25 years* = *$\$1775*10^5$*

### IV.1.12. Balances and main results

PVSYST software generated balances and main results of a PV system that contains variable such as Global irradiance at a horizontal plane, ambient temperature, horizontal diffuse irradiation, global incidence in collector plane. It also includes the effective global irradiance for I AM (Incidence angle modifier) not shading, effective energy for the output array, performance ratio, energy injected to the grid, and detailed system losses as shown in Table.1.

The annual global irradiance for this location is found as 2026.7 kWh/$m^2$ and global incidence in collector plane on annual basis is 2155 kWh/$m^2$. The horizontal diffuse irradiation on annual basis and Average ambient temperature found as 827.98 kWh/$m^2$ and 27.99 $^0$C are respectively. The effective global irradiance for I AM not shading is 2041.1 kWh/$m^2$ and effective energy for the output array is 166863 MWh. Similarly, the performance ratio and energy injected into the grid are 74.80% and 161198 MWh are respectively.

**TABLE.1 BALANCES AND MAIN RESULTS**

| | GlobHor kWh/m$^2$ | Diff Hor kWh/m$^2$ | T_Amb $^0$C | GlobInc kWh/m$^2$ | GlobEff kWh/m$^2$ | EArray kWh | E_Grid kWh | PR |
|---|---|---|---|---|---|---|---|---|
| January | 115.9 | 50.10 | 18.96 | 154.5 | 147.4 | 12717667 | 12281396 | 0.795 |
| February | 129.1 | 56.14 | 20.66 | 158.9 | 150.9 | 12855702 | 12418895 | 0.781 |
| March | 163.6 | 73.39 | 23.75 | 180.7 | 170.9 | 14286977 | 13806252 | 0.764 |
| April | 192.7 | 75.86 | 27.54 | 191.4 | 180.9 | 14748665 | 14244474 | 0.744 |
| May | 222.7 | 82.11 | 32.07 | 200.5 | 189.1 | 15108456 | 14590559 | 0.728 |
| June | 219.2 | 83.81 | 33.09 | 188.7 | 177.4 | 14220456 | 13735823 | 0.728 |
| July | 206.8 | 96.82 | 35.27 | 182.8 | 171.2 | 13693370 | 13227102 | 0.724 |
| August | 199.4 | 90.95 | 35.77 | 190.8 | 179.7 | 14156004 | 13671333 | 0.717 |
| September | 178.2 | 68.80 | 32.69 | 189.3 | 179.7 | 14211158 | 13727839 | 0.725 |
| October | 160.4 | 57.75 | 29.66 | 192.7 | 183.9 | 14730131 | 14232165 | 0.739 |
| November | 129.4 | 45.37 | 24.95 | 173.9 | 166.4 | 13815668 | 13357602 | 0.768 |
| December | 109.3 | 46.88 | 21.03 | 150.9 | 143.6 | 12319215 | 11904116 | 0.789 |
| Year | 2026.7 | 827.98 | 27.99 | 2155.0 | 2041.1 | 166863468 | 161197556 | 0.748 |

## IV. RESULTS AND DISCUSSIONS

This session includes the simulation results of the proposed design of 100MW PV grid connected system and PTC plants by using PVSYST and SAM software. The parameters that were obtained during the simulation are performance ratio, produced energy, LCOE, specific production, Energy injected into the grid, ambient temperature and array losses. For evaluating the performance of the proposed PV grid connected system these results were analyzed. In this paper, all the tables were generated during the simulation process for this region are illustrated in detail.

### V.1. Main simulation results

After carrying out the detailed analysis and performance of a proposed PV system, the main results and parameters evaluated during the simulation are:

1. For a 100MW, PV system the total energy produced i.e. 161198 MWh/year and 157152 MWh/year for PTC.
2. Specific production for annual basis is referred as 1612 kWh/kWp/year.
3. The levelized cost of electricity (LCOE) is determined as $0.04404/kwh for Solar PV and as $0.0153/kwh for PTC

### V.2. Normalized production

For the assessment of PV system, the normalized production is defined by the IEC norms which have standardized values [26]. From the performance and simulation of this study, the system losses, collection losses and produced useful energy (inverter output) were evaluated as shown in Figure.8. The Figure shows the collection loss or PV-array losses $L_C$ is 1.33 kWh/kWp/day similarly, system loss at inverter $L_S$ is 0.16 kWh/kWp/day and produced useful energy (inverter output) $Y_F$ is 4.42 kWh/kWp/day.

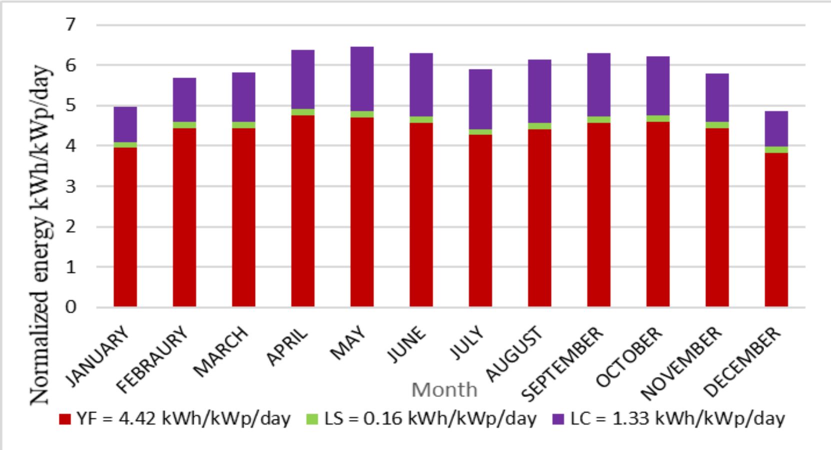



**Fig.8. Normalized production (per installed kWp): Nominal power 100000 kWp**

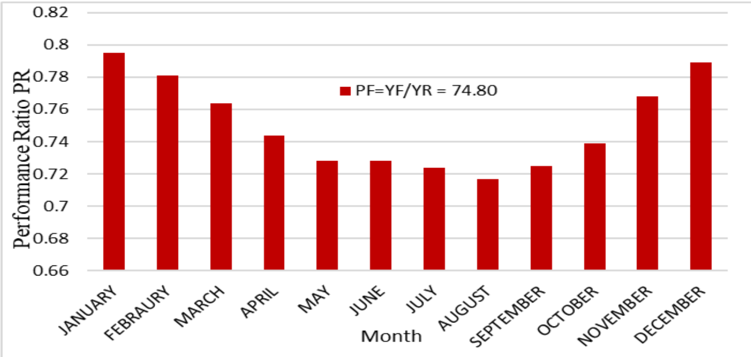



**Fig.9. Performance ratio (percentage) monthly**

**TABLE 2. NORMALIZED PERFORMANCE COEFFICIENTS**

| | $Y_R$ kWh/m²/day | $L_C$ | $Y_A$ kWh/m²/day | $L_S$ | $Y_F$ kWh/m²/day | Lcr | Lsr | PR |
|---|---|---|---|---|---|---|---|---|
| January | 4.98 | 0.882 | 4.10 | 0.141 | 3.96 | 0.177 | 0.028 | 0.795 |
| February | 5.68 | 1.084 | 4.59 | 0.156 | 4.44 | 0.191 | 0.027 | 0.781 |
| March | 5.83 | 1.219 | 4.61 | 0.155 | 4.45 | 0.209 | 0.027 | 0.764 |
| April | 6.38 | 1.462 | 4.92 | 0.168 | 4.75 | 0.229 | 0.026 | 0.744 |
| May | 6.47 | 1.594 | 4.87 | 0.167 | 4.71 | 0.247 | 0.026 | 0.728 |
| June | 6.29 | 1.550 | 4.74 | 0.162 | 4.58 | 0.246 | 0.026 | 0.728 |
| July | 5.90 | 1.479 | 4.42 | 0.150 | 4.27 | 0.251 | 0.026 | 0.724 |
| August | 6.15 | 1.588 | 4.57 | 0.156 | 4.41 | 0.258 | 0.025 | 0.717 |
| September | 6.31 | 1.572 | 4.74 | 0.161 | 4.58 | 0.249 | 0.026 | 0.725 |
| October | 6.21 | 1.463 | 4.75 | 0.161 | 4.59 | 0.235 | 0.026 | 0.739 |
| November | 5.80 | 1.193 | 4.61 | 0.153 | 4.45 | 0.206 | 0.026 | 0.768 |
| December | 4.87 | 0.892 | 3.97 | 0.134 | 3.84 | 0.183 | 0.028 | 0.789 |
| Year | 5.90 | 1.332 | 4.57 | 4.57 | 4.42 | 0.226 | 0.026 | 0.748 |

### V.3. Performance Ratio

The annual average performance ratio obtained from the simulation is 74.80% shown in Table 2. The monthly values shown in Figure 9 and tabulated in Table 3. Performance ratio has a maximum value of 79.5% during January and minimum of 71.7% in August.

### V.4. Incidence energy in collector plane

The annual average reference incident energy for the system $Y_R$ is 5.904 kWh/m$^2$/day as shown in Figure 10. The maximum Reference incident energy is 6.47kWh/m$^2$/day during the month of May and the minimum value is 4.87kWh/m$^2$/day during December as shown from Table 2.

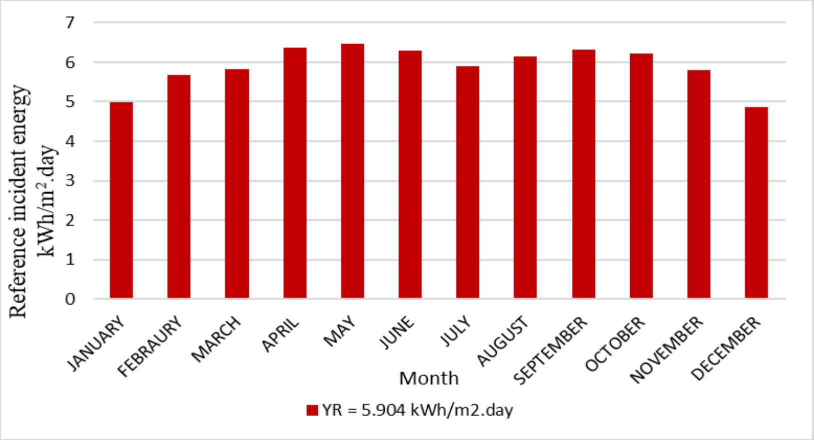



**Fig.10. Reference incident energy monthly**

### V.5. Meteo and incident energy

Ambient temperature and average wind velocity variations plotted against the various stages of Global irradiation is shown in Figure.11. Table 3 shows that the ambient temperature $^0$C increases from January to July with respect to wind velocity m/s and thereafter decreases from August to December simultaneously. The global horizontal irradiance kWh/m$^2$ increases from January to May and then decreases from June to December. The highest value of global horizontal irradiance recorded as 222.7 kWh/m$^2$ during May and lowest value of 109.3 kWh/m$^2$ in December. The ambient temperature $^0$C is highest in August with a value of 35.77 $^0$C and in January it is lowest at 18.96 $^0$C. The wind velocity recorded as 4.0 m/s highest in March and lowest as 3.2m/s in December. The annual comparative analysis of solar PV and PTC plant shown in Table.4.

**TABLE.3 METEO AND INCIDENT ENERGY**

| | GlobHor kWh/m² | DiffHor kWh/m² | T_Amb °C | WindVel m/s | GlobInc kWh/m² | DifSInc kWh/m² | Alb_Inc kWh/m² |
|---|---|---|---|---|---|---|---|
| **January** | 115.9 | 50.10 | 18.96 | 3.5 | 154.5 | 57.23 | 1.551 |
| **February** | 129.1 | 56.14 | 20.66 | 3.9 | 158.9 | 62.76 | 1.729 |
| **March** | 163.6 | 73.39 | 23.75 | 4.0 | 180.7 | 76.85 | 2.189 |
| **April** | 192.7 | 75.86 | 27.54 | 3.9 | 191.4 | 75.71 | 2.580 |
| **May** | 222.7 | 82.11 | 32.07 | 3.9 | 200.5 | 77.62 | 2.983 |
| **June** | 219.2 | 83.81 | 33.09 | 3.8 | 188.7 | 77.02 | 2.917 |
| **July** | 206.8 | 96.82 | 35.27 | 4.0 | 182.8 | 89.29 | 2.753 |
| **August** | 199.4 | 90.95 | 35.77 | 4.0 | 190.8 | 88.00 | 2.668 |
| **September** | 178.2 | 68.80 | 32.69 | 3.6 | 189.3 | 71.30 | 2.386 |
| **October** | 160.4 | 57.75 | 29.66 | 3.3 | 192.7 | 64.75 | 2.146 |
| **November** | 129.4 | 45.37 | 24.95 | 3.2 | 173.9 | 53.83 | 1.731 |
| **December** | 109.3 | 46.88 | 21.03 | 3.2 | 150.9 | 55.03 | 1.462 |
| Year | 2026.7 | 827.98 | 27.99 | 3.7 | 2155.0 | 849.40 | 27.095 |

**TABLE.4 ANNUAL COMPARATIVE PARAMETER ANALYSIS OF SOLAR PV AND PTC PLANTS**

| | GlobHor kWh/m$^2$/day | Diff Hor kWh/m$^2$/day | DNI kWh/m$^2$/day | T_Amb $^0$C | E_Grid kWh | LCOE |
|---|---|---|---|---|---|---|
| Solar PV | 6.41 | 6.63 | 1.98 | 27.99 | 161197556 | $0.04404/kWh |
| PTC | 6.41 | 6.63 | 1.98 | 27.99 | 157151520 | $0.01533/kWh |

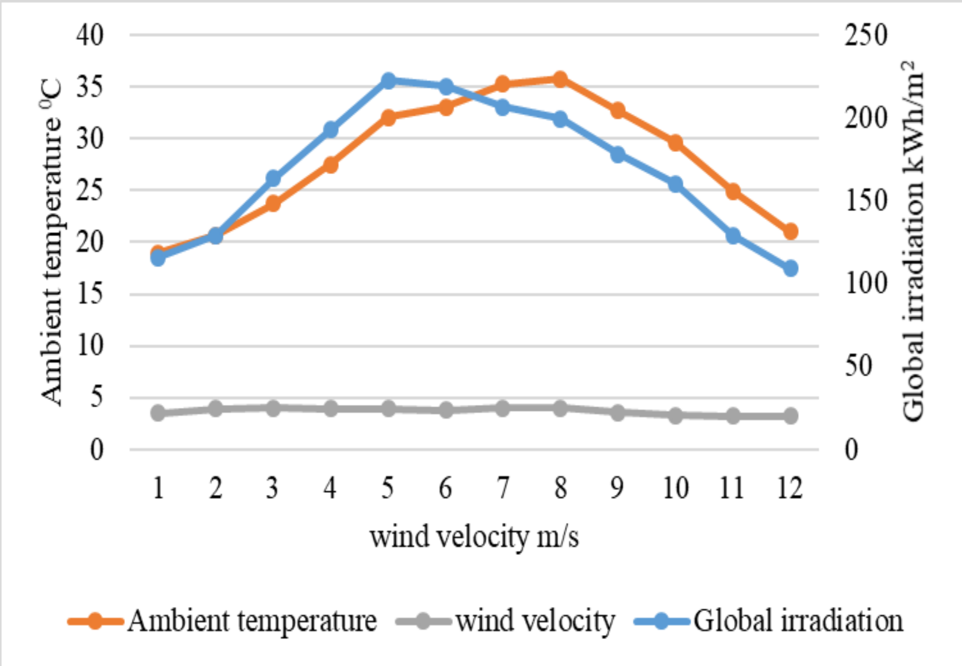



**Fig.11. Ambient temperature, wind velocity, and Global irradiation**

**V.6 Results generated from PVSYST simulation with arrow losses diagram**

The geographical coordinates (24.43$^0$ N 54.65$^0$ E) for 100MW PV system is located at Abu Dhabi (UAE). The average height of the horizon is 5.8$^0$ with PV field orientation tilt of 30$^0$ and Azimuth 0$^0$. The total nominal power of 100MW PV array consists of 909090 modules with 18316 inverter pack. The path of the sun for this region as shown in Figure. 12

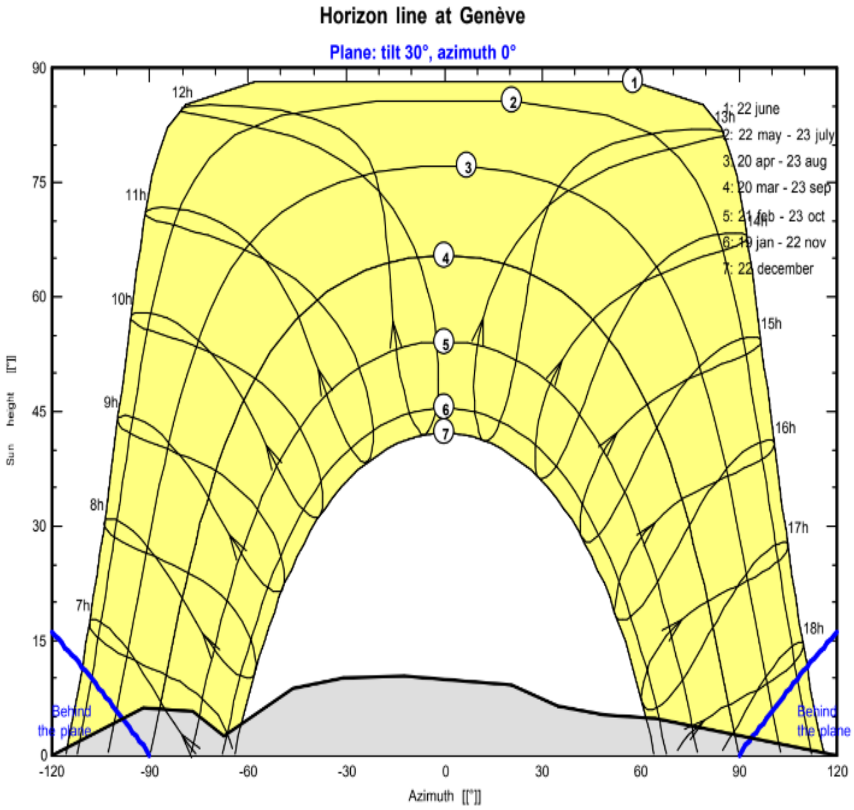
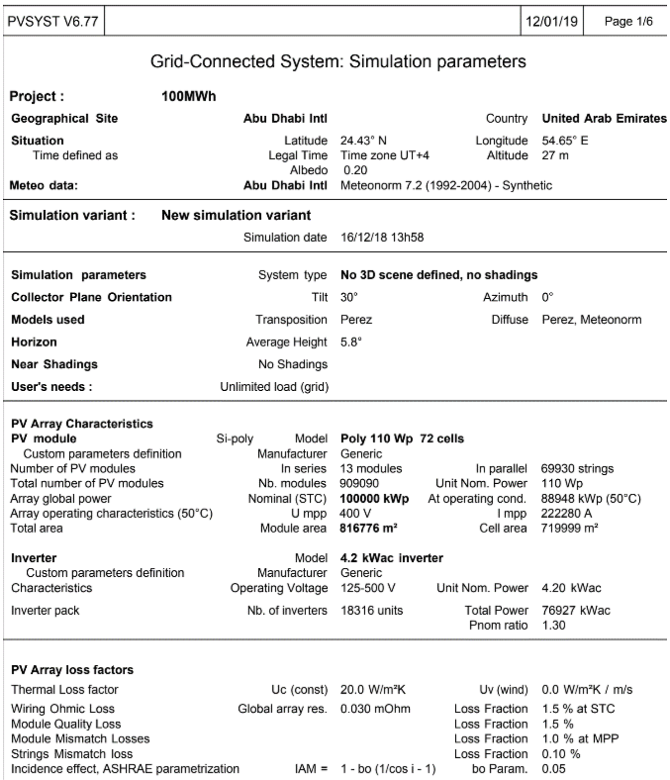



**Fig.12. Path of the sun over a year in Abu Dhabi**



| | | | | |
|---|---|---|---|---|
| PVSYST V6.77 | | | 12/01/19 | Page 1/6 |

**Grid-Connected System: Simulation parameters**

| | | | | |
|---|---|---|---|---|
| **Project :** | **100MWh** | | | |
| **Geographical Site** | | **Abu Dhabi Intl** | Country | **United Arab Emirates** |
| **Situation** | Latitude | 24.43° N | Longitude | 54.65° E |
| Time defined as | Legal Time | Time zone UT+4 | Altitude | 27 m |
| | Albedo | 0.20 | | |
| **Meteo data:** | **Abu Dhabi Intl** | Meteonorm 7.2 (1992-2004) - Synthetic | | |
| **Simulation variant :** | **New simulation variant** | | | |
| | Simulation date | 16/12/18 13h58 | | |
| **Simulation parameters** | System type | **No 3D scene defined, no shadings** | | |
| **Collector Plane Orientation** | Tilt | 30° | Azimuth | 0° |
| **Models used** | Transposition | Perez | Diffuse | Perez, Meteonorm |
| **Horizon** | Average Height | 5.8° | | |
| **Near Shadings** | No Shadings | | | |
| **User's needs :** | Unlimited load (grid) | | | |
| **PV Array Characteristics** | | | | |
| **PV module** Si-poly | Model | **Poly 110 Wp 72 cells** | | |
| Custom parameters definition | Manufacturer | Generic | | |
| Number of PV modules | In series | 13 modules | In parallel | 69930 strings |
| Total number of PV modules | Nb. modules | 909090 | Unit Nom. Power | 110 Wp |
| Array global power | Nominal (STC) | **100000 kWp** | At operating cond. | 88948 kWp (50°C) |
| Array operating characteristics (50°C) | U mpp | 400 V | I mpp | 222280 A |
| Total area | Module area | **816776 m²** | Cell area | 719999 m² |
| **Inverter** | Model | **4.2 kWac inverter** | | |
| Custom parameters definition | Manufacturer | Generic | | |
| Characteristics | Operating Voltage | 125-500 V | Unit Nom. Power | 4.20 kWac |
| Inverter pack | Nb. of inverters | 18316 units | Total Power | 76927 kWac |
| | | | Pnom ratio | 1.30 |
| **PV Array loss factors** | | | | |
| Thermal Loss factor | Uc (const) | 20.0 W/m²K | Uv (wind) | 0.0 W/m²K / m/s |
| Wiring Ohmic Loss | Global array res. | 0.030 mOhm | Loss Fraction | 1.5 % at STC |
| Module Quality Loss | | | Loss Fraction | 1.5 % |
| Module Mismatch Losses | | | Loss Fraction | 1.0 % at MPP |
| Strings Mismatch loss | | | Loss Fraction | 0.10 % |
| Incidence effect, ASHRAE parametrization | IAM = | 1 - bo (1/cos i - 1) | bo Param. | 0.05 |

**Fig.13. Simulation parameters for 100MW project**

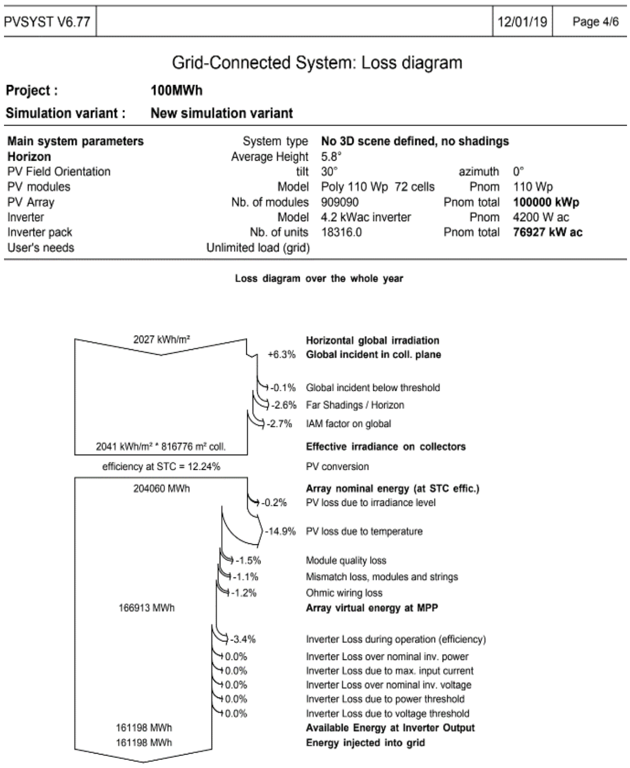



**Fig.14. Losses diagram over the whole year**

Grid-connected PV system unable to generate 100% energy delivered from the sun due to certain losses. Figure.14 shows the losses diagram over the whole year for Abu Dhabi region. A collector plane received about 2027 kWh/m$^2$ of horizontal global irradiation; therefore, the losses in energy are 5.4%. After the PV conversion from PV cell to electrical energy, the array nominal energy is 204060 MWh and available energy at inverter output on annual basis is 161198 MWh, which also injected into the grid. The efficiency at STC is 12.24%. Array virtual energy at MPP obtained is 166913 MWh due to PV loss, mismatch loss and ohmic wiring losses. The inverter losses during the operation are 3.4%.

## V. CONCLUSION

In this paper, PVSYST and SAM software used to design analysis for the dimension and optimization to decide the optimal size and its specifications of a 100MW PV grid connected system at Abu Dhabi (UAE) region. The design of the PV model is a truly an effective way to coordinate emission of greenhouse gases go into the atmosphere and electricity production to protect the environment. The analysis and simulation results were calculate to verify the design and arrangements of the system. Simulation result shows the annual plant's electricity generation recorded as 161198MWh/year for Solar PV and 157152MWh/year for PTC; the performance ratio (PR) is 74.8% per year. The generating station designed to operate with a PV field orientation tilt 30$^0$ and azimuth 0$^0$ is considered. The yearly global horizontal irradiation measured at this location is 2026.7 kWh/m$^2$. The average ambient temperature found to be 27.99 ◦C, with rainfall mainly occurring during winter months. The LCOE as $0.04404/kwh for Solar PV and $0.01533/kwh for PTC calculated for the designed project with a lifetime of 25 years. The global incidence in collector plane on annual basis is 2155 kWh/m$^2$. The horizontal diffuse irradiation on annual basis is 827.98kWh/m$^2$. The effective global irradiance for array incidence loss not shading is 2041.1kWh/m$^2$ and effective energy for the output array is 166863 MWh. The average wind velocity monitored as 3.9m/s. The shading on PV modules be avoided otherwise; shading will reduce the output PV modules. PV installing should be away from long trees, towers, flatirons and buildings.

By installing a solar power system, there will be a difference in an electric bill. From the analysis of the proposed utility scale 100MW system in Abu Dhabi region, it is observed that investing in a PV system is a smart sensible choice that not only reaps economic benefits but also ensure clean and sustainable energy future.

**Nomenclature**

| | |
|---|---|
| AC | Alternating Current |
| CUF | Capacity Utilization Factor |
| DC | Direct Current |
| $E_{DC}$ | DC output energy of the PV system in kWh |
| EArray | Effective Energy for the output array in MWh |
| $E_{AC}$ | AC output energy of the PV system in kWh |
| EffSysR | System Efficiency in percentage |
| EffArrR | Array Efficiency in percentage |
| E_Grid | Injected Energy into the grid in MWh |
| GlobHor | Global horizontal irradiation in kWh/ $m^2$ |
| $G_o$ | Reference irradiance of PV in kWh/ $m^2$/day |
| GlobInc | The global incident in collector plane |
| GlobEff | Global effective correction, for IAM and shadings in kWh/ $m^2$ |
| GCPVS | Grid-connected photovoltaic system |
| $H_t$ | Absolute irradiance in-plane in kWh/ $m^2$/day |
| $I_{DC}$ | DC output current of the PV system in amps |
| IEA | International Energy Agency |
| IEC | International Electrotechnical Commission |
| I AM | Incidence angle modifier |
| $L_S$ | System losses in kWh/kWp/day |
| $L_C$ | Capture losses in kWh/kWp/day |
| LCOE | levelized cost of electricity |
| PTC | Parabolic trough collector |
| $P_o$ | Minimal solar power in kWp |
| $P_{E, STC}$ | The extreme power of the installed PV array at STC of 1KW/$m^2$ |
| $P_{AC}$ | Generated AC power |
| $P_{DC}$ | Generated DC power |
| PV | Photovoltaic |
| PR | Performance ratio in percentage |
| RE | Renewable energy |
| STC | standard testing condition, 1000 W/$m^2$, 25$^0$C, A.M =1.5 |
| SPP | solar power plant |
| Si-Poly | silicon poly-crystalline |
| T Amb | The ambient temperature in °C |
| $V_{DC}$ | the output voltage at DC of the PV system in volts |
| $Y_A$ | Array yield |
| $Y_R$ | Reference yield |
| $Y_F$ | Final System yield |
| $\eta_{Inv}$ | Inverter efficiency |
| $\eta_{sys}$ | System efficiency |
| $\eta_{pv}$ | PV module efficiency |

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