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Design and Development of Grid-Connected Solar PV Power Plant Using PVsyst

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Abstract:

As we know, the biggest problem that threatens today's world is climate change and global warming. Alongside that, Afghanistan does not have a reliable source of power, and people who live in cities do not have full access to electricity. So, we need immediate access to electricity. Therefore, among all other renewable sources, the only one that is feasible in the target area and could solve this problem soon is investing in a solar PV power plant. This study aims to develop a standard procedure for the design of grid-connected solar PV systems using PVsyst software. The project began with a broad database of meteorological data, including global daily horizontal solar irradiance, and also a database of various renewable energy system components from different manufacturers. This paper will explain the grid solar power limited in the year 2023. The photovoltaic power plant has a solar radiation of 6.22 KWh/Sq./day, covering 162.66 acres of land. The operating module temperature varies from -40°C to 85°C, with a tilt angle of 32 degrees. The various power losses (PV losses due to irradiation level, temperature, soiling, inverter, wiring, power electronics, grid availability, and interconnection) amount to 2006 KWh/m2, with a total production of 60513314 KVAh/year, and the performance ratio is calculated from simulation, giving an annual PR of 75.16%.

Keywords: Design, Development, PVsyst, Grid connected, Solar PV power plant.

1. Introduction:

According to the US Energy Information Administration, there is a projected 56% increase in global energy demand between 2010 and 2040, primarily driven by the rapid economic growth in Asia (Cronshaw, 2015). Since prehistoric times, man has attempted to capture sun energy for lighting, cooking, energy, and military requirements. The design of sun devices to concentrate solar energy on enemy cults has been attempted since antiquity by the ancient Greeks, Egyptians, and subsequently Muslims (Abas et al., 2018). The life and energy cycles on earth are propelled by energy drifts that are enabled by solar radiations. The sun, which is 93 million kilometers from Earth, produces energy by a massive thermonuclear fusion event. The photosphere and core of the sun have temperatures between 5500 °C and 20,000,000 °C. Each second, the sun's core converts around 657 million tons of hydrogen isotopes into 653 million tons of helium (Abas et al., 2019).In a solar power plant that is connected to the grid, the solar panels generate DC power, which is then converted into AC power and provided to the grid for distribution and use. Since solar radiation is at its strongest during the day, it may be possible to get the most electricity possible from the PV system (Caldera et al., 2021),

(Rahman et al., 2021). The depletion of conventional energy resources is running at no time these days. Beside that, Carbon dioxide (CO2), one of the three major greenhouse gases, has increased in atmospheric concentration since pre-industrial times, and scientific evidence confirms its direct association with climate change (Lin & Jia, 2020). Furthermore, the cost of energy is rising, so, for this purpose solar energy is inexhaustible source that, is abundant, pollution free, distributed throughout the earth and recyclable. In addition, It is crucial to refer to up-to-date reports and reliable sources for the latest information on global energy demand trends.It is important to acknowledge that highly developed countries are actively striving to transition to cleaner energy sources and may have different energy objectives compared to regions experiencing rapid economic growth (Dellosa et al., 2021). Afghanistan has a very good state for the development of solar power plant particularly its south regions and mainly to the high mean daily. It has more than 300 sunny days, the target power plant is going to be installed at one of the `southern province of Afghanistan, Kandahar city and the surveyed place is located at Aino-Mina town of Kandahar city. At the moment Kandahar city, receives its energy from Kajaki dam from Helmand province and faces with many shortages even during the summer season. So, this project would fulfill the current and future demands of energy of this town based on its master.

The hindrance factor is low conversion efficiency and high installation cost. Combination of series and parallel of solar modules made arrays, but the amount of energy which is going to be produced by the solar panels depend on weather-condition or simply atmospheric conditions for instance (temperature, and solar irradiation).

2. Materials and Method

This particular study aimed to determine the optimal configuration of a grid-connected solar PV plant for the utility electric distribution cooperative situated in Kandahar, Afghanistan. Solar power is accessible universally; however, in order to maximize the efficiency of a solar panel or array, it is crucial to align or "orient" it precisely towards the radiant energy of the sun. This is because increased surface area exposed to direct sunlight leads to higher output from the photovoltaic panel (Hay, 2016). The designated land area for this PV farm is at least 162.66 Acres and includes all necessary components. The simulation process exclusively relied on PVsyst software, which is widely utilized by professionals for reliable analysis and simulation of solar PV installations (Rout & Kulkarni, 2020), (Saraswat, 2016), (Satish et al., 2020), (ur Rehman et al., 2020), (Siregar & Hutahuruk, 2020), (Soualmia & Chenni, 2016), (Hamouche & Shabat, 2019).In here the overall objective in designing a solar power plant through providing land is to use land by solar at most and maximum level, in order to produce more and be cost effectively. To offer it somehow cheap we have to know how much space do we have and find out the available data regarding solar energy in the target place and the size of the power plant with the specifications of the system and components that is used in the power plant, also its evaluation criteria, and design optimization.

System Design

For designing the system, we already select one of the well-known software that has used in most of the academic publication and with the most reliable data’s that is PVsyst, version of 7.3.1, (Gao et al., 2016), (Pawluk et al., 2019), (Banik & Sengupta, 2021), (Muthulingam et al., 2015), (Loganathan et al., 2014), (Daneels & Salter, 1999). Also, the components which are used in a power plant is simply classified into two broad categories, 1) Major components, and 2) Minor components and figure 1, indicates a full view of a PV power plant that includes all the components.

Major Components

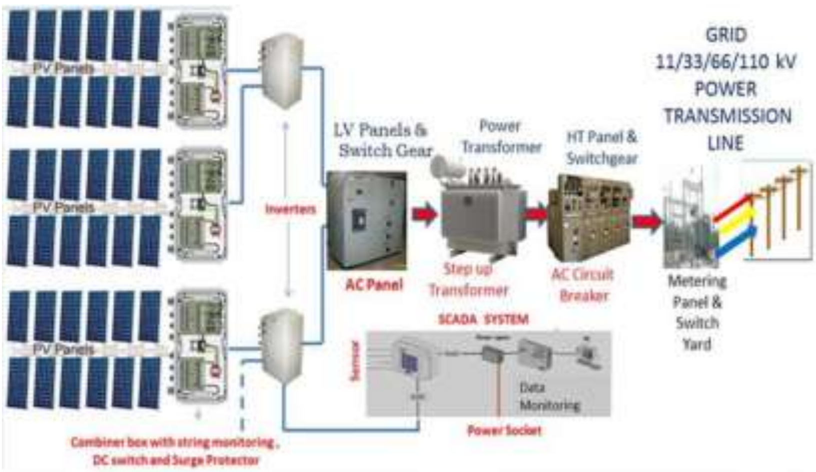
1. Solar PV Model
2. Grid tie inverter
3. Grid system

Solar PV modules are the technologies that convert solar energy into useful energy directly and a grid tie inverter is an inverter which gives and can receive electrical energy from the grid or national utility and a grid system is a system is a system that produced energy is given to the national utility.

Minor Components

1. Dc array junction Box
2. Control room
3. Cables
4. Earthling
5. SCADA (supervisory control and data acquisition system)
6. Water facilities
7. Fencing system and Road inside the plant
8. Mounting structures

9. **Fig-1: schematic diagram of a solar power plant**



Minor components are the small or supportive components that is used in a power plant and a DC array junction box combines all the output wires from modules and in return give us two wires and is used to reduce the amount of output wires to make it suitable for inverter input and a control room is a place where the whole power plant is controlled technology and human resource facilities. Also, cables are used to combine and transmit produced energy from various arrays and to give it to the grid.

Moreover, earthing is used for safety and control of the system from lightening, SCADA is a software for distance control of the system (Piyatadsananon, 2016). Water facilities, fencing and mounting structures are used for cleaning, saving solar park for irresponsible people and animals interventions and mounting structures to keep the panels the panels with the required tilt angle. Furthermore, we need to understand the sunshine hours that is usable, the cloudy and days with no sunshine and all meteorological data (wind power, temperature, sunshine hours, natural disaster and so on). The location that is not to be near to high rise buildings and agricultural field along with the present and future demand should be considered, also the system performance, total cost and system protection and easy maintenance are all the factors that is need to be considered while designing (Pawluk et al., 2019).

DC Side PV Plant

This side includes the PV modules that is used in power plant and modules are used in series and parallel and while connecting modules in series the voltage of the array is increasing with the constant current of a panel in an array and the total should be greater than inverter minimum, (MPP) maximum power point voltage but total open circuit voltage at minimum Module tem should be smaller than inverter Max voltage , while in parallel connection the total current is increasing with the constant voltage of a panel in an array. Moreover, Max current shall not be more than Inverter Max Input current and number of Array combiner boxes – with or without string monitoring based on number of inputs selected for each box, also main junction boxes should be equal to the number of inverter inputs.

AC Side PV Plant Design

AC side cables are required for commissioning and connecting ac components with regards, and switchgear is used for control, protect and distribute the power within the plant and with the grid that LT or low voltage usually operates between 415V to 1000Volts and MV operates 1000Volts to 33KV also power transformer is used to increase the voltage up to the grid voltage. Moreover, high tension switchgear is used for power transition and distribution and operates between 33KV and hundreds KVs, with electronic protecting equipment’s and metering system and transmission lines are used to transmit the produced energy to the consumers.

3. Technical and Site Data

3.1 Site Location

The selected area is located at Aino-Mina, Kandahar city of Kandahar province, with a Latitude 31.65° N and longitude 65.77° E, 162.66 Acre land is specified at a distance of almost 15km from the city of Kandahar Province. And on the selected area no wild life and archeological monuments are in danger. And the site is well save and well connected to the sub road.

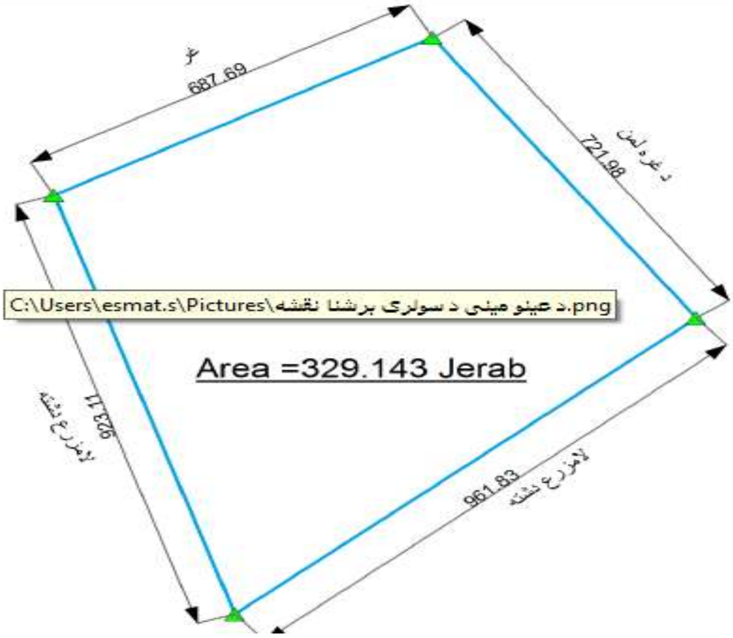
Here are some other aspects of selected area:

1. Wild animals: No wildlife is reported to be present in this area.
2. Health risk: No health hazards are caused by solar plant. In fact, the solar plant is environment friendly.
3. Archaeological and Historical places: There are no archaeological monuments or historical places in this area.

Figure-2 shows the province that the power plant is going to be installed and Figure-3 shows the specific area and land which is going to be used for Solar PV power plant.

Figure-2: Kandahar Province, Afghanistan

Figure 3: selected site



The site is located far away from high rise buildings and agricultural fields and has a polygonal shape which two sides of the site is in touch with hill and mountain with a length of 721.98 meter and 687.69meters respectively, and two other sides of the site are locked by non-agricultural fields with lengths of 961.83meter and 923. 11meters.The detailed estimate and properties are along hereby.

3.2 Solar PV selection

Solar PV Technology converts sun’s natural energy to useful electrical energy. Photo Voltaic modules are made of mono crystalline / polycrystalline solar cells connected in series and parallel modes. Type of solar panel used in this project is poly crystalline.

Mono crystalline solar panels are the most efficient type of solar panels but are also the most expensive. Their performance, somewhat is better in low light conditions. We have selected Trina Company and poly crystalline because the weather is hot in the selected area and mono is not efficient in hot sites and the overall efficiency of the selected PV module is about 15.29% with a warranty of about 25 years which is shown in Table-1.

Fig-3: Poly crystalline Solar Panels

Table-1: solar panel specification

PV module	
Manufacturer	Trina Solar
Model	TSM-300PEG14
(Original PVsyst database)	
Unit Nom. Power	300 Wp
Number of PV modules	116592 units
Nominal (STC)	34.98 MWp
Modules	4164 Strings x 28 In series
At operating cond. (50°C)	
Pmpp	31.37 MWp
U mpp	912 V
I mpp	34384 A
Total PV power	
Nominal (STC)	34978 kWp
Total	116592 modules
Module area	228774 m²
Cell area	204325 m²

Table-1 show us the specification of the selected with panel for the power plant, which this module is manufactured by the Trina Solar and it has a total of 300wp nominal power and operated between -40 and 85 degrees of Celsius and its maximum system voltage is 1000volt, so that more modules are easy to be connected in series. In the power plant a total of 116592 PV modules will be used and with a nominal power of 34.98Mwp. Furthermore we have 4164 strings and 28 in series which covers a total of 228774 square meter area.

3.3 Inverters Selection

Inverters are devices which convert DC current into AC current and there are various types of inverters off-grid and hybrid or on-grid inverters. Off-grid inverters are used for low and local systems like residential systems and up to watts and few Kws.

But hybrid is used for utilizing from two sources like solar & grid or solar and battery with/without grid, while on-grid inverters are used in places where all are huge portion of produced energy is given to consumers. Here we have selected on-grid inverter of German company by the name of SMA with a capacity of 2.5MW each that operates in MPPT mode and overall 12 inverters are selected in this plant, so, figure-4 shows the selected inverter and table-2 shows its specifications.

Fig-4: Sunny Central 2500-EV inverter

Table-2: inverter specification

KVA rating	**2500KVA**
Input DC voltage	1500V
Input DC current	3200A
Output AC voltage	550V
No. phases	3
Type	GEC
Efficiency	Approximately 95-97%
No of inverters	12

The table indicates the rating capacity of the selected inverter that is 2500KVA and it has input DC voltage and current of 1500V and 3200A respectively. Its output is AC with a voltage of 550V, 3-phase and efficiency of 95-97%.

3.4 Combiner Box Selection

There are wires which are coming from panels or strings and PV modules are pre-wired almost with connectors and its junction box/combiner box that collect together wires and gave us two wires in a conduit.

And this box usually contains some safety materials like, fuse or breaker for each string and a surge protector the selected junction box is shown in figure-5 and its specifications in Table-3.

Fig-5: junction box

Table-3: specification of selected junction box

Model	**GPRO-GD10X**
Maximum DC Input Range	1500V
No of DC Inputs	1 - 52
Maximum Input Fuse* Rating, A	6/10/12/15/20/30
Maximum string current per fuse holder with all string fuse**	Reduction factor 0.55
Conductor Size	4 – 10 Sq.mm
No of DC Outputs	1
Maximum DC Current, A	Unto 630A
Isolator/MCB*, A	100/250/315/400/500/630
Surge Protection Device (SPD)*	1500V DC, Class C/Class B/ Class B+C
Operating Temperature	-25 to 55
Enclosure Type	Transparent Top Cover
Protection Type/Protection Class	IP65/65
Connectors* @ Output	MC4/MC3
Cable gland clamping range, mm	17-50mm

Wall mounting	Yes
Bus Bar*	Yes
Operating conditions	Temp : -20 to +55 Deg. C ; RH : 0 – 95% non Cond
Type of Protections(As per Clients requirement)	Short-Circuit, Surge
International standards followed	IEC 60364
Disconnection switch	Optional
Design Life	25years+

The above table shows all the required specifications of selected junction box, it can handle up to 1500V as an input voltage and up to 52 input wires are can be used. Also, maximum current of 630A and input cable size of 4-10 square mm with -20 to 55 degrees of Celsius operating temperature. And it has been designed for more than 25 years which is well selection for our power plant.

3.4.1 Selection of Junction Box/Combiner Box

At first it's a need that string's voltages be verified and for this purpose we need to find out V_{oc} and V_{max} of each string, in the following equations Voc indicates open circuit voltage and Vmax shows maximum voltage of each module respectively, also N refers to number of modules in a string.

i. One string Voc= N*Voc/module= 27*45.9= 1239v
ii. One string Vm=N*$V_{m/module}$= 37.2*27=1004 v

By considering the safety and Voc of strings we select a combiner box which its input voltage be 1500V and input current of 630A and we have a total of 104 wires which includes positive and negative wires that comes from a string to a junction box, $I\ max/jb$ shows the maximum current that we give to our junction boxes and $I\ sc/module$ indicates the short circuit current of each module.

iii. No- connected string in one junction box= $\frac{I\ max/jb}{I\ sc/module}$

No- connected string in one junction box= $\frac{463\ A}{9.07A} = 51\ strings\ in\ parallal\ in\ one\ junction\ box$

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iv. string needed for 1 inverter = $\frac{Total\ no\ of\ string}{Total\ no\ of\ inveter} = \frac{4164}{12}\ 347$

v. No of JB needed for one inverter=$\frac{No-string\ in\ one\ inverter}{No\ of\ string\ in\ one\ JB} = \frac{347}{51} = 7JB$

vi. Total no of junction boxes needed for the project= No of junction boxes × No of inverters = 7×12= 84 Junction Boxes.

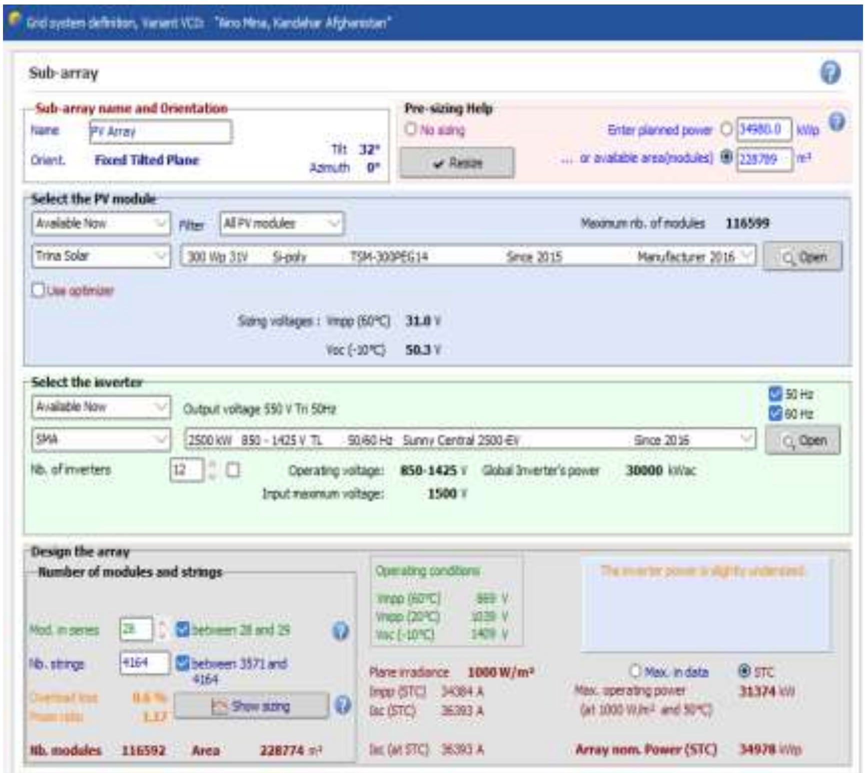
As far, as inverters are having just two lines as inputs, so we are in need of selecting a combiner box for each 7-junction boxes.

Design Based on Software

Pvsyst software which is a reliable software has been chosen for design of the system and we are providing to the software the land that is exclude of extra spaces for internal roads, safety towers of the plant, distances between the rows and

Control room and this is a need for testing and commission of the system to have a preliminary data of feasible power generation. The system and plant performance along with the efficiency of the selected components are calculated based on the given data to the software and we design the system based on the described and in hand data of all the components.

Fig-7: system Design



4. Results and Discussion

Table Monthly Mateo values

Geographical Site
Kandahār
Afghanistan

Situation

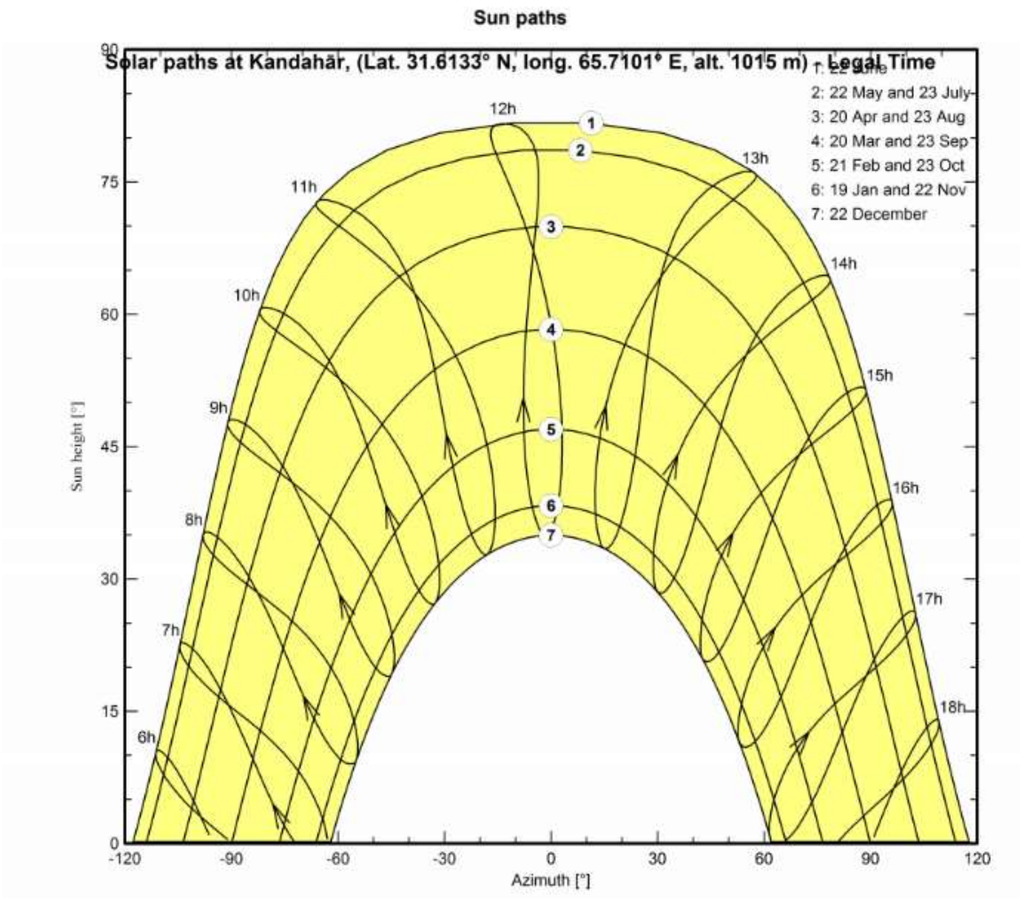
Latitude	31.61 °N
Longitude	65.71 °E
Altitude	1015 m
Time zone	UTC+4.5

Monthly Meteo Values

Source NASA-SSE satellite data 1983-2005

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Year	
Horizontal global	112.5	128.2	167.1	186.9	214.5	217.8	212.4	202.7	180.3	162.1	118.8	102.6	2005.9	kWh/m²
Horizontal diffuse	27.3	29.7	45.9	55.5	62.9	62.4	66.0	58.0	44.1	31.3	26.7	25.7	535.5	kWh/m²
Extraterrestrial	179.4	200.5	269.9	306.0	344.5	343.6	349.9	327.9	278.9	238.7	184.8	166.8	3190.9	kWh/m²
Clearness Index	0.627	0.639	0.619	0.611	0.623	0.634	0.607	0.618	0.646	0.679	0.643	0.615	0.629	ratio
Ambient Temper.	6.1	8.4	13.9	20.8	26.2	30.3	30.6	29.2	25.9	19.4	13.7	8.5	19.4	°C

Chart-1: Solar Paths at Kandahar



(Lat. 31.61° N Long. 65.71° E Alti.1015m)

All the features which is given are based on the geographical location of the plant and metrological data of the target place, panels orientation, shading information, array configuration, loss parameters and etc.

4.1. Main Results of Simulation

The system is designed with fixed angle and its proposed production will be 67339MWh/year. Specific production: Nominal power of the array is divided by the produced energy (P_{nom} at STC). By considering irradiance conditions for instance orientation, site location, meteorological conditions that could indicate potential of the system. So, specific production is equal to 1738Kwh/Kwp/year and with a 75.16% performance ratio. Some values are listed in Table-3 as below yearly like temperature as an average and a total of irradiation or energies.

Table-3: Main results

Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_User kWh	E_Solar kWh	E_Grid kWh	EFrGrid kWh
January	112.5	27.28	6.09	176.6	168.2	5208773	669600	257978	4848137	411622
February	128.2	29.68	8.37	178.9	170.4	5198012	604800	265448	4829466	339352
March	167.1	45.88	13.86	200.3	190.1	5637059	669600	309594	5217526	360006
April	186.9	55.50	20.80	193.6	182.9	5235549	648000	322671	4812275	325329
May	214.5	62.93	26.22	199.3	187.4	5231829	669600	315200	4356427	354400
June	217.8	62.40	30.27	192.4	180.7	4960738	648000	346938	4519124	301062
July	212.3	66.03	30.63	192.1	180.6	4967372	669600	325232	4143852	344368
August	202.7	57.97	29.16	201.1	189.8	5242572	669600	337202	4806839	332398
September	180.3	44.10	25.86	204.0	193.1	5367067	648000	299254	4648390	348746
October	162.1	31.31	19.39	214.3	203.9	5817967	669600	289769	5416182	379831
November	118.8	26.70	13.72	181.2	172.2	5132943	648000	269050	4764852	378950
December	102.6	25.73	8.50	168.0	159.7	4908611	669600	269210	4542697	400390
Year	2006.0	535.51	19.46	2301.8	2179.0	62908494	7884000	3607547	56905767	4276453

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_User	Energy supplied to the user
T_Amb	Ambient Temperature	E_Solar	Energy from the sun
GlobInc	Global incident in coll. plane	E_Grid	Energy injected into grid
GlobEff	Effective Global, corr. for IAM and shadings	EFrGrid	Energy from the grid

The above table shows yearly and average datas of global horizontal radiation, horizontal diffuse radiation, energy that comes from the sun and energy injected to the grid and from the table we can understand that energy injected to the grid is highest in October that is5416182 Kwh and the lowest energy given to grid is 257978 Kwh.

Table-6: Main results

System Production			
Produced Energy	60513314 kVAh/year	Specific production	1730 kWh/kWp/year
Used Energy	7884000 kVAh/year	Performance Ratio PR	75.16 %
Apparent energy	58272913 kVAh/year	Solar Fraction SF	45.76 %

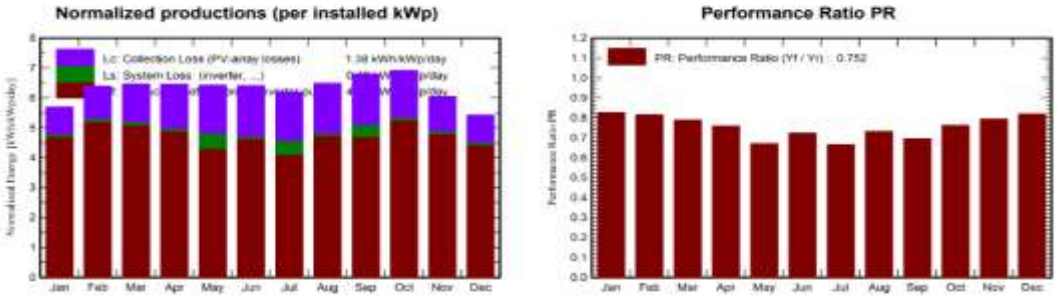
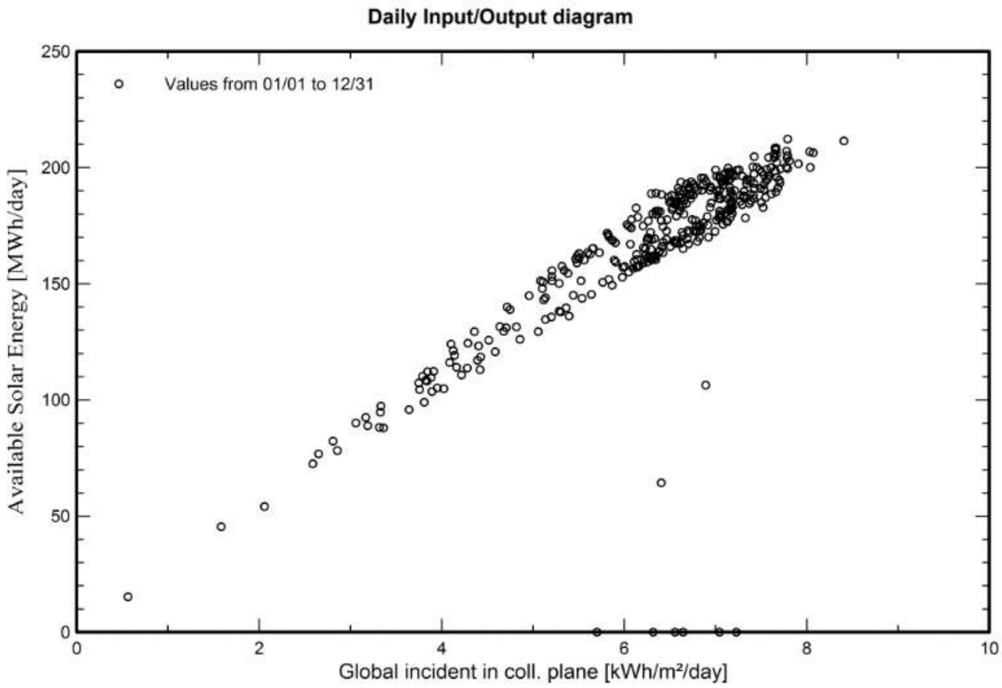


Chart-1: Production per installed kwp: Nominal power with Performance Ratio

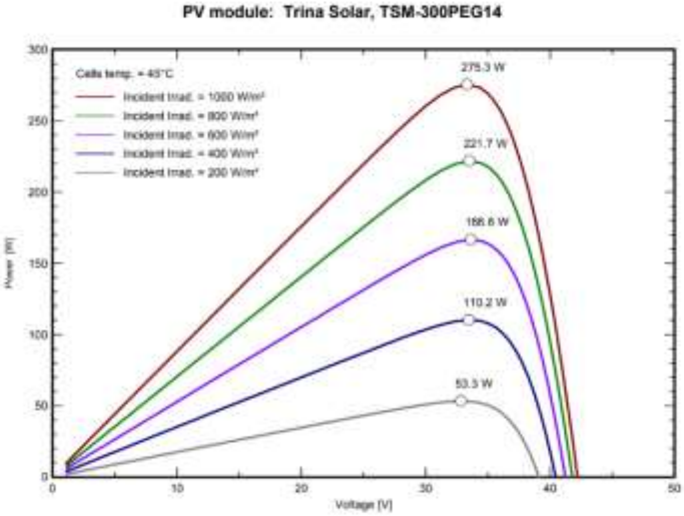
The above table clearly shows us the resulted energy over a year that is produced by the power plant and explains that 60513314KVAh/year is its produced energy and 7884000KVAh/year is its used energy and a total of 58272913KVAh/year is its apparent energy. Furthermore, it indicates the performance ratio of the power plant over a year which is 75.16%.

Chart-2: Daily System Output Energy



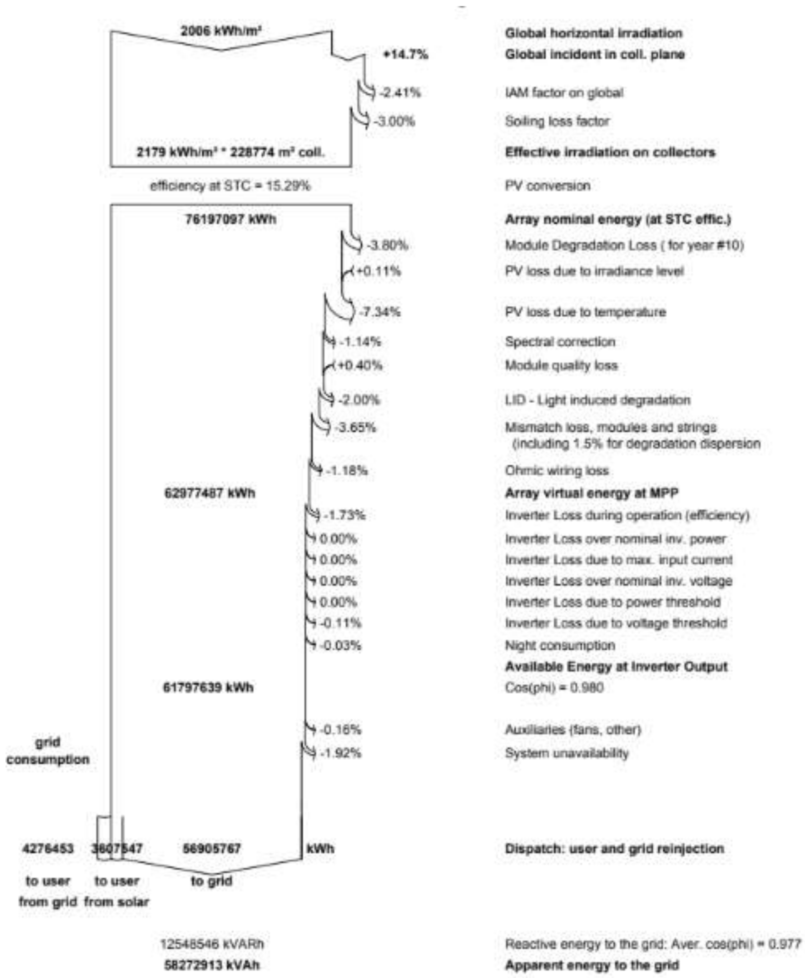
The figure indicates that in a day we can produce over 200MWh/day with the insulation of almost 9 Kwh/m2/day and plant efficiency of 75.16%.

Chart-3: Power vs. Voltage



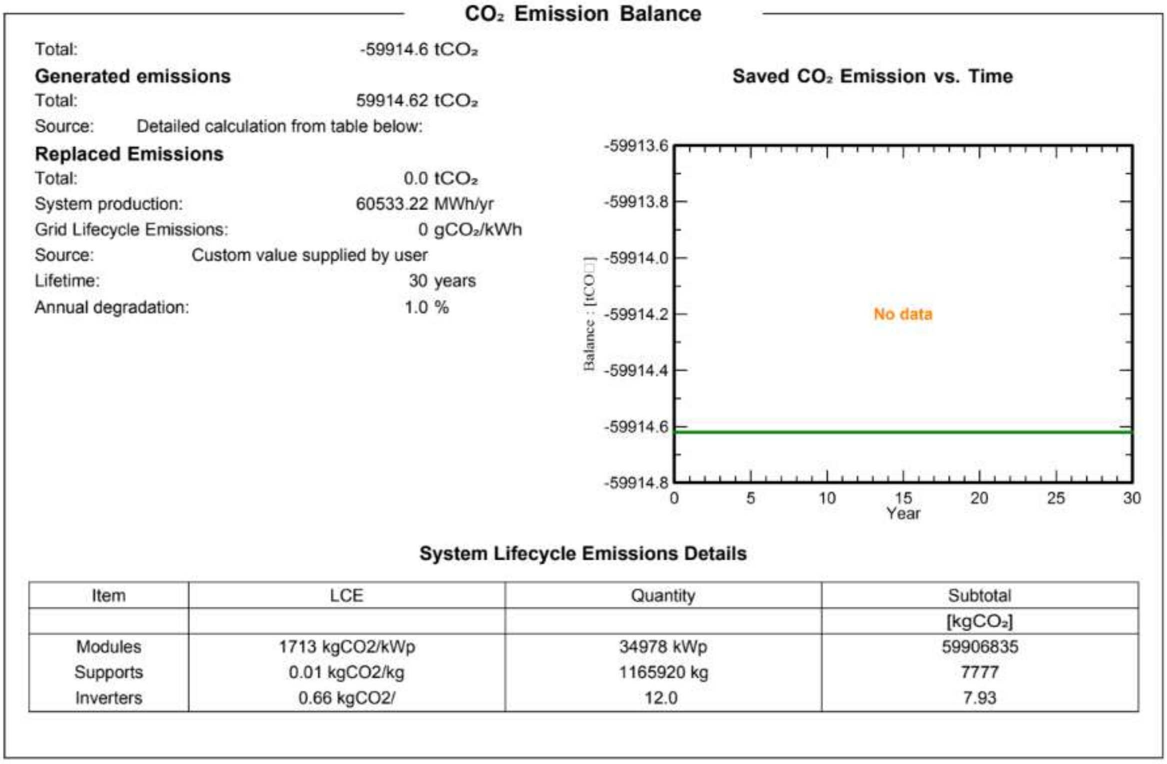
For the chart 3, we can clearly understand that at 39V and cell temperature of up to 45 degrees of Celsius the incident radiation yields 1000 watt per square meter.

Chart-4: Losses at Plant



From the chart-4, we can clearly find out all the losses that is occurring in the power plant and affects our energy that is going to be injected to the grid. And it indicates that from a total of 12548546 kVARh produced energy from the plant we can only contribute with the grid with an amount of 58272913 kVAh.

Chart-5: The restricted amount of CO2 that will be mitigated



From the chart 5, we can clearly understand that if the same amount of energy 60533.22Mwh/year is going to be produced from any other source that contains Co_2 gases that will produce 59914.64 ton of Co_2 that by installing and developing this plant we could produce -59914.64 ton of Co_2 which is equivalent to 713Kg CO_2 /Kwp of modules for a period of 30 years with an annual degradation rate of 1%.

5. Conclusion

The project is plan to design at Aino Mina, Kandahar city and based on the given data to the PVsyst software, it has been understood that we can produce 1730Kwh energy per Kwp in a year. And a total of 116592 modules of Trina Solar with $300W_p$ capacity had been introduced to the system. Also, the power plant requires 12 inverters which is made of SMA Company with a total capacity of 2.5 MW each.

Moreover, by installing this system we could save 59914.6 tCO_2 for a period of 30 years. The power plant has an amount of 7884MWh constant load that is consumed by the different structures and lighting of the plant inside the power plant. Moreover, as the project is on-grid power plant it gives 58272913 KVAh from a total of 60513314 KWh/year.

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