Sudan University of Science and Technology
College of Engineering
School of Electrical and Nuclear Engineering

Study of Solar Power Plant Using PV sys 6.8.8

دراسه محطة طاقة شمسية باستخدام PV sys 6.8.8

A Research Submitted In Partial Fulhillment For The Requirement Of

The Dgree Of B.sc (Honor) In Electrical Engineering

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بسم الله الرحمن الرحيم

الآية

قال تعالى:

﴿وَقُلِ اعْمَلُوا فَسَيَرَى اللَّهُ عَمَلَكُمْ وَرَسُولُهُ وَالْمُؤْمِنُونَ

وَسَتُرَدُّونَ إِلَى عَالِمِ الْغَيْبِ وَالشَّهَادَةِ فَيُنَبِّئُكُمْ بِمَا كُنْتُمْ

تَعْمَلُونَ﴾

صدق الله العظيم

التوبة –الآية (105)

DEDICATION

To

Endless love

Our mothers

To

Man who teach me to be man

Our fathers

To

Our teacher &our colleagues

AKNOWLEDGMENT

First, we need to thank fully our god [Allah] that without his blessing this work will not complete.

Then all thank for our supervisor Ust **ABD ELSLAM ABD ELAZEZ** to his patience with us and countless hours and valuable efforts to guide and advise us to complete the work in his fair way.

Lastly we need to thank our teachers in electrical and nuclear engineering school and Eng. Al Taheer and Eng. Nazar in **MINISTRY OF WATER RESOURCES AND ELECTRICITY** to their efforts in helping and support.

Abstract

The objective of this research is study a solar photovoltaic power plant focusing on the design a large-scale PV solar power plant, specifically a 64 MW PV plant. The different parameters obtained by means of specialized PV software (PVsyst). The main components in a large-scale PV plant are described: PV modules, mounting structures and solar inverters. The calculations regarding the PV plant design are made for a specific location previously selected.

The site selected for the installation is in the location of Al Bagaer which meets all the requirements for the installation of a PV plant. The design parameters calculated are the number of PV modules in the system, the number of inverter, the total installed capacity and the area.

المستخلص

الهدف من هذه البحث دراسه محطه توليد بالطاقه الشمسيه ذات القدرات الكبري 64 ميقاواط حيث تمت دراسه المعطيات باستخدام برنامج PV syst 6.8.8 وكذلك مكونات المحطه من الواح شمسيه الي مبدلات ومساحه الموقع الذي تم اختياره مسبقا . الموقع الذي تم اختياره هو الباقير وذلك لانه مناسب تماما لهذه المحطه

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ACRONYMS AND ABBREVATIONS:

PV	Photovoltaic
ILR	Irradiation correction factor
POI	Point of interconnection
AU	Astronomical units
Wp	Watt peak
ACE	Area control error
VRE	Variable renewable energy
PPA	Power purchase agreement
HVRT	High voltage ride – through
LVRT	Low voltage ride – through
Ro Co F	Rate of change of frequency
AGC	Automatic generating control
DG	Distributed generators
PV syst	Photovoltaic system program
GLobHor	Horizontal global irradiation
DiffHor	Horizontal diffuse irradiation
T_Amb	T amb
Goloblnc	Global incident coll. plane
GlobEff	Effective global corr. for IAM and shading
E Array	Effective energy at the out put of the array
E- Grid	Energy injection into grid
PR	Performance ratio
SEGCC	Solar energy grid connection code
EDC	Electricity distribution code
GC	Grid code
LOCE	Levelized cost of energy

CHAPTER ONE
GENERAL CONCEPTS

1.1 INTRODUCTION:

Energy is a fundamental input to economic activity, however a major transformation is required in the way we produce, deliver and consume energy. The current energy system is largely dependent on fossil fuels, which negatively impact air quality, and contribute significantly to carbon emissions.Global demand for energy is rapidly increasing, arising from population and economic growth,
especially in emerging market economies, which will account for 90% of energy demand growth to 2035.There is currently a window of opportunity to undertake transformational change in the energy supply sector to meet economic and environmental objectives, as there is a need to replace aging plants and add new capacity, especially in emerging economies, to meet growing electricity demand[1]
Conventional fossil fuel generating units across Sudan are being retired in response to the first same objectives, also the unconventional Marawe,Sinar and AL Rosiers Dams , ETHIOPIAN AND EGYTIAN grid tie in,work to cover demand needs and to reatch so far. The Lack of access to clean, affordable and reliable energy in Sudan, is a brake on human and economic development; it is a major obstacle to achieving the development goals.Also Traditionally, the costs for operation services were embedded in the utility's cost-of-service or recovered through the transmission tariff.Needs of Khartoum and broader provision for these services, variable energy resources like solar another sources can play a role in supplying them and the incremental costs for doing so,it must be considered.**Most** of the solar technology installations in the country are Photovoltaic [PV] with a total installed capacity of about 2 MW approximately half of the installed capacity is associated with the telecommunication industry [e.g. remote off-grid antennas satellites and

isolated from the grid] not acces the new solar energy as utility. After losing its oil-rich south the country is now seeking for alternatives[2], that can secure its energy needs and yet meet Sudan's action plan in combating climate changeand a find the road map of an energy transition.The report of International Energy Agency expect that the world's electrical generating capacity will increase to nearly 5.8 million megawatts by the year 2020, up from about 3.3 million in 2000. However, the world's supply of fossil fuels our current main source of electricity will start to run out between the years 2020 and 2060 according to the petroleum industry's best analysts.Sudan is rich with sunlight and have abundance of sunshine with an average duration ranging between 8.5 to 11 hours per day. Sudan's solar energy density ranges between 436-639 W/m2[2],the map below [Fig. 1.1] reflects Sudan's Global Horizontal Irradiation.

Large Solar Power plant connectrd to the Grid in Sudan is a project to explain and pass through general consepts focused on general solar energy,plant desing and integration.It's a milestone on energy transformation in our country not all but limited to technical concern,integration requirements,economic valuation, to make the view more reilestic.

1.2 The Problem:

Sudan have constrains in develpement hiegh operation as cost for thermal plants, hiegh demand of power, stability of grid , Lack of fossl feul .Now it's seeking for alternatives, that can secure its energy needs and yet meet Sudan's action plan in combating climate change.Solar energy tansission can make gradually for clean energy.

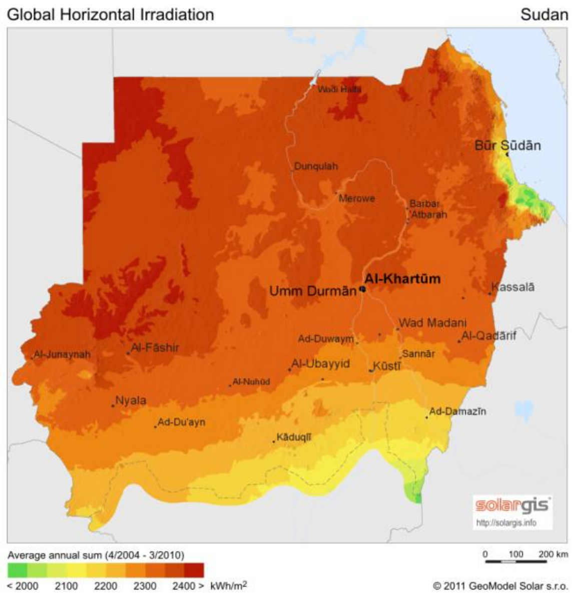


Figure 1.0 :The map reflects Sudan's Global Horizontal Irradiation

1.3 Objectives:

- Study of solar powr plant using PV sys 6.8.8
- Review of general concepts for solar power plant.

1.4 Methodology :

Power plant study with PV syst 6.8.8 programme**.**

1.5 Project layout:

This project consist of five chapter including **Chapter one**: the scope of each chapter explained as state below. **Chapter Two:** this chapter obtains background of solartechnology power plant component. **Chapter Three:**solar plant study . **Chapter Four**: simulation, calculation and results with PV sys 6.8.8 programme.**Chapter Five**: this chapter shows as conclusion and recommendations.

CHAPTER TWO

SOLAR TECHNOLOGY

2.1 Introduction:

Absorption of a photon in a material means that its energy is used to excite an electron from an initial energy level to a higher energy level . Photons can only be absorbed if electron energy levels are present so that their difference equals to the photon energy. Almost all solar cells contain junctions between [different] materials of different doping. Since these junctions are crucial to the operation of the solar cell.The working principle of solar cells is based on the photovoltaic effect, i.e. the generation of a potential difference at the junction of two different materials in response to electromagnetic radiation. The photovoltaic effect is closely related to the photoelectric effect, where electrons are emitted from a material that has absorbed. Solar Energy is produced by the sun harnessed by solar collection methods such as solar cells Converted into usable energy such as electricity Photovoltaic Solar Cells Generate electricity directly from sunlight Solar cells are devices that take light energy as input and convert it into electrical energy, the main parameters that are used to of solar cells. [3]

2.2 Important characterise performance fators for solar sells:

i. **Open-circuit voltage [Uoc**]: the voltage that provides the solar PV cell when no load is connected. Its value is around 0.6-0.7 V for silicon and is proportio[nal to the logarithm of the illumination level.

ii. **Short-circuit current [Isc**]: the current that flows when the terminals of the solar PV cell are short-circuited. Its value is around 20-40 mA and proportional to the illumination level.

iii. **Maximum power voltage [Ummp]:** the voltage where the solar PV cell provides maximum power.

iv. **Maximum power current [Immp]:** the current where the solar PV cell provides maximum power.

v. **Fill factor[FF]** :which is defined as the ratio of the actual maximum obtainable power to the theoretical maximum, which is given by the product of the open-circuit voltage and the short-circuit current. This parameter is very important to evaluate the performance of solar cells.

vi. **Peak Watt [Wp]:** PV modules are rated by their total power output, or peak Watts. A peak Watt is the amount of power output a PV module produces at STC of a module operating temperature of 25°C in full noontime sunshine [irradiance] of 1,000 W/m2.

vii. **The conversion efficiency**: is calculated as the ratio between the maximal generated power and the incident power.

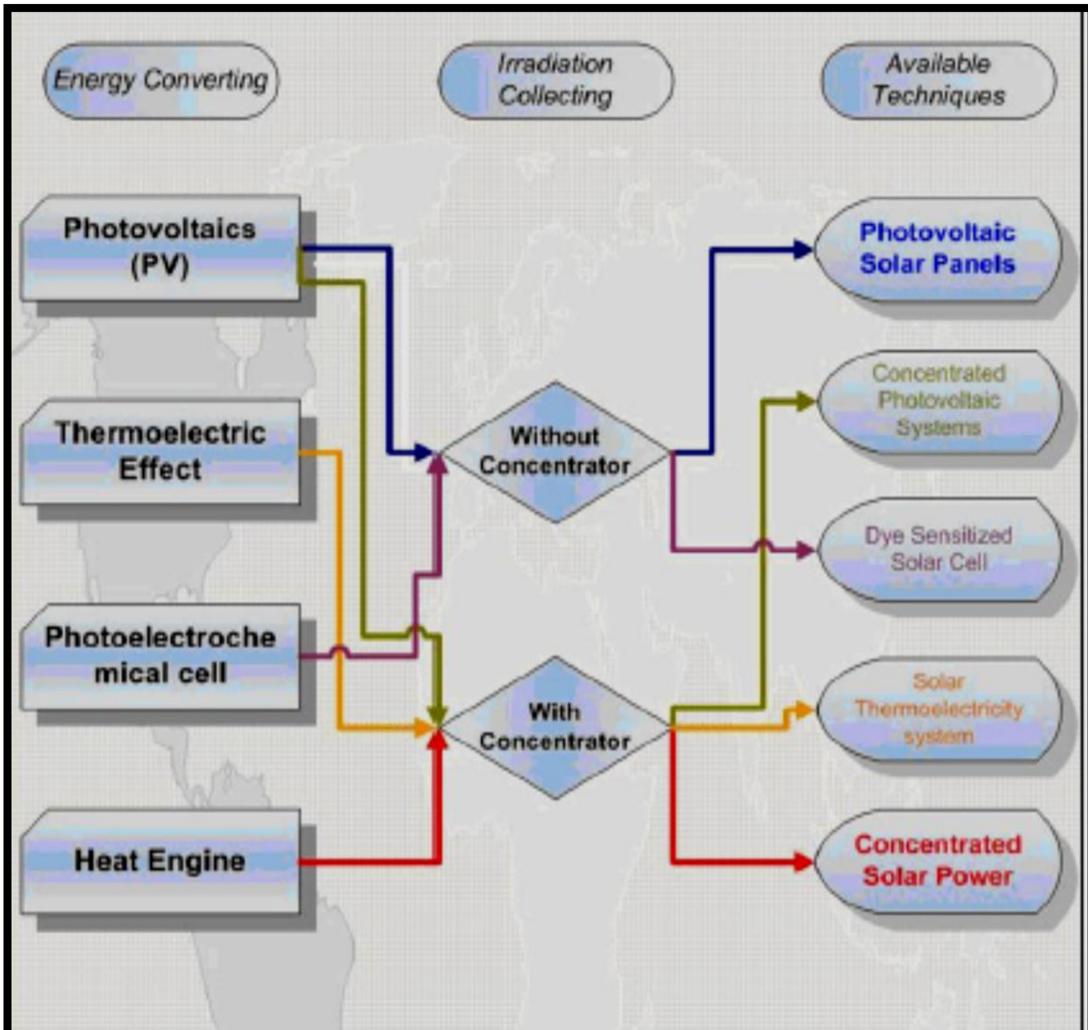
2.3 Types of Solar Generation

There are several kinds of solar techniques that are currently available. However, each of them is based on quite different concepts and science and each has its unique advantages,it's as follow:

- Photovoltaic Solar Panels . - Concentrated Photovoltaic System
- Dye Sensitized Solar Cell. - Solar Thermoelectricity System.

5- Conentrated Power Solar .

Analysis and comparison between different technologies will help to adopt the most efficient and beneficial technology given a specific set of conditions.Fig[2.1] below explain overview of solar technologies. Our project depend on photovoltaic solar power plant technology . The solar plant produce power which directed to the grid via a substation.



Photovoltaic Solar Panels	Most commonly used techniques in today's market
Concentrated Photovoltaic Systems	The highest efficiency ever achieved in lab
Dye Sensitized Solar Cell	Biomimics techniques based on cheap organic materials
Solar thermoelectricity system	Based on the application of thermoelectricity materials
Concentrated Solar Power	Commonly used based on the application of mature heat engine

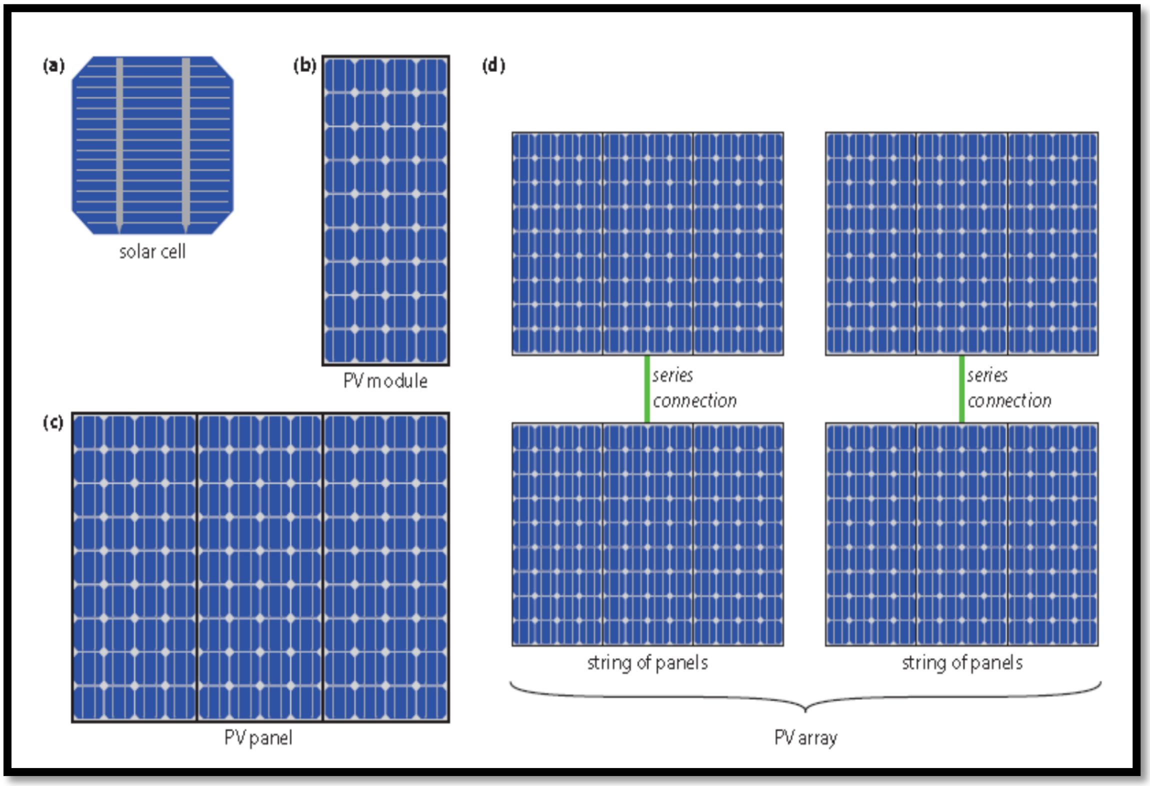
Figure 2.1: Solar Technology

2.4 Solar plant Component and consedaration:

The elements described component below are going to be considered during the calculations used for the system design in chapter four . The components described are: PV modules, inverters.

2.4.1 PV modules:

A PV module, is a larger device in which many solar cells are connected, as illustrated in Fig.[2-3] [b].The names PV module and solar module are often used interchangeably. A solar panel, as illustrated in Fig. 17.1[c], consists of several PV modules that are electrically connected and mounted on a supporting structure. A PV array consists of several solar panels, an example of such an array is shown in Fig.[2-3] [d]. This array consists of two strings of two solar panels each, where string means that these panels are connected in series. If we make a solar module out of an ensemble of solar cells, we can connect the solar cells in different ways: first, we can connect them in a series connection as shown in Fig. 17.2 [a]. In a series connection the voltages add up. For example, if the open circuit voltage of one cell is equal to 0.6 V, a string of three cells will deliver an open circuit voltage of 1.8 V. For solar cells with a classical front metal grid, a series connection can be established by connecting the bus bars at the front side with the back contact of the neighbouring cell, as illustrated in Fig. [2-3] [b]. For series connected cells, the current does not add up but is determined by the photo current in each solar cell. Hence, the total current in a string of solar cells is equal to the current generated by one single solar cell. Secondly, we can connect solar cells in parallel as illustrated in Fig.[2-3] [c], which shows three solar cells connected in parallel. If cells are connected in parallel, the voltage is the same over all solar cells, while the currents of the solar cells add up. If we connect e.g. three cells in parallel, the current becomes three times as large, while the voltage is the same as for a single cell, as illustrated below.



Fig[2-3] : PV array ,modules,solar cell

2.4.2 Array:

I. The area : after determining the solar modules to be used,we have to calculation the space requirements for the PV plant may be accomplished as for example: 64 MW is the required plant capacity, 1.30 is the desired ILR used to scale land requirement. Thus, we determined the amount of space and array, by the following example [you will find in chapter four this calculation done with PV sys]:

Ex.1:Area calculation

$$\text{Number of modules} = \frac{\text{Total MW}}{\text{Module powr}} = \frac{64 * 10^6}{285\ \text{W}} = 224561\ \text{Module}$$

$Panel\ Area$ = 1.9 m^2

$Total\ Area\ of\ Panels$ = 224561 $*$ 1.9 $* 10^{-6}$ = 0.4267 m^2

Ns : Number of series connected PV modules per PV string.

Nr: Number of rows of PV sets per block.

Fy : Distance between adjacent PV blocks.

Nc : Number of module.

B : PV modules tilt angle.

DIM1: Maximum permissible length of the southern side of the available installation area [5] **.**

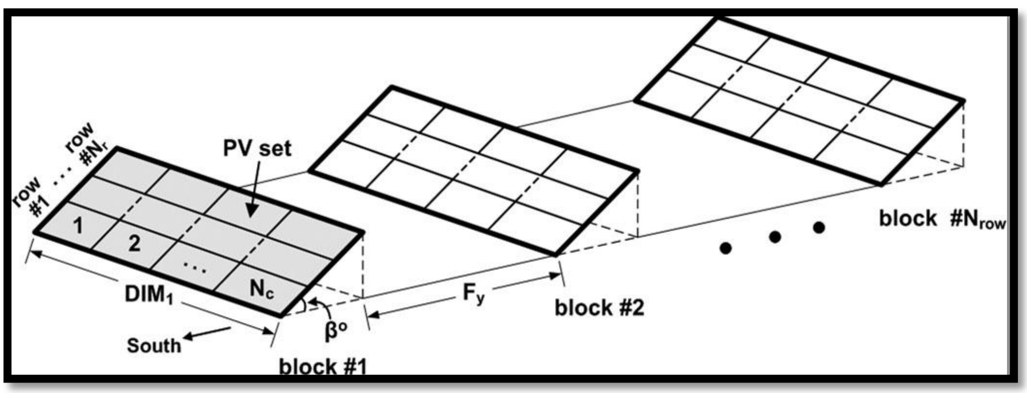


Fig [2.4]: Arrangement of the PV power generation sets in blocks within the available installation area and the PV power generation sets in rows within each block.

The arrays will be laid out in a single block containing all panels, racks, inverters and step-up transformer. There will be a total of 800 arrays in the plant. See Fig [2.4]. The row spacing is 1.2m the inverter access road is 1.5m wide [5].

II. **Mounting Structures to the ground:** Mounting structures are used to fix the PV modules to the ground and they determine the tilt angle and the orientation of the modules. A classification of the mounting structures can be done depending on their assembly to the ground:

   a) Pole mounts: Mounting structures are directly installed into the ground or embedded in concrete.
   b) Foundation mounts: Structures are fixed into the ground by means of concrete slabs or poured footings.
   c) Ballasted footing mounts: Mounting structures do not penetrate into the ground and are fixed to it by means of the weight of concrete or steel bases [6].

The selection criteria of the mounting structures involve many factors such as: cost of manufacturing, cost of installation and difficulty of installation, lifespan of the structures, resistance to corrosion or protection against adverse climatic conditions. Besides, mounting structures are the responsible to endow to the PV modules the required tilt angle and orientation. Regarding this aspect there are two main categories of mounting structures: fixed structures and tracking axis systems. Fixed structures are not capable to modify neither the orientation nor the tilt angle. This option is the less costly system, but the energy production will be not optimum. Tracking axis systems can be divided in 1-axis tracking systems and 2-axis tracking systems, the difference between both systems is the number of degrees of freedom. It is usually generate more shading losses than fixed systems due to the movement of the PV panels, note that for higher tilt angle of the modules, inter-row spacing has to be higher or the shading losses will be larger.All string which of consists modules [or panels] are connected in series. They distributed on racks,and will be combined in at the combiner boxes. Figure [2.5] [6] .

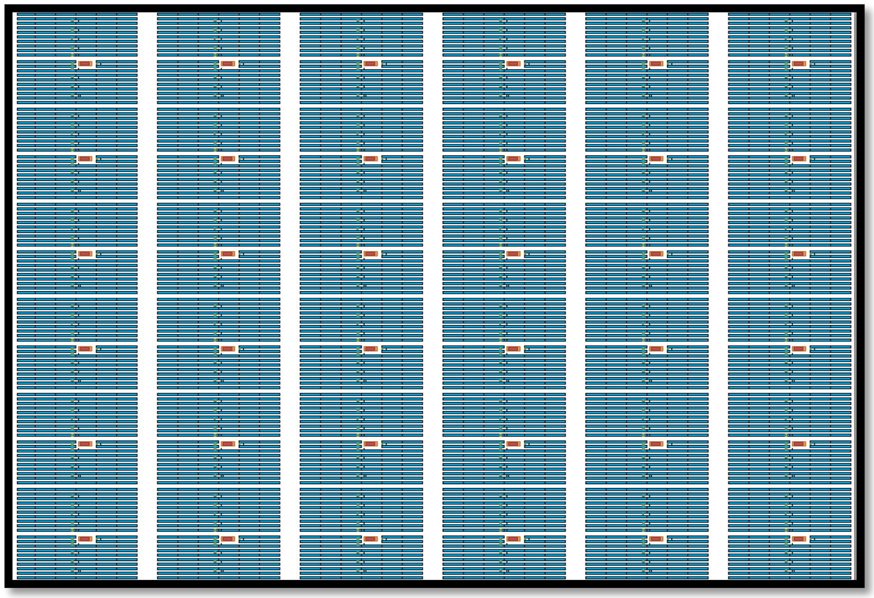


Figure 2.5 : 6X6 Solar Plant Arrangment Layout

III. Array Parameters:

Here we use a PVSYS software, provided to assist in designing the solar array layout. Taking into consideration panel parameters, string parameters, current output, combiner box capacity, inverter capacity, ILR [irradiance correction factor], and continuous current correction.

2.4.3 Inverter :

Since PV modules generates power at DC current, at some point this generated electricity is needed to be converted into AC current to accomplish with grid requirements. To invert the polarity of the source to AC and to synchronize the power generated with the grid an inverter is required.The inverter has CB DC inputs,and CB AC output 3-phase via direct throat connection to a matching step-up transformer. The transformer high side is fed to the collector arrangement.

Inverters are usually designed to comply with the requirements of each country's grid code. At a minimum, the following features are generally required:

1] Tolerance of frequency and voltage deviations

2] Controlling of the active power production

3] Controlling of the reactive power production

4] Controlling of the power factor

5] Controlling of the voltage at the point of interconnection [POI]

6] Reactive power support during under- and over-voltage at the POI

7] A P-Q capability curve for leading and lagging power factor at POI to regulate voltage in the operational range required by the grid operator generally [7]

2.4.3.1 Invertors Tepology:

PV inverters can be classified in different topologies. The topology of the solar inverter will determine the connections between the PV modules and the inverter and their possible applications. Different topologies of PV inverters can be seen in Figure [2.6].

i. **Central inverters**: range of 100-1000 kW with three-phase topology and modular design for large power plants [tenths of MW] with unit sizes of 100, 150, 250, 500 or 1,000 kW.

ii. **String inverters:**. Currently, the most successful technology is the string inverter. Most of these inverters use either Metal Oxide Field Effect Transistors [MOSFET] or Insulated Gate Bipolar Transistor [IGTB] semiconductors instead of thyristors to perform self-commutated switching actions. High input voltages are possible to avoid voltage amplification stages, yet smaller voltages are possible [e.g. AC module] by incorporating additional DC-DC conversion or line frequency transformers at the output. has a string of inverters connected in series with an AC module.

iii. **Multistring inverters**: for medium large roof-top plants with panels configurated in one to two strings

iv. **Module integrated inverters**: for very small PV plants

v. **Mini central inverters**: typically > 6 kW for larger roof-tops or smaller power plants in the range of 100 kW and typical unit sizes of 6, 8, 10 and 15 kW [7] .

Because of the purpose of this project is the design and modelling of a large-scale PV solar power plant, in this chapter the attention will be focused on central inverters. The most used central inverters configuration

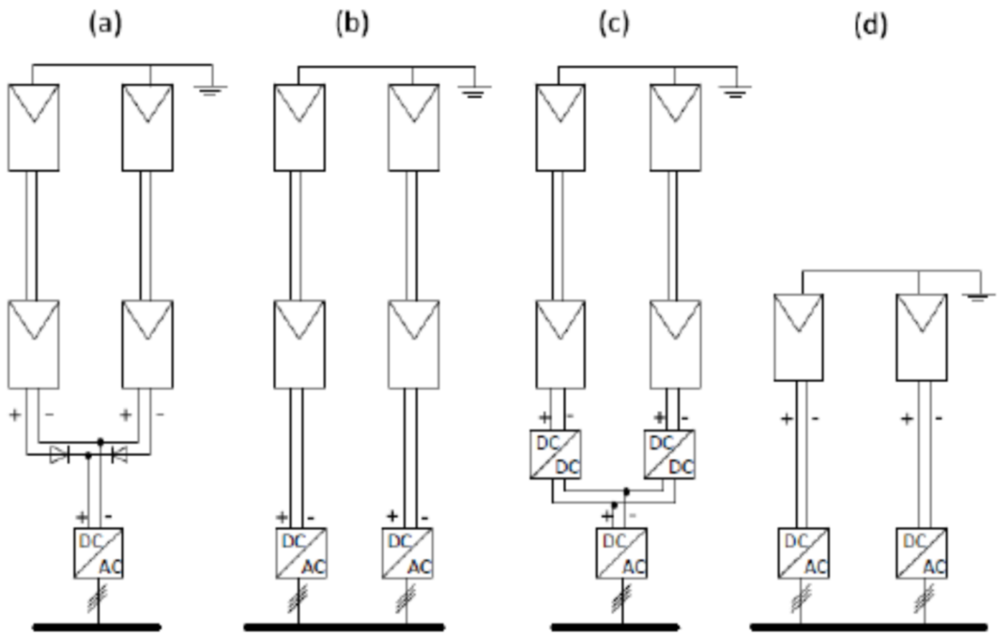


Fig. [2.6] : PV inverter topologies: [a] Central inverter, [b] String inverter, [c] Multistring inverter and [d] Module integrated inverter .

is two-level voltage source inverter [2L-VSI] which is composed of three half-bridge phase legs connected to a single dc-link **.** The main advantages of central inverters are the reliability and robustness compared with other inverter's topologies, but the main drawbacks of this technology are the increased mismatch losses and the absence of MPPT for each string of the array connected**.** Normally, the inverters installed in large-scale PV solar power plants are containerised type. This type of commercially available inverters also contains the transformer and the switchgear in the same structure. With this solution, inverter, transformer and switchgear can be manufactured offside the PV plant reducing the cost of installation **.** The most common inverter's manufacturers for utility-scale applications are ***SMA*, *ABB* and *Kaco* [8].**

2.4.4 Conductors and Fuse Protection

The conductor selection is based on correction scaled currents DC and AC conductors.The string conductor is preselected by the module manufacturer. Fuses are selected based on maximum current calculations.The string conductors and jumpers will be open air. DC feeder conductor will be buried at least 30 inches, measured from top of conductor [9] .

2.5 PV site position from the sun:

For planning we should now the importance sun position,in a PV system it is crucial to know the position of the sun in the sky at the location of the solar system at a given time.

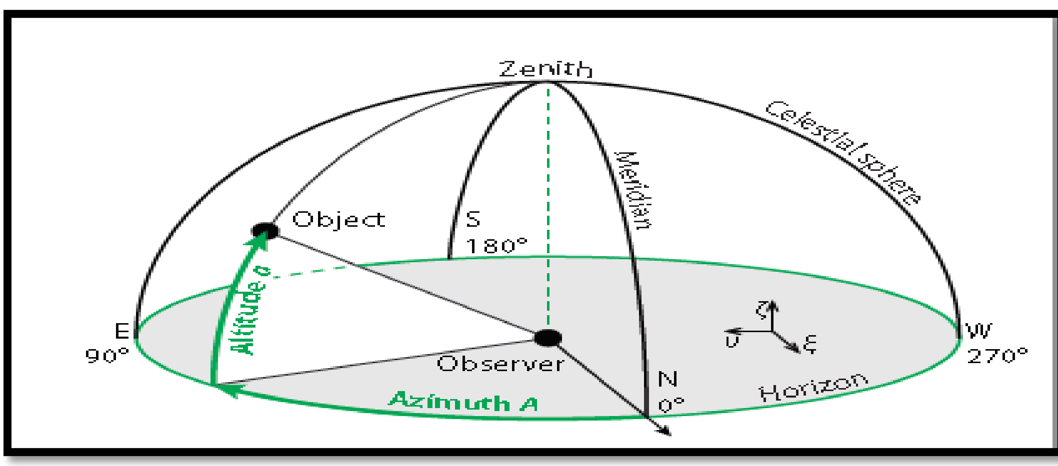


Fig [2.7] [a] **The Athemous**

For photovoltaic applications it is most convenient to use the horizontal coordinate system, where the horizon of the observer constitutes the fundamental plane. In this coordinate system, the position of the sun is expressed by two angles that are illustrated in Fig.[2.7]: The altitude a that is the angular elevation of the centre of the solar disc above the horizontal plane. Its angular range is [- 90,+ 90], where negative angles correspond to the object being below the horizon and thus not visible.

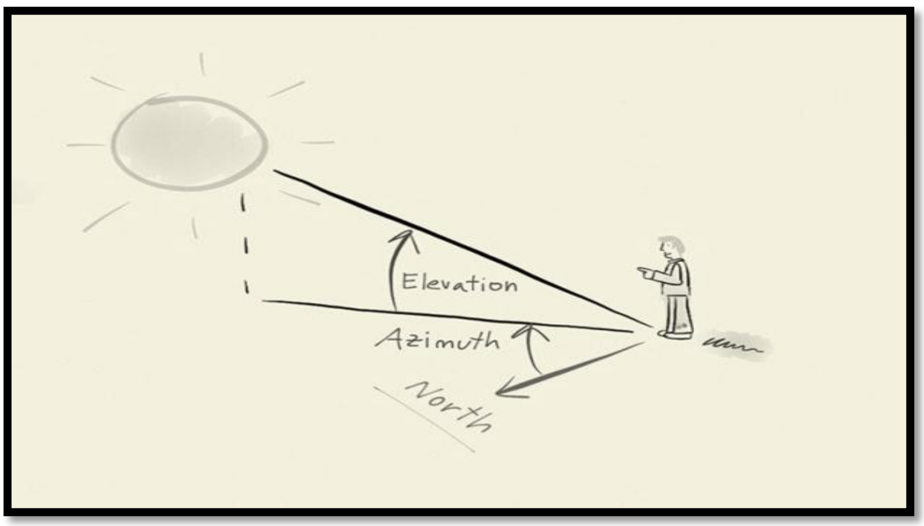


Fig [2.7] [b] the definition of the altitude a and the azimuth A in the horizontal coordinate system. Note that North is at the bottom of the figure.

The azimuth that is the angle between the line of sight projected on the horizontal plane and due North. It is usually counted eastward, such that A = 0, 90, 180, 270,correspond to due North, East, South and West, respectively. Its angular range is A [0, 360]. Then we have to estimate the radiation it might also be convenient to approximate the distance of the Sun from the Earth in astronomical units [AU].All this calculation made easely by using PVsys sowftwares. The solar module is mounted on a horizontal plane and that it is tilted under an angle *q*M, as illustrated in Fig [2.7] . Shadowing had to be kept in mind when planning a PV system that consists of several rows of PV modules, which are placed behind each other .

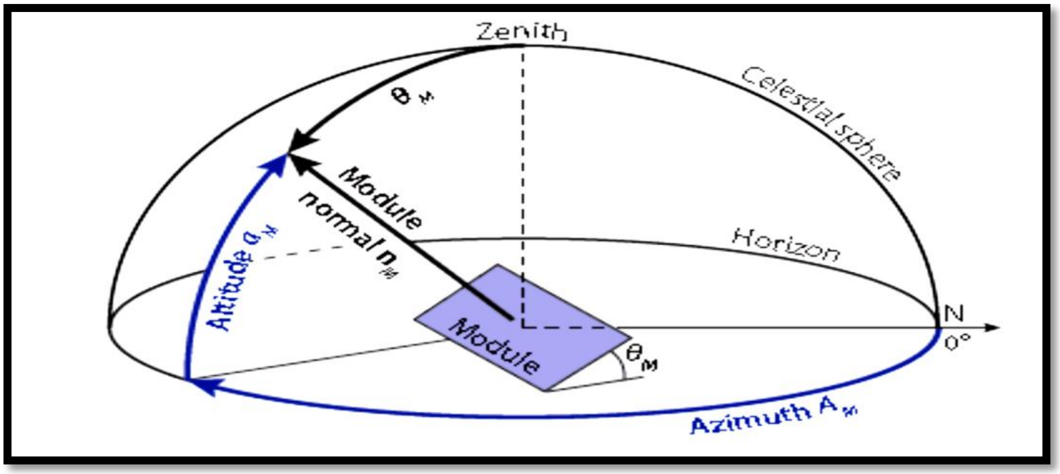


Fig [2.7] [c] **the angles used to describe the orientation of a PV module installed on a horizontal plane**

Temprature, Wind Performance, Humidty and *Tempartuer*:The effect of temperature on solar cell performance is cooler panels allow more energy to get through like an electric current. Solar panels cooled by 1 degree Celsius are 0.05 percent more efficient,this percentage adds up over time .Here's where the wind comes in the wind cools solar panels though it won't make or break you solar panel production overall.. While the wind doesn't give the sun's light rays any extra *oomph* when powering panels, the effect of wind is a boost in solar efficiency.*Humidity* can slow efficiency in two ways:

i. Tiny water droplets, or [like beads of sweat] and reflect or refract sunlight away from solar cells. This reduces the amount of sunlight hitting them and producing electricity.
ii. Consistent hot, humid weather can degrade the solar panels themselves over their lifetime. This is true for both crystalline silicon cells and thin film modules, but cadmium telluride [thin film] solar cells perform about 5 percent better in tropical climates.[10]

Fig. [2.8] : Wind effect on solar panels .

2.6 Important Terms and Concepts in solar plant Desing:

There are many conceps for desing solar plant should be taken in account which effect the project,like tilt,azimuth angles and ILR ratio.

2.6.1 Tilt Angle and Azimuth

Tilt angle is dependent on terrain, latitude and weather pattern to a small degree. The optimal angle for the selected area in Boone is 15%. Note, this will change based on terrain inclination. While the azimuth of 180 degrees with respect to true north implies mid-day peak load .

2.6.2 Inverter Load Ratio:

The most important factor in solar power generation design is the **inverter load ratio [ILR].** The ILR is the ratio of DC solar capacity and inverter AC output. Since panel production conditions and actual conditions vary significantly at any given time and day, the DC power input design should about 130% of the AC output rating. This corresponds to an ILR of about 1.30. For majority of the time, the inverter input will not output above rated AC capacity, in the times that it does, the inverters will clip output and dissipate the excess power as heat. Thus the ILR is a metric of inverter utilization. The inverter is supplied with a matching step up transformer.

2.6.3 Irradiance Correction Factor

A second safety factor called the irradiance correction factor [Isc – irradiance correction] was utilized as a fail safe for current spikes a string may experience in times of exceptionally high solar radiation. This factor is valued at 1.25, requires a secondary correction factor before all others. All conductors must be designed with this calculated current scalar applied.

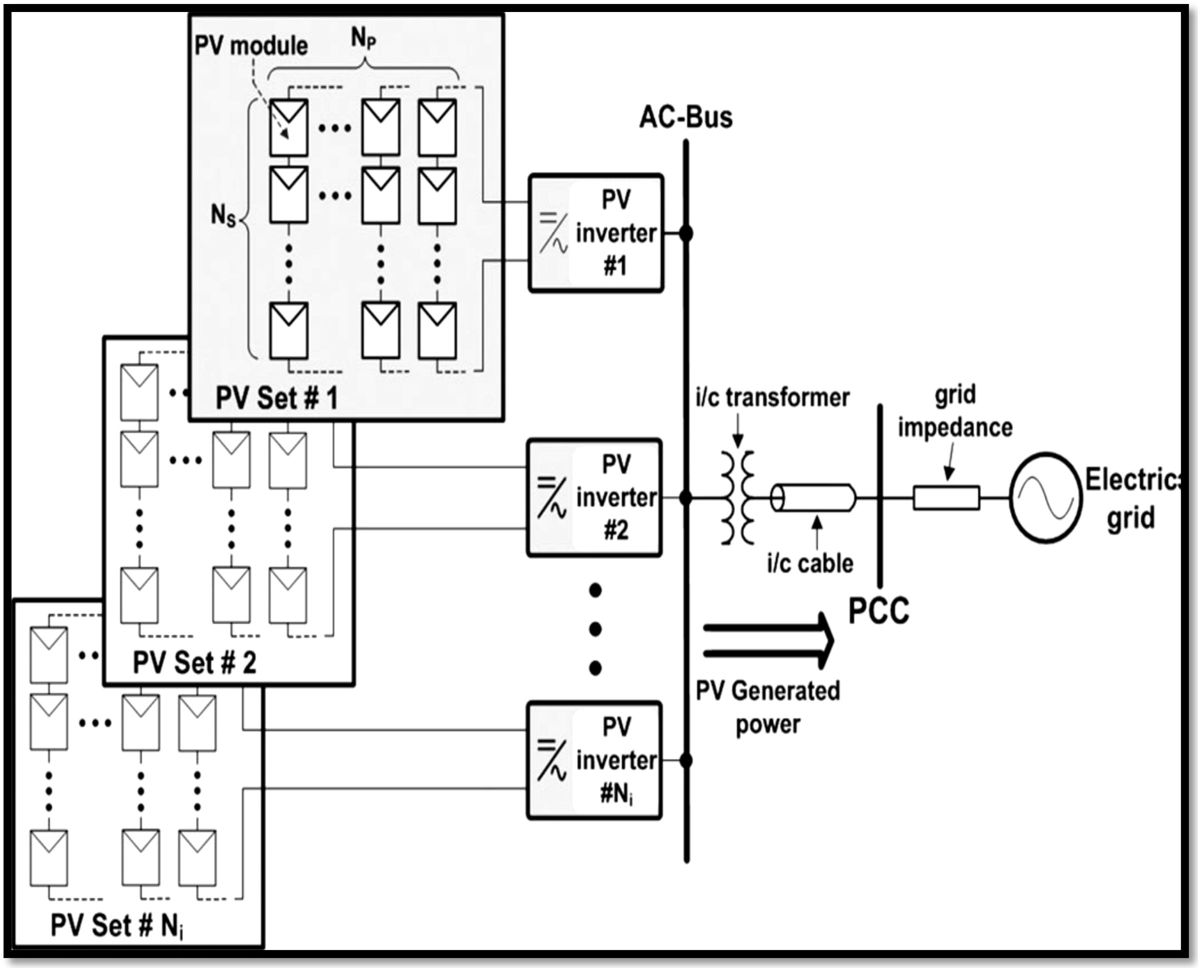
2.6.4 Continuous Current Multiplier

A safety multiplier, requires overcurrent device ratings shall not be less than 125% of the maximum currents calculated. All conductors must be rated for continuous current along with the irradiance correction factor.

2.7 Substation Component Design:

The purpose of the substation is to collect all solar array power and feed into the grid after stepping up voltage to distribution level. It will consist of the following :

A. Collector – Input from solar arrays' transformer. The collector arrangement is the set of inputs from inverter skid. Attached to each of the inverter is a transformer which steps up the voltage to bring it to a sub-transmission level. The collector is not directly located at the substation but is the sum of all the inverter skids in each array of the solar power plant. The string, sent Power flow through the substation to the feeders bus, finally voltage is stepped up.fig [2.2]
B. Feeder – Output from collector, input to bus, Surge arrestor.
C. Key Protection – Circuit breakers, protection relays, capacitor bank, and step-up transformer. Outputs to grid .
D. Capacitor bank: Capacitor bank stabilizes harmonics associated with three phase currents and helps maintain a power factor of 0.95. Component specifications were provided by utility [11].



Figure[2.9]: Block diagram of PV plant layout.

Summary :

- Photovoltaic solar cells generate electricity directly from sunlight,they are devices that take light energy as input and convert it into electrical energy.
- Our project depend on photovoltaic solar power plant technology,that solar plant produce power which directed to the grid via a substation.
- A PV module, is a larger device in which many solar cells.The names PV module and solar module are often used interchangeably. A solar panel, consists of several PV modules that are electrically connected and mounted on a supporting structure. A PV array consists of several solar panels,this

array consists of strings of solar panels, where string means that these panels are connected in series and parallel.

- The azimuth that is the angle between the line of sight projected on the horizontal plane and due North.

The mounting structures involve many factors such as: cost of manufacturing, cost of installation and difficulty of installation, lifespan of the structures, resistance to corrosion or protection against adverse climatic conditions.For mounying panel structure we choosed fixed structures which are not capable to modify neither the orientation nor the tilt angle. This option is the less costly system, but the energy production will be not optimum.

- Because of the purpose of this project is the design and modelling of a large-scale PV solar power plant,we use central inverters, The main advantages of central inverters are the reliability and robustness compared with other inverter's topologies,and the most used,in backage contains inverter ,transformer and switchgear in the same structure manufactured for utility-scale applications.
- Solar Power Plant components areLocation,Solar Inverter [kW],Solar Panel [Wp], Combiner Box DC Voltage [V],Inverter Load Ratio [ILR= 1.300,Combined Solar Inverter Output andFixed Rack System.

CHAPTER THREE

SOLAR SYSTEM STUDY

3.1 Introduction:

Solar-Grid integration is the technology that allows large scale **solar power** produced from **PV** system to penetrate the already existing **power** grid. This technology requires careful considerations and attentions including in areas of **solar** component manufacturing, installations and operation[13]. Integration technology has become important due to the world's energy requirements which imposed significant need for different methods by which energy can be produced or integrated, in addition to the fact that integration of solar energy into non-renewable sources is important as it reduces the rates of consuming of non-renewable resources hence reduce dependence of fossil fuels. Global installed [12].

When new generation is connected to the electricity grid, the power system needs to adapt to it. For traditional large-scale generation sites, however, the power system may need reinforcement to accommodate the new generation. Small-scale electricity production, such as small-scale solar PV, is usually connected to the low voltage distribution grid, whereas utility-scale solar PV and wind turbines are connected to the medium-voltage distribution grid or regional transmission grid. In response to the recent solar as a renewable energy, four phases of integration have been distinguished to describe the progressive stages of solar penetration in the grid, including its impacts and challenges.

The integration of a significant share of solar into power grids may require a transformation of the existing networks. The following changes address the needs for system flexibility and security of energy supply in a grid with a growing number of solar plants.

The Solar technologies are intrinsically different from the synchronous generation that constitutes the majority share of generation resources in the grid during Phases 1, 2, and 3 [see TABLE 3.1: Phases of solar Integration]. Therefore, in addition to the grid improvements for solar adoption, additional solar capabilities need to be provided in order to successfully integrated process in the grid fig [3.1], [13].

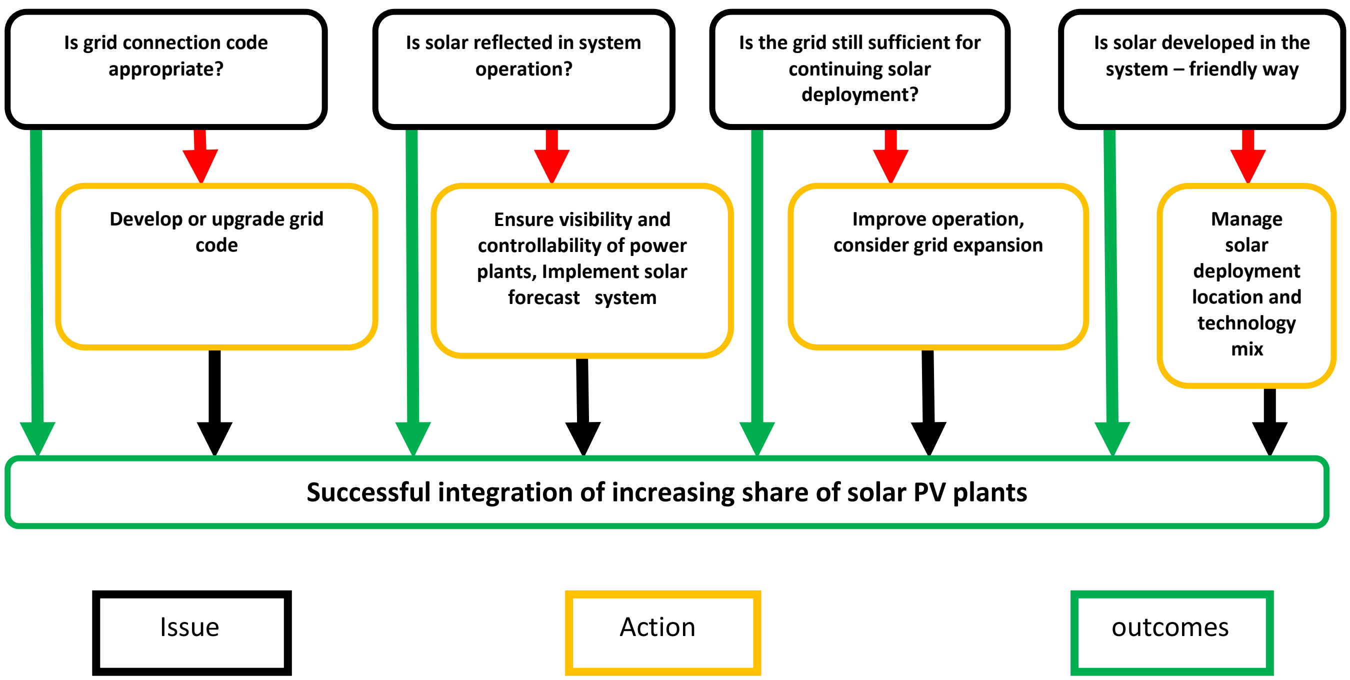


Fig [3.1] Successful solar integration process .

3.2 General integration Phases in the grid:

We should have *grid integration study which* is an analytical framework for evaluating a power system with high levels of variable solar energy. The study include, four phases of solar integration have in the grid, as shown in table [3-1] , each phase involves a different set of power system interconnection and operational challenges [13].

Phase	Description
1	Solar capacity is not relevant at the all - system level
2	Solar capacity become noticeable to the system operator
3	Flexibility becomes relevant with greater swing in the supply/demand balance
4	Stability becomes relevant.

Table [3-1] General phases of integration

3.3 The process of grid integration study:

The succeful integration steps fig. [3.1] to the grid are:

i. Collecting data fig. [3.2].

ii. Devlope scenarios fig.[3.2].

iii. Smuliat the power system fig. [3.3].

iv. Analyze and report fig. [3.4].

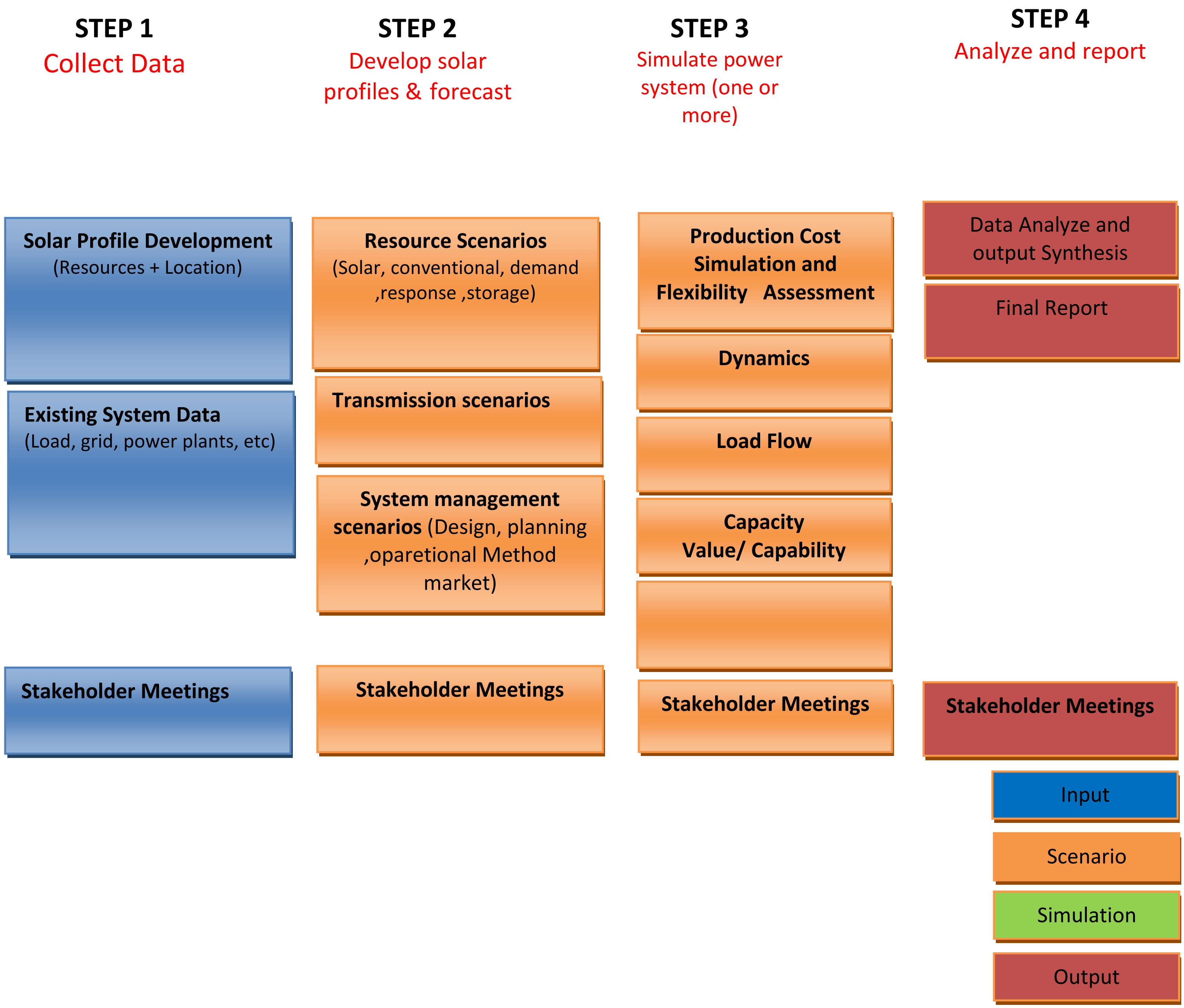


Fig [3.2] Successful solar integration four steps .

STEP 1 : COLLECT DATA

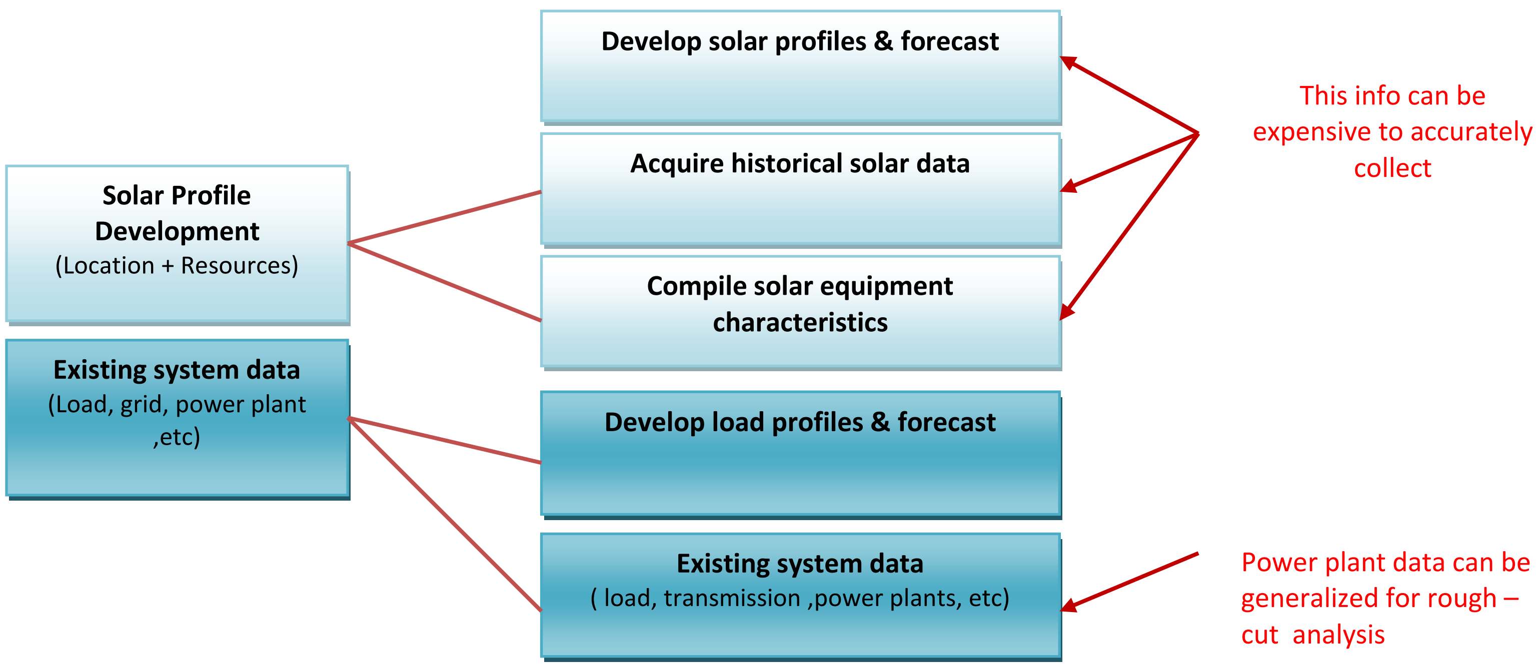


Fig [3.3] Collect Data

STEP 2: DEVELOP SCENARIOS

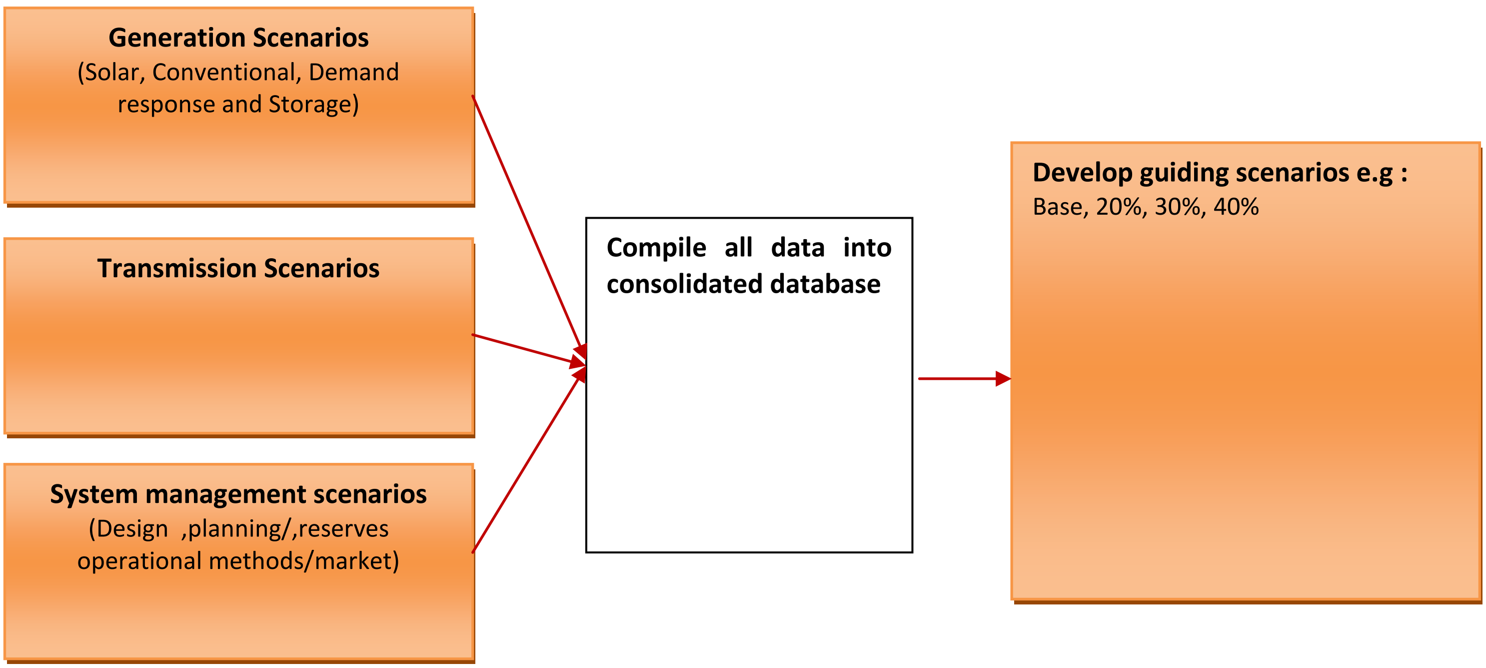


Fig [3.4] Develop Scenarios.

STEP 3: Simulate the Power System

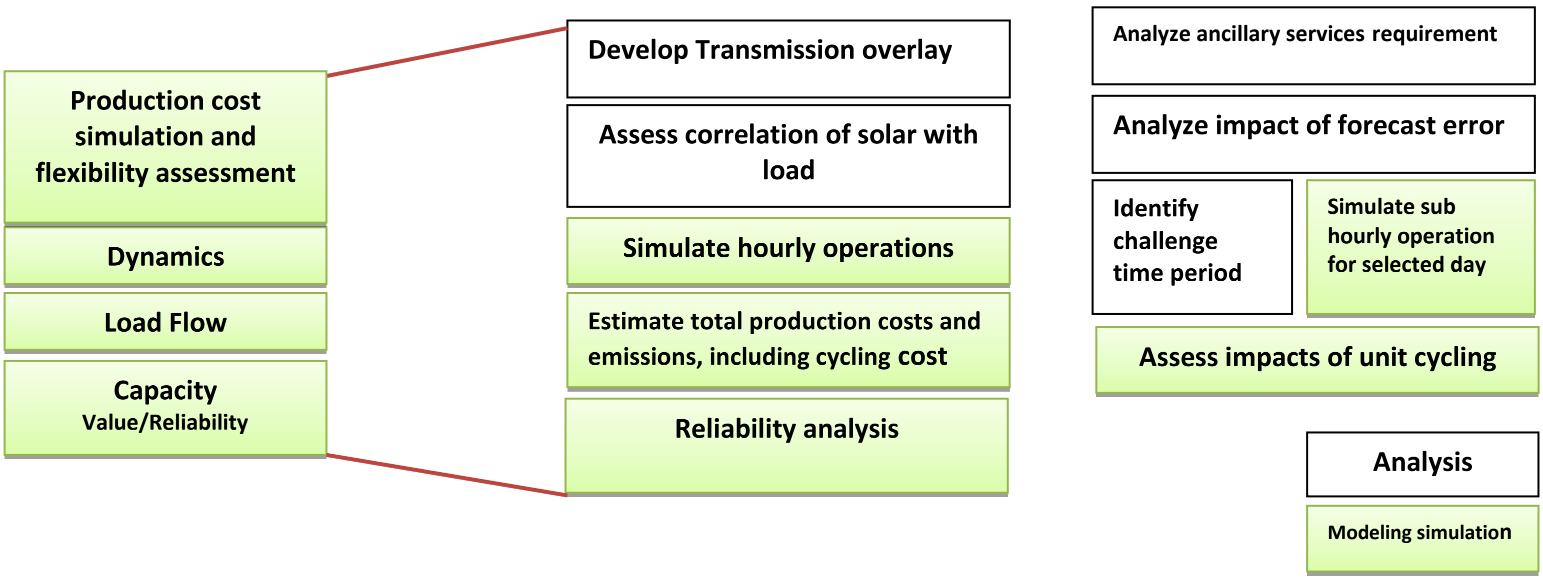


Fig [3.5] Simulate the Power System.

STEP 4: ANALYZE AND REPORT

Data Analysis and output SynthesisProduction Cost Simulation and Flexibility Assessment

Final Report

Evaluate performance under normal/ abnormal conditions:

-Performance concern - Review existing practice

-Secondary reserve for frequency response

Develop Transmission overlay

Develop transmission Overlay

Evaluate mitigation measures

- Comparative approach

- Measures of efficacy

Fig [3.6] Analyze and Report.

3.4 The Solar generation plant scale classification:

Variable-generation sources – which include wind, solar, ocean and some hydro – are all renewable-based. There are two major attributes of this variable renewable energy [VRE] that distinguish it from conventional forms of generation and may affect planning and operations for bulk power systems: the variability and a higher degree of uncertainty**.** In recent years, the most auspicious usage of PV-based generations has been their integration into the interconnected power grid. In the category of distributed systems, PV may be broadly classified into four types:

[1 Very large scale, the power capacity is higher than 100 MW.

[2] Large - scale, it is considered around 1 to 100 MW.

[3] Medium Scale, it is around 250- 1000 KW.

[4] Small scale PV systems, the range of capacities is up to 250 kW.

Here in this project we will focus on "utility-scale" – i.e., generally over 1 megawatts [MW] – implementations of solar photovoltaic [PV] power plants in the bulk power system. Small PV connected at distribution levels, such as residential and small commercial installations are out of the scope of this project. Conceptually, modern VRE [8].

3.5 Design consideration and concepts for interconnection:

3.5.1 Essential ability of generator and operator for interconnection solar plants:

1] Voltage regulation and reactive power capability

2] Low- and high-voltage ride-through

3] Inertial-response [effective inertia as seen from the grid]

4] Control of power ramp rates and/or curtailing of power output

5] Frequency control [governor action, automatic generation control, reserve, etc.]

The ability and extent of variable generation to provide the above functions affects the way in which PV plant can be readily integrated into the power system. Interconnection procedures recognize the unique characteristics of variable-generation technologies but focus on the overall performance of the bulk power system rather than that of an individual generator [14].

3.6 Interconnection Stages

In general, bringing a utility-scale generation resource online can be divided into three major stages, each with its own set of required studies:

1] Stage 1 [Interconnection Studies]: Network-wide and project-specific planning encompassing various interconnections studies in addition to project development.

2] Stage 2 [Design Studies]: Resource modeling and registration and, in the case of private PV plants, the signing of power purchase agreement [PPA]

3] Stage 3 [Control Studies]: Connection to the grid, commissioning, and testing, followed by commercial operations [14].

3.7 Technical concerns for PV Plants interconnection for new generation:

Utilities usually have various technical concerns about connecting new generation to their transmission and distribution facilities and integrating it into the bulk power system. For solar plants, most of the concerns fall into the following categories:

1] *Standards and Procedures:* PV integration in the grid requires maturity of standards and procedures to ensure reliable and optimal grid operations.

2] *Remote Dispatch:* The dispatch capabilities are limited and require improvement.

3] *System area control error [ACE]:* PV plants' ramp rates in the morning and evening, along with their response to clouds, are of major concern as they impact system ACE and area voltages.

4] *Power Quality*: PV plants must be aware of electromagnetic transients, flicker, and harmonics impacts in the system, if only to know that their plant is not causing a system problem.

5] *Reactive power support and regulation*. Voltage regulation and power factor control are limited and require improvement.

6] ***High-voltage ride-through [HVRT], low-voltage ride-through [LVRT], and islanding***. PV plants, along with all other generation, must be able to handle correctly any issues arising from new PV interconnections and/or new grid codes.

7] *System-normal and contingency operation [slow regulation]:* This involves the PV plant's impact on system-normal and contingency flows and voltage.

8] *Transient and Voltage Stability [Dynamic Events]:* The dynamic change in the PV plant's output could, in combination with other system events, cause unforeseen, fast-acting issues.

9] *Fault currents:* This refers to the impact of additional PV plants on short-circuit current ratings.

10] *Stability Models*: The stability models require further development for conducting studies [14].

3.8 The technical requirements for integration between solar and traditional plants:

1] Regulation, automatic response to grid events, and controls

a] Voltage control/reactive power control: This relates to the ability of PV plants to respond to voltage fluctuations at their point of interconnection [POI]. Reactive power from generators assists the flow of power and variations in that reactive power will affect local voltage. All equipment connected to the system is expected to be able to operate within a range of the nominal values, typically ±10 to ±15 percent of the nominal value for voltage, depending on the country's grid code.

b] Frequency control/active power control*:* This is the ability to provide active [or real] power regulation, particularly downwards, in response to over-frequency [measured in watts]. Variations in active power output will have an impact on system frequency. The control of active power may be via AGC. All equipment connected to the system is expected to be able to operate within a range of the nominal values, typically **−5 to +3 percent** of the nominal value for frequency.

c] Spinning reserves: These are extra reserves of power that can be made immediately available by power plants that are already connected and operating to reduce the area control error [ACE], which is proportional to the frequency deviation, thereby correcting imbalances that cannot be corrected with AGC.

In systems with non-negligible PV penetration, spinning reserves should be quantified dynamically and proportionally to the expected PV output.

d] Fault ride-through: PV plants may or may not have the capability to remain connected to the network for a certain length of time during voltage disturbances. PV plants should provide reactive power in the event of low voltage, contributing to the management of faults.

e] Active and reactive power control: This specifies the capability to limit active and reactive power production in response to signal from system operator. This is an advanced feature applicable to grids with significant variable energy penetration.

f] Synthetic inertia: This is relevant for very high shares of PV. PV plants do not provide inertia to the system, so at higher shares the rate of change of frequency [Ro CoF] will increase. Synthetic inertia can be engineered, but this requires very advanced control methods and additional hardware components.

g] Monitoring and supervisory controls

i] Metering and SCADA: This specifies the location of installation and properties of the revenue meter, general monitoring parameters and controls for SCADA, protocols for data exchange between PV plant and system operators.

ii] Communication systems: These are to allow the system operator to monitor the output of PV plants in real time, as well as direct control of PV plants via AGC.

2] Power quality: The main aspects of power quality include harmonics and flicker, which occur in terms of waveform distortions and short–term fluctuations. The limits on power quality parameters need to be specified and respected.

3] Protection systems: These are to isolate faults and mitigate the impact of faults on the electrical network. Standards for protection systems are required in all phases of PV deployment. PV plants are responsible for protecting their equipment from faults in the grid. The situations in and duration for which PV plants should stay connected should be specified for the plants.

4] Forecasting and analysis

a] Solar resource forecasting: This relates to tools for forecasting the output of PV power plants over different time frames [e.g., frequency, duration, and resolution] to help system operators and planners schedule dispatch able power plants and spinning reserves cost effectively. Forecasting tools become more important as more PV plants are connected to the system.

b] Simulation models: These are models that replicate the physical behavior of the electric grid, which are used to simulate possible scenarios to facilitate decision-making in power system planning and operation. Accurate and updated grid and generator models are required to ensure the accuracy of the simulation. Generation owners should provide simulation models of the power plants connected to the system [14].

3.9 Economics and performance of a PV plant

After calculating the various parameters of the photovoltaic plant, an economic study is necessary to analyze the profitability of the plant, at the same time; we should have a primary idea about the costs of the investment.

To do so, we propose a study that will go through the following steps:

- Determination of the investment cost of the project.
- Determination of operating costs.
- Calculation of estimated kWh cost.
- Determination of project profitability criteria [12].

Summary:

- The goal of this chapter is to review the current and future discussions regarding generation and integration of large-scale solar generation into a conventional fossil-fuel national grid.
- The effects of this integration on system stability and security should therefore be considered carefully even before installations of plant. The use of advanced integration technologies should be considered before plant installation, this will help the generation and distribution company to foresee the possible impact of PV integration and generation on system stability.
- In this project the “utility-scale” large power plant integration discussed not DG connected at distribution levels, such as residential and small commercial installations are out of the scope of this project. Conceptually, modern.

- For successful integration should know before integration grid connection code, solar reflected in system operation, Is the grid still sufficient for continuing solar deployment, Is solar developed in the system friendly way.
  - The process of grid integration study are in four steps collect data, Develop solar profiles & forecast Simulate power system [one or more] and Analyze and report.
  - The Solar generation plant scale classification Very large scale above [100MW],large scale around [1-100]MW, medium scale [250-1000]KW and small scale up to 250 KW.
  - Essential ability of generator and operator for interconnection solar plants are Voltage regulation and reactive power capability, Low- and high-voltage ride-through, Inertial-response [effective inertia as seen from the grid], Control of power ramp rates and/or curtailing of power output, Frequency control [governor action, automatic generation control, reserve, etc.]
  - Interconnection Stages studies are Interconnection Studies, Design Studies and Control Studies
  - Technical concerns for PV Plants interconnection for new generation a standards and procedures, remote dispatch,

    system area control error [ACE],power Quality, reactive power support and regulation, system-normal and contingency operation [slow regulation], *high-voltage ride-through [HVRT], low-voltage ride-through [LVRT], and islanding,* system-normal and contingency operation [slow regulation], transient and voltage stability [Dynamic Events],fault currents and stability models.
  - The technical requirements for integration between solar plant and traditional plants are regulation, automatic response to grid events and controls, power quality, protection systems, forecasting and analysis.

- An economic study is necessary to analyze the profitability of the plant, at the same time; we should have a primary idea about the costs of the investment

CHAPTER FOUR

PV PLANT CALCULATION AND SIMULATION

4.0 PV syst program:

PVSYST is a photovoltaic system analysis software program developed by the Energy Group at the University of Geneva in Switzerland and can be used at any location that has meteorological and solar insulation data it is widely used due to the many parameters available for the user to modify [15].

4.1 First contact with PV syst this gives access to the four main parts of the program:

4.1.1 Preliminary design:

Provides a quick evaluation of the potentials and possible constraints of a project in a given situation.[fig 4.1]

4.1.2 Project design:

It is the main part of the software and is used for the complete study of a project.

4.1.3 Databases:

Includes the climatic data management which consists of monthly and hourly data, synthetic generation of hourly values and importing external data. The databases contain also the definitions of all the components involved in the PV installations like modules, inverters, batteries, etc.

4.1.4 Tools:

Provides some additional tools to quickly estimate and visualize the behavior of a solar installation. It also contains a dedicated set of tools that allows measured data of existing solar installations to be imported for a close comparison to the simulation.

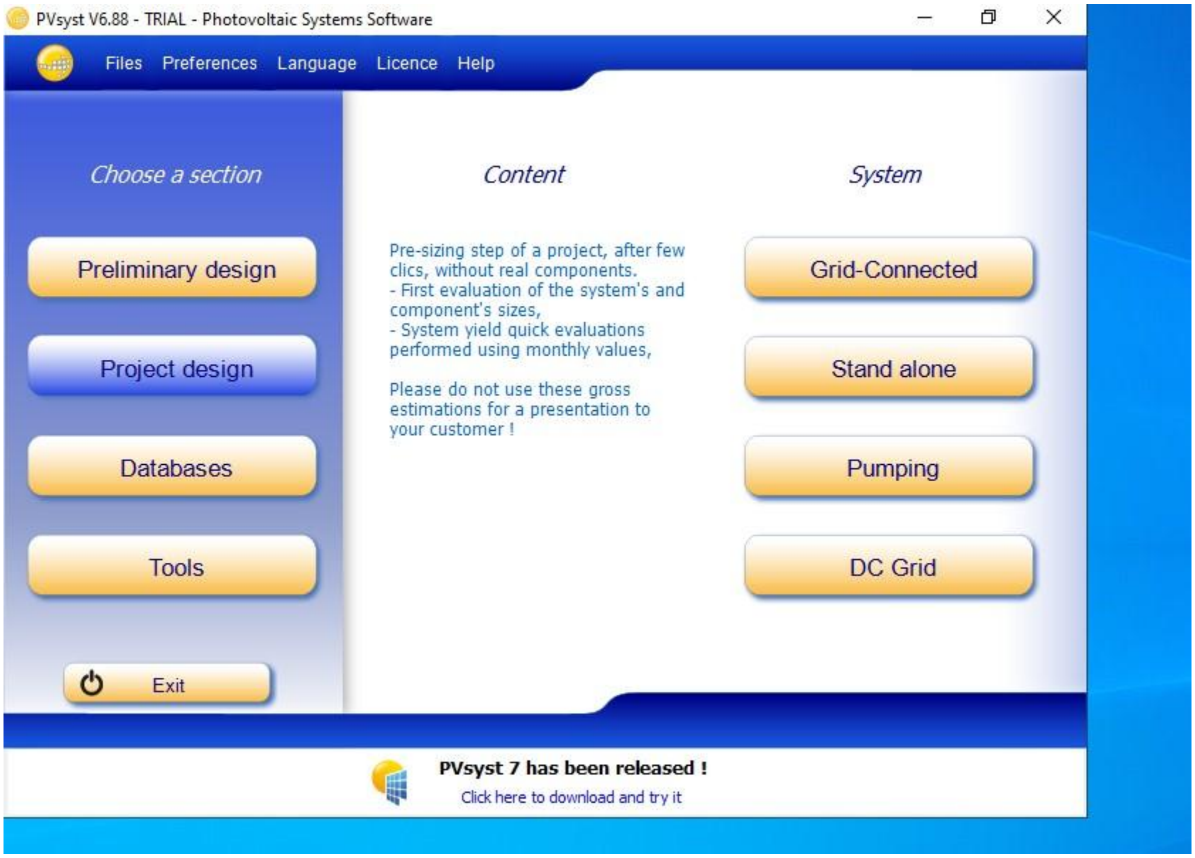


Fig [4-1] PV system software main page

When you choose "Grid connected" project, you will get the following dashboard for the management of a project:

4.2 Steps in the development of the project:

There are general steps should be follwod for establishing the desaing in the programme descriped in the following.

4.2.1 Pre-Design Phase:

- Site and meteorology: Khartoum

- System definition: The nominal power of the system is set at 64 MW

- System specifications definition: The module type is set as standard with poly-Si module.

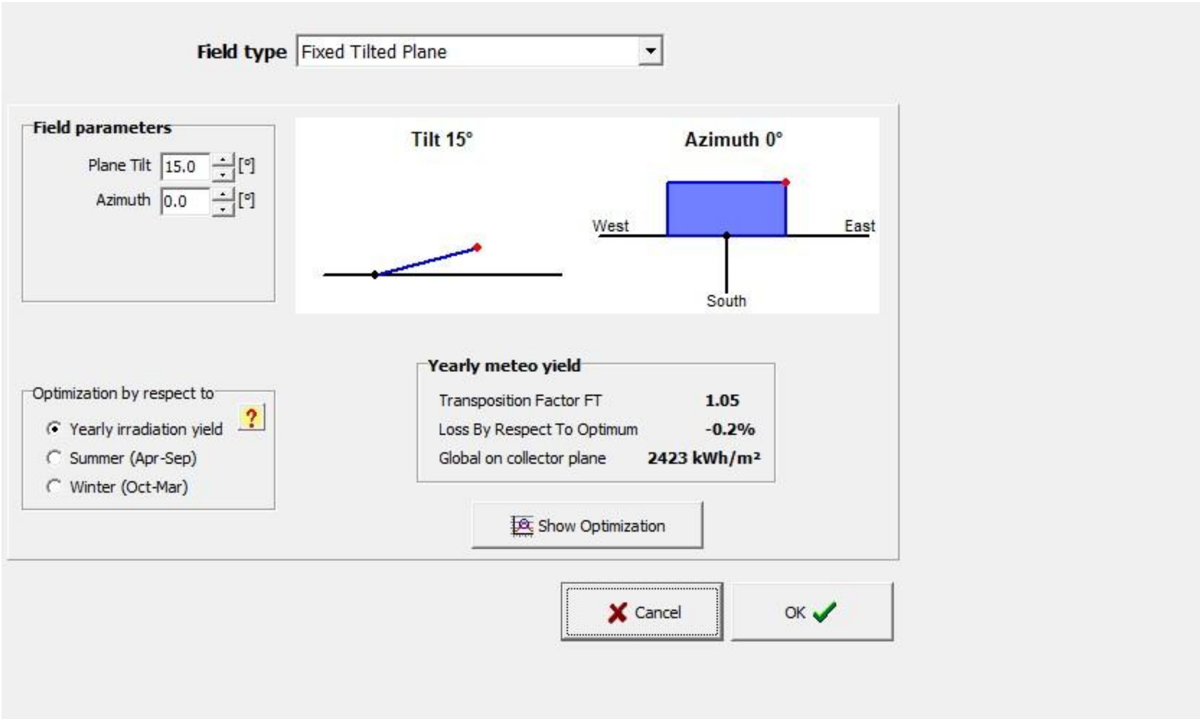


Fig. [4.2] Orintation of solar panel

This is acollector (fix)plane orintation to show the best suited orientation for a PV system fig [4.2] depending on the location Al Bagaer. For an optimization on annual yield, optimum tilt angle is defined in 15º and azimuth angle in 0º (south oriented).With transportation factor of 1.05,loss by respect to optimum – 0.2% and global on collector plane 2423 kwh/m^2 .

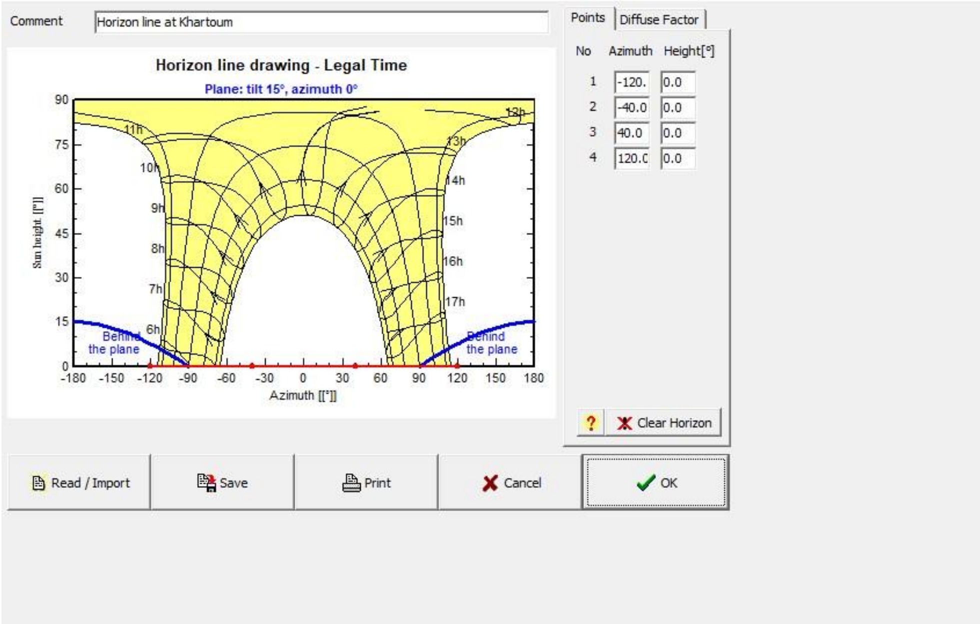


Fig. [4.3] Horizon Line drawing – Legal Time

The above fig [4.3] is about sun path, 90 is latidute of the sun,6 h -11 h are the morning hours, 12 h – 17 h are the afternoon, the tilt angle is 15^0 and azmouth is 0^0

4.2.2 Design Phase:

Once the pre-design phase is the final design of the PV power plant project is made. The steps to calculate the PV solar power plant final design are shown below:

- Location and climate data: In this case, to make the calculation more accurate a location closer to the real location of the PV project is added to the meteorological database. The closer possible
- PV modules orientation definition: For this simulation, the PV modules are
- determined as fixed. The tilt angle of the PV modules installed is going to be 15 dgree.

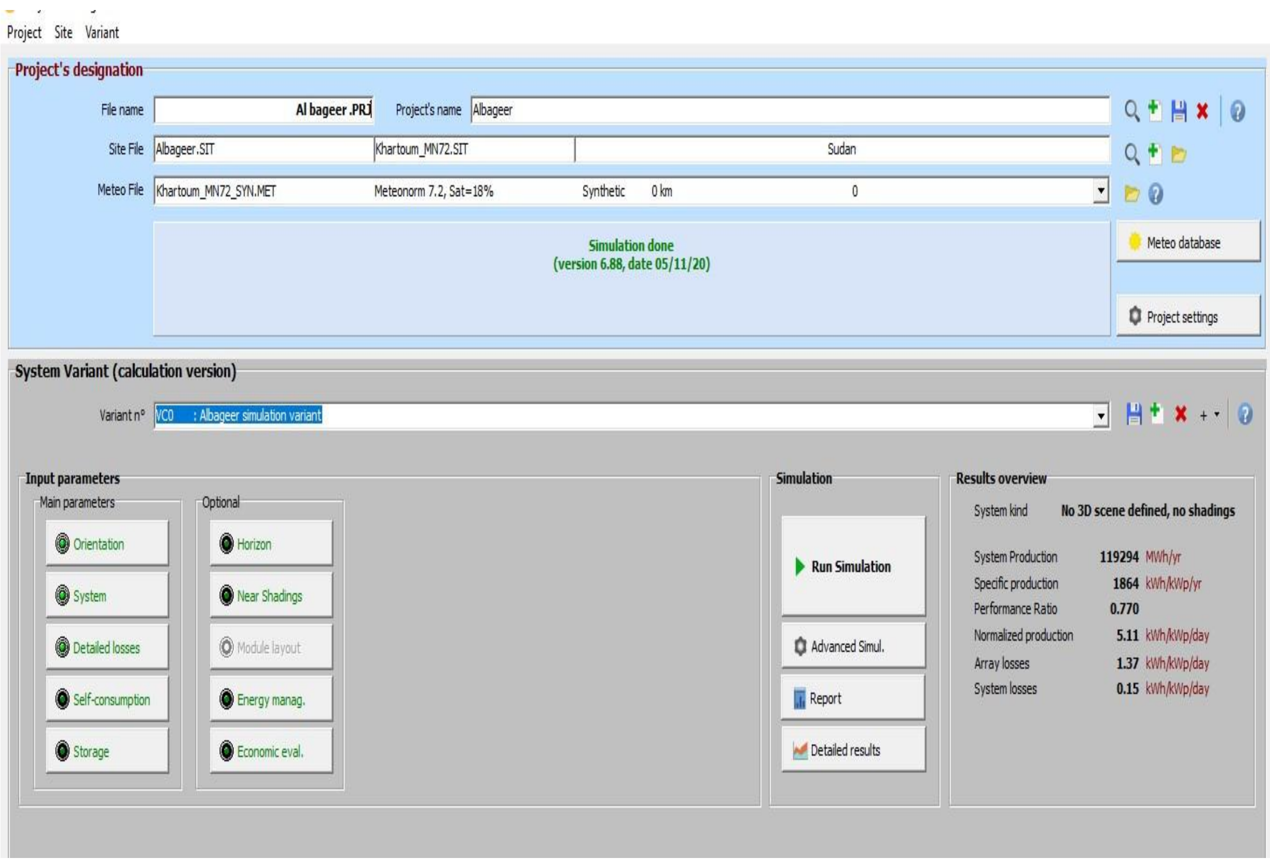


Fig. [4.4] Project's designation

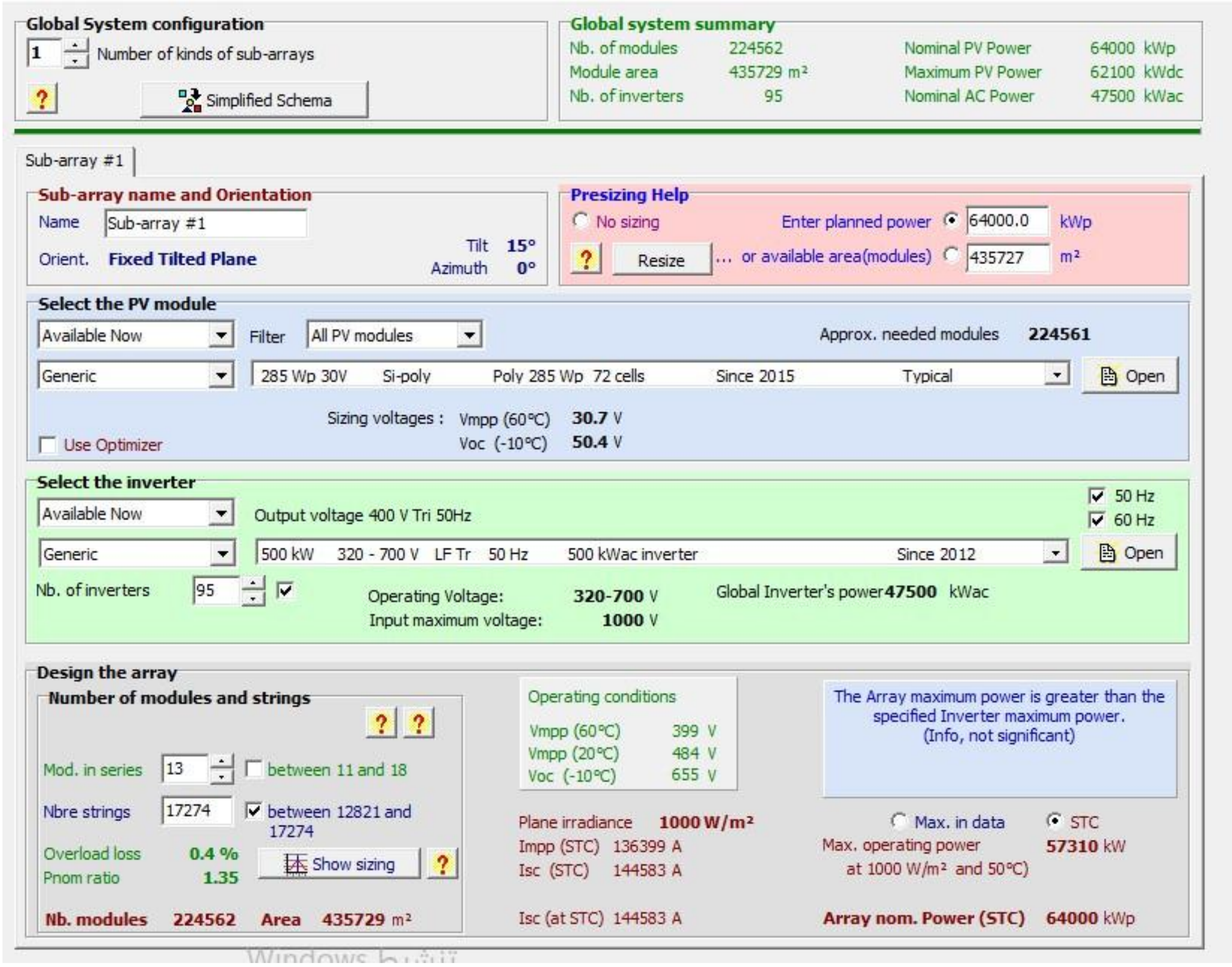


Fig. [4.5]: Grid system definition " Albageer simulation variant"

4.4 PV Sys PV Plant report:

In this report we have4/4 pages in the top right corner you will find the following table 4.1: Report contents

Report contents	
Page Number	Description
1/4	Grid-Connected System: Simulation parameters
2/4	Grid-Connected System: Main results
3/4	Grid-Connected System: Special graphs
4/4	Grid-Connected System: Loss diagram

Grid-Connected System: Simulation parameters

Project : **Albageer**

Geographical Site	**Khartoum**		Country	**Sudan**
Situation	Latitude	15.36° N	Longitude	32.70° E
Time defined as	Legal Time	Time zone UT+2	Altitude	380 m
	Albedo	0.20		
Meteo data:	**Khartoum**	Meteonorm 7.2, Sat=18% - Synthetic		

Simulation variant : **Albageer simulation variant**

Simulation date 06/11/20 16h06

Simulation parameters	System type	**No 3D scene defined, no shadings**		
Collector Plane Orientation	Tilt	15°	Azimuth	0°
Models used	Transposition	Perez	Diffuse	Perez, Meteonorm
Horizon	Free Horizon			
Near Shadings	No Shadings			
User's needs :	Unlimited load (grid)			

PV Array Characteristics

PV module Si-poly	Model	**Poly 285 Wp 72 cells**		
Original PVsyst database	Manufacturer	Generic		
Number of PV modules	In series	13 modules	In parallel	17274 strings
Total number of PV modules	Nb. modules	224562	Unit Nom. Power	285 Wp
Array global power	Nominal (STC)	**64000 kWp**	At operating cond.	57310 kWp (50°C)
Array operating characteristics (50°C)	U mpp	420 V	I mpp	136399 A
Total area	Module area	**435729 m²**	Cell area	392894 m²
Inverter	Model	**500 kWac inverter**		
Original PVsyst database	Manufacturer	Generic		
Characteristics	Operating Voltage	320-700 V	Unit Nom. Power	500 kWac
Inverter pack	Nb. of inverters	95 units	Total Power	47500 kWac
			Pnom ratio	1.35

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.	0.052 mOhm	Loss Fraction	1.5 % at STC
Module Quality Loss			Loss Fraction	-0.8 %
Module Mismatch Losses			Loss Fraction	1.0 % at MPP
Strings Mismatch loss			Loss Fraction	0.10 %

Incidence effect (IAM): Fresnel smooth glass, n = 1.526

0°	30°	50°	60°	70°	75°	80°	85°	90°
1.000	0.998	0.981	0.948	0.862	0.776	0.636	0.403	0.000

Grid-Connected System: Main results

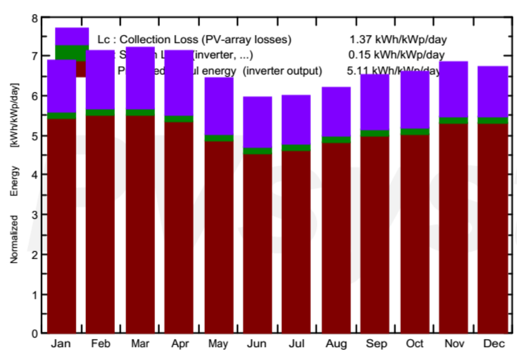
Project : **Albageer**

Simulation variant : **Albageer simulation variant**

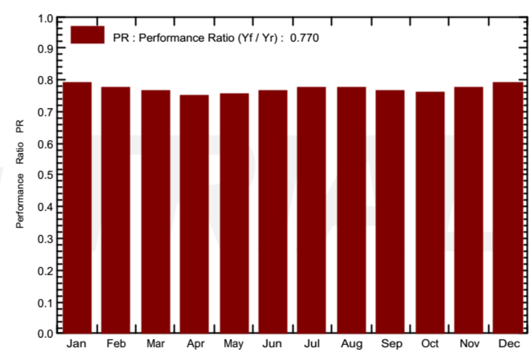
Main system parameters	System type	**No 3D scene defined, no shadings**		
PV Field Orientation	tilt	15°	azimuth	0°
PV modules	Model	Poly 285 Wp 72 cells	Pnom	285 Wp
PV Array	Nb. of modules	224562	Pnom total	**64000 kWp**
Inverter	Model	500 kWac inverter	Pnom	500 kW ac
Inverter pack	Nb. of units	95.0	Pnom total	**47500 kW ac**
User's needs	Unlimited load (grid)			

Main simulation results				
System Production	**Produced Energy**	**119398 MWh/year**	Specific prod.	1866 kWh/kWp/year
	Performance Ratio PR	77.05 %		

Normalized productions (per installed kWp): Nominal power 64000 kWp



Performance Ratio PR



Albageer simulation variant

Balances and main results

	GlobHor kWh/m²	**DiffHor** kWh/m²	**T_Amb** °C	**GlobInc** kWh/m²	**GlobEff** kWh/m²	**EArray** MWh	**E_Grid** MWh	**PR**
January	179.6	31.97	23.64	213.2	208.1	11121	10791	0.791
February	177.6	39.22	26.18	199.4	194.9	10198	9885	0.775
March	211.6	58.74	29.29	223.1	217.3	11247	10912	0.764
April	216.0	65.62	32.90	213.9	207.4	10606	10296	0.752
May	212.0	79.48	35.04	200.0	192.9	9947	9657	0.754
June	193.2	81.54	34.64	178.8	172.2	9012	8748	0.764
July	198.3	87.05	32.76	185.5	178.7	9471	9199	0.775
August	198.1	91.49	31.61	192.9	186.5	9883	9598	0.778
September	190.6	71.64	32.37	195.5	189.5	9872	9580	0.766
October	187.4	61.83	32.82	204.7	198.7	10277	9981	0.762
November	175.5	38.82	28.44	205.5	199.9	10501	10197	0.775
December	173.0	30.75	25.00	208.8	203.8	10876	10553	0.790
Year	2312.8	738.14	30.41	2421.3	2350.0	123012	119398	0.770

Legends:

GlobHor	Horizontal global irradiation	GlobEff	Effective Global, corr. for IAM and shadings
DiffHor	Horizontal diffuse irradiation	EArray	Effective energy at the output of the array
T_Amb	T amb.	E_Grid	Energy injected into grid
GlobInc	Global incident in coll. plane	PR	Performance Ratio

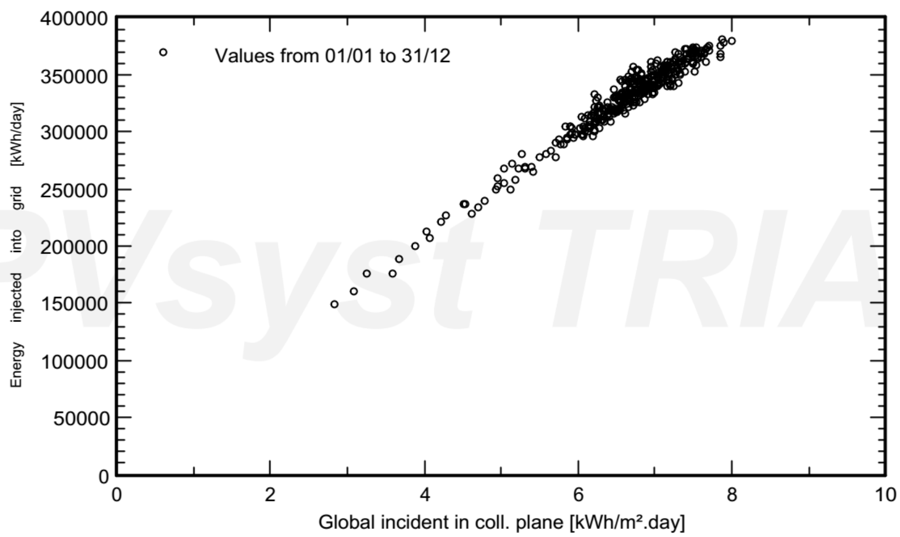
Grid-Connected System: Special graphs

Project : **Albageer**

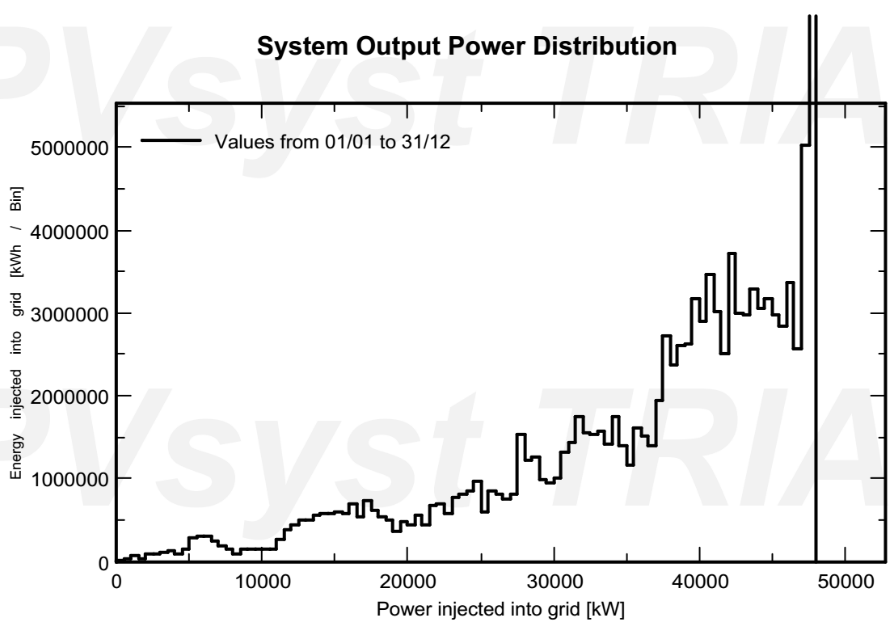
Simulation variant : **Albageer simulation variant**

Main system parameters	System type	**No 3D scene defined, no shadings**		
PV Field Orientation	tilt	15°	azimuth	0°
PV modules	Model	Poly 285 Wp 72 cells	Pnom	285 Wp
PV Array	Nb. of modules	224562	Pnom total	**64000 kWp**
Inverter	Model	500 kWac inverter	Pnom	500 kW ac
Inverter pack	Nb. of units	95.0	Pnom total	**47500 kW ac**
User's needs	Unlimited load (grid)			

Daily Input/Output diagram



System Output Power Distribution



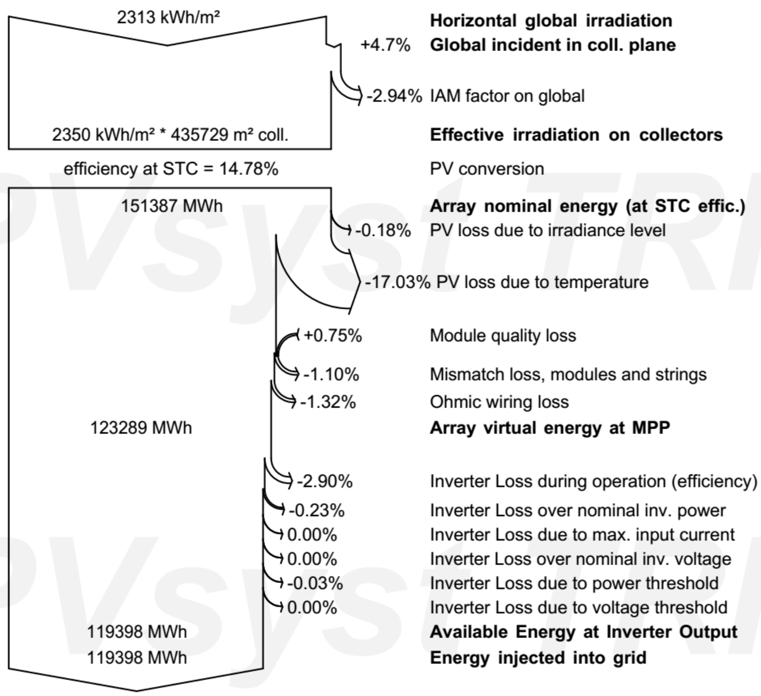
Grid-Connected System: Loss diagram

Project : **Albageer**

Simulation variant : **Albageer simulation variant**

Main system parameters	System type	**No 3D scene defined, no shadings**		
PV Field Orientation	tilt	15°	azimuth	0°
PV modules	Model	Poly 285 Wp 72 cells	Pnom	285 Wp
PV Array	Nb. of modules	224562	Pnom total	**64000 kWp**
Inverter	Model	500 kWac inverter	Pnom	500 kW ac
Inverter pack	Nb. of units	95.0	Pnom total	**47500 kW ac**
User's needs	Unlimited load (grid)			

Loss diagram over the whole year



4.5 Report conclusion:

In the following tables 4.2 project details are mentioned taken form PV syst report. Table 4.3 about quantities of project components.

Project Details	
Khartoum – Al bagaier	
Capacity	**64 MW**
PV module	**Si-Poly, 285wp, 72 cell, Generic**
Type of installation	**Ground-mounted**
array peak Power	**64000KWac**
Orientation parameters	**Plane tilt/azimuth = 15° / 0°** **Fixed Tilted Plane**
Shading consideration	**Shade-free**
Grid voltage	**33KV or above**
Phase connection	**3-phase**
Grid frequency	**50Hz**
Available/required area	**435727 m2[apprx.]**
Safety level	**IP65**

Table [4.2]: Simulation parameters

Item	Quantity
PV array	**1**
Total number of PV modules	**35088**
Inverters	**95**
Module area	**435727 m^2**
Produced energy	**119398 MW.h/year**
Performance ratio	**77.05%**

Table [4.3]: Simulation variant

CHAPTER FIVE
CONCLUSION AND RECOMMNDATIONS

5.1 Conclusion:

- The study is focused on the design a large-scale PV solar power plant, specifically a 64MW PV plant. The design is carried out a methodology for the calculation of the different parameters required for the realization of a project of this nature with PV sys programme. The site selected for the installation is in the location of South *Khartoum- Al Bageer project* which meets all the requirements for the installation of a PV plant power.
- In this study, current solar-grid integration technologies are identified, benefits of solar-grid integration are highlighted, solar system characteristics for integration. This study will help in the implementation of solar-grid integration in new projects.
- Power quality should be considered in the context of solar interconnection as they explain most of functional requirements,limitation,and impacts and impacts associated with the power quality aspects of interconnection:IEEE SCC-22,IEEE 1159,IEEE P1159,IEEE 1346,..etc
- Several key challenges surface when evaluating the integration of energy into a green growth framework, especially one needed to address the consequences of climate change due to increased emissions

5.2 Recommendations:

- We recommended that to follow four-part approach to establishing a green growth agenda for alternative energy presents opportunities to foster an environment where multiple solutions can be forged to solve climate change.

- Black start capability or back up should be in account of solar PV plant in event of disturbance in power system to which they are connected
- All designs must meet NFPA70 National Electrical Code [NEC] requirements. Successful connection of a medium-scale solar plant should satisfy requirements of both the Solar Energy Grid Connection Code [SEGCC] and the appropriate code, the Electricity Distribution Code [EDC] or the Grid Code[GC] as the connection level apply.
- We advaice that to do many simulation senareos for selecting the best solar plant desaing and componenets also the study of the project should include economic evaluation.
- Economical evaluation of solar plant is very important for desing.

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