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Thème

Design and simulation load flow of grid - connected PV system on distribution network Using ETAP software Application Ain ELmelh /Msila PV station

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ABSTRACT

Nowadays, the integration PV system on distribution network is getting popular because of its advantage of renewable integration to the traditional power grid.in this project, a design of 20MW of micro grid system under different operating conditions to connect a distribution network are presented. the model of PV plants, inverters, cables, power transformer and 60KV transmission line was modeled using ETAP softwere. The load flow of all system starts with a PV module to consumers is studied and the parameters of Ain Elmelh PV station has used to approved all results. The simulation results have practical significance for real engineering.

<u>Keyword:</u> photoelectric, solar irradiation, photovoltaic power plants, Power grid, Electrical Transient Analyzer Program, Load Flow, transformer substation, power flow, short circuit analysis, harmonic analysis.

نبذة مختصرة

في الوقت الحاضر، أصبح نظام الدمج الكهروضوئي على شبكة التوزيع شائعًا بسبب ميزته للتكامل في هذا المشروع، يتم تقديم تصميم 20 ميجاوات لنظام الشبكة الصغيرة المتجدد في شبكة الطاقة التقليدية. في ظل ظروف تشغيل مختلفة لتوصيل شبكة التوزيع. تم تصميم نموذج المحطات الكهروضوئية والمحولات والكابلات ومحول الطاقة وخط النقل 60 كيلو فولت باستخدام برنامج

ETAP software 19.0.1

يتم دراسة تدفق الحمل لكل النظام بوحدة كهروضوئية نمطية للمستهلكين واستخدمت معلمات محطة عين الملح الكهروضوئية للموافقة على جميع النتائج. نتائج المحاكاة لها أهمية عملية للهندسة الحقيقية

<u>الكلمات الرئيسية:</u> الكهروضوئية، الإشعاع الشمسي، محطات الطاقة الكهروضوئية، شبكة الطاقة، برنامج محلل الكهرباء العابر، تدفق الحمل، المحولات الفرعية، تدفق الطاقة، تحليل الدارة القصيرة، التحليل التوافقي.

TABLE OF CONTENTS

Chapter II: Sizing Photovoltaic plant connected to the electrical network

Chapter III: Description of Ain El Melh photovoltaic plant with a capacity of 20 MW

Chapter IV: Design And Simulation Of Grid Connected PV System For Ain El Melh Grid using ETAP Software

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

- **Vmpp** : the maximum peak power voltage of an individual panel in volts (V).
- **Voc** : the open circuit voltage of an individual panel in volts (V).
- **% Eff** : It shows the calculated panel efficiency in percent.
- **Impp** : the maximum peak power current of an individual panel in amperes.
- **Icc** : the short circuit current of an individual panel in amperes.
- **Alpha** : This coefficient is used to calculate the short circuit current Icc.
- **Beta** : This coefficient is used to calculate the open circuit voltage of the panel **Voc**
- **Delta** : This coefficient is used to calculate the open circuit voltage based on irradiance levels other than base irradiance Voc.
- **Temp** : the base temperature used by manufacturer to determine rated panel power in degrees Celsius (C).
- **Irrad** : the base irradiance used by manufacturers to determine rated panel power in W/m2.
- **I_L or I_{PH}**: Current generated by solar energy [A]
- **I_O** : Diode saturation current [A]
- **V_{PV}** : Ideal unit Cell thermal voltage [V]
- **A** : Diode quality factor (1~1.5)
- **K** : Boltzmann's constant (1.381×10-23) [J/K]
- **T** : Kelvin Temperature at standard test condition (=25°C+273.15) [K]
- **Q** : Charge of the electron (1.602×10-19) [C]
- **n_s** : Number of PV cells connected in series
- **R_{SH}** : Cell parallel(shunt) resistance [Ω]
- **R_S** : Cell series resistance [Ω]
- **I(t)** : solar intensity
- **A_C** : is Area of solar cell.
- **η_{Tref}** : is the module’s electrical efficiency at the reference temperature Tref, and at solar radiation of 1000W/m2,
- **β_{ref}** : The temperature coefficient,
- **γ** : The solar radiation coefficient,
- **T_0** : The (high) temperature at which the PV module’s electrical efficiency drops to zero,

- **T_{NOCT}** : the Nominal Operating Cell Temperature,
- **E_J** : daily energy consumed
- **E** : the irradiation of the place in kWh/m²/day
- **K_P** : called the panel coefficient and equals 0.8
- **η_{ond}** : 90% inverter efficiency
- **η_{reg}** : regulator efficiency 90%
- **E** : is Energy (kWh),
- **A** : is total Area of the panel (m²),
- **R** : is solar panel yield (%), (electrical power (in kWp) of one solar panel divided by the area of one panel).
- **H** : is annual averag annual average solar radiation on tilted panels.
- **β** : is the temperature de-rating factor
- **Idc** : DC current (A)
- **Vdc** : DC voltage (V)
- **P0** : Nominal Power at STC.
- **Ht** : Total Horizontal irradiance on array plane (Wh/m2),
- **Go** : Global irradiance at STC (W/m2).
- **YA** : Array yield,
- **Y_R** : Reference yield,
- **Y_F** : Final yield,
- **P_R** : Performance ratio,
- **L** : size of the sensor.
- **P** : total distance occupied by each panel
- **α** : sun elevation angle (usually taken on December 21, i.e. an angle of 16°).
- **β** : inclination of the panels.
- **Vmin** : the minimum DC voltage of the inverter in percent of the rated voltage.
- **Vmax** : the maximum DC voltage of the inverter in percent of the rated voltage.
- **%PF** : the rated power factor of the inverter in percent.
- **Rg** : the resistance to ground in Ohms.
- **K** : the short-circuit multiplication factor in percent

- **NOCT** : the normal operating cell temperature (NOCT) in degrees Celsius (C).
- **FLA** : the rated full load current of the inverter in amperes
- **DIF** : Diffuse horizontal irradiation kWh/m², MJ/m²
- **DNI** : Direct normal irradiation kWh/m², MJ/m²
- **ELE** : Terrain elevation m, ft
- **GHI** : Global horizontal irradiation kWh/m², MJ/m²
- **GTI** : Global tilted irradiation kWh/m², MJ/m²
- **GTI_opta** : Global tilted irradiation at optimum angle kWh/m², MJ/m²
- **OPTA** : Optimum tilt of PV modules °
- **PVOUT _total** : Total photovoltaic power output kWh, MWh, GWh
- **PVOUT_specific**: Specific photovoltaic power output kWh/kWp

GENERAL INTRODUCTION

Increasing demand and scarcity in conventional sources have triggered the scientist to pave way for the development of research in the field of renewable energy sources especially solar energy, the global emerging trend of deregulated electricity market has underpinned a remarkable stride in the paradigm of distributed by the use of huge photovoltaic plants or wind plants to cope with the inevitable shortcomings such as power outage, poor quality, voltage regulation. These photovoltaic power plants installed not only provide better services to the consumers as backup sources but also eliminate pollution, greenhouse gas emission, and global warming. Where solar energy generation has grown enormously around the world. At the end of 2021 and it is predicted that solar energy will become the second-largest renewable generation source in the world after wind by 2050 [40]. as types of non-renewable energy (oil and natural gas) sources will exhaust one day, it is very important to find alternative electrical energy sources like wind, sea waves, and solar energy. One of the Great wealth.

Numerous nations have already implemented similar systems in their electrical grids, including the Algeria that has tremendous scope of generating solar energy. The reason being the geographical location and it receives solar radiation almost throughout the year, which amounts to 2000 h of sunshine, and it can reach up to 3900 hours, especially in the highlands and the desert. Where Algeria receive 1–5 kW h of solar radiation per sq meters in the north (about 1860 kWh per year per square meter) and 5–7 kW h of solar radiation per sq meters in the great south (about 2738 kWh per year and per square meter) [18, 42].

Algeria has an ambitious plan to build large grid-connected solar power plants, with a cumulative installed capacity of 22 GW by 2030 [41], and the photovoltaic solar power plants, built as part of this project, will be spread over ten wilayas and will mobilize a total area of around 6,400 hectares. Where Algeria has registered modest success so far in terms of procuring renewable energy capacity and build 4,000MW of solar photovoltaic (PV) plants between 2017 and 2021. Where will allow Algeria to meet national energy demand while preserving its fuel. resources and the completion of this projects would allow to position Algeria on the international market via the export of electricity at a competitive price [25].

Due to evolution in the power system, for the last few years' electrical engineers have been concentrating on the power system studies using software tools. That revolutionized in the field of electrical engineering after the development of powerful computer based software. Where This research work highlights the effective use of Electrical Transient Analyzer Program (ETAP 19.1) software for analyses and monitoring of electrical power system, Where this paper deals with the Ain El Melh photovoltaic power plant 20MW simulation in Electrical Transient Analyzer Program (ETAP). and this paper is focused on the detailed analyses, which performs numerical calculations of large integrated power system with fabulous speed besides, generating output reports which will be helpful in implementation of a system. which includes current flowing in every branch, power factor, active and reactive power flow, short circuit analysis and harmonic distortion etc. of large power system. Based upon the recorded data obtained from an actual the Ain El Melh photovoltaic power plant which has been implemented in ETAP for Off - line monitoring and analyses.

I.1.The photovoltaic cell (PV):

The photovoltaic cell (PV) or solar cell is the smallest main element of a photovoltaic installation. The first photovoltaic module was built by Bell Laboratories in 1954 [01], can withstand bad weather.

is comprised of many layers made of semiconductor materials such as silicon each with a specific purpose. The most important layer of a photovoltaic cell is the specially treated semiconductor layer to interact with incoming photons from the Sun in order to generate an electric current, it is comprised of two distinct layers (p-type and n-type—see Figure I.1), a solar cell is simply a semiconductor diode that has been carefully designed and constructed to efficiently absorb and convert light energy from the sun into useful electrical energy (DC), through a process called the photovoltaic effect (see below).

A photovoltaic cell produces a voltage of approximately 0.6 volts, regardless of its surface. But the larger the surface of the cell, the greater the intensity of the current produced, this cell therefore constitutes a very low power generator, insufficient for current electrical applications. These cells are therefore associated in modules (in series and/or in parallel,). In order to obtain the desired voltages/currents, then transformed into alternating current (AC) by converter inverter can be sent to the network.

There are several different types of PV cells which all use semiconductors

I.2.Principle of photoelectric conversion:

PV effect is known as a physical process in which a PV cell converts the absorbed sunlight energy into electricity. It was first experienced in 1839 by Henri Becquerel [02].

The electrons in the atoms of the PV cell are energized by the energy of the absorbed light. With this energy, these electrons move from their normal positions in the semiconductor PV material, and they create an electric flow, that is, electric current through an external electric circuit connected to the PV cell terminals. The built-in electric field that is a specific electric feature of the PV cells provides the voltage potential difference that drives the current through an external load [03].

When two differing p–n semiconductor layer are brought into contact, an electric potential is created between n- and p-type semiconductor layers. Electrons wander across the junction and jump to the p-type semiconductor leaving behind a static positive charge. Simultaneously the holes wander across the junction leaving behind a static negative charge. These free electrons and holes join up and disappear.

At a certain level, a depletion zone is created at the p–n junction where there are no more chances of any charge carrier migration. These separated static positive and negative charges create an electric field across the depletion zone. This built in electric field provides the force or voltage needed to drive the current through an external circuit. When the photon energy from the sun is absorbed by the semiconductor layer it is transferred to the electrons of the material. The electrons get sufficient energy to move to the conduction band which in-turn leaves a "hole" in the valence band. Valence electrons escape from the normal positions in the atoms of semiconductor material and become a part of electric flow or current. This voltage causes electrons to move toward the negative end and holes toward the positive direction. When there is a sufficient amount of sun energy, i.e., when the absorbed photon energy is greater than the bandgap energy of the materials used in the PV cell, the atoms collide and free electrons start to migrate, creating the current of electricity [04]

Figure I.1 shows the pictorial representation of the working of Working Principle P-n junction structure and current flow in a PV cell.

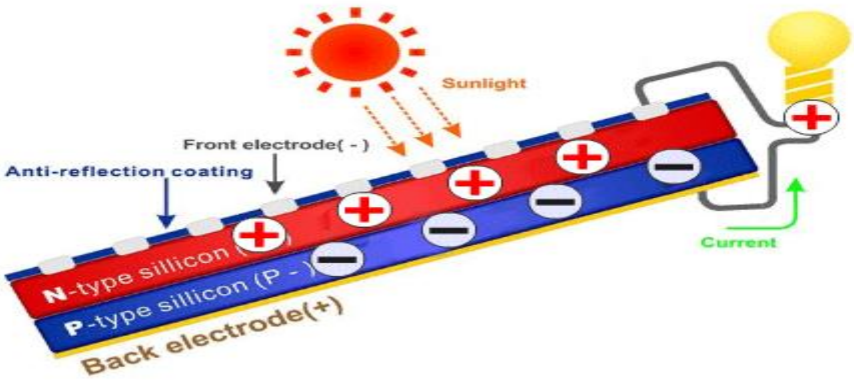

Figure I.1. Schematic representation of Photovoltaic effect in a solar cell

I.3.Electrical characteristic of photoelectric conversion:

Under a given illumination, and under very specific test conditions, standard Test Conditions (STC). (Light emission of 1000 W/m², temperature of 25°C, spectral conditions Air Mass 1.5). And to allow a comparison of the efficiency of different cells, characteristics are defined photovoltaic cell by a current-voltage curve (I-V) representing all the electrical configurations that the cell can take [05]. Three physical quantities define this curve Figure I.2:

- Its open circuit voltage: Vco. This value would represent the voltage generated by an unconnected illuminated cell.
- Its short-circuit current: Isc. This value would represent the current generated by an illuminated cell connected to itself.

- Its maximum power point: MPP obtained for an optimal voltage and current: Vopt, Iopt (sometimes also called Vmpp, Impp).

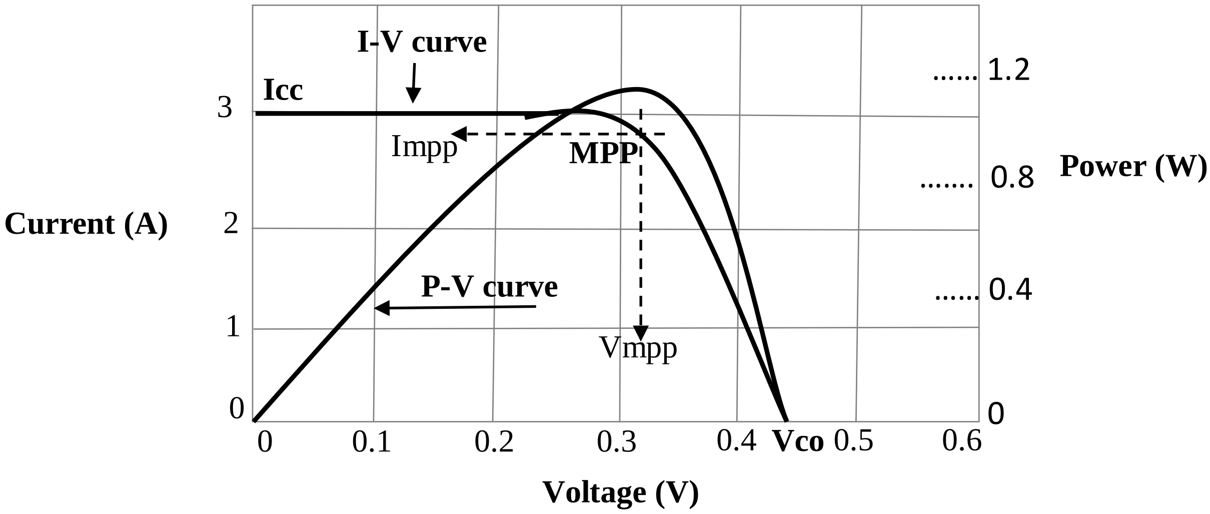

Figure I.2. I V, P V Characteristics Waveform of Solar Cell Array - Diagram

I.4.The influence of temperature on a photovoltaic cell:

One of the main parameters that affect the solar cell performance is cell temperature, the solar cell output decreases with the increase of temperature. Therefore, it is important to select the proper solar cell technology that performs better at a specified location considering its average temperatures.

the overall effect of temperature on a solar cell is to reduce the efficiency of the device by around 0.4 %. By each degree of increase in cell temperature above 25°C [07,37]. of total energy and This reduction in efficiency can be seen as a shift in the maximum power points on the I-V characteristics, as shown in Figure I.3 [08].

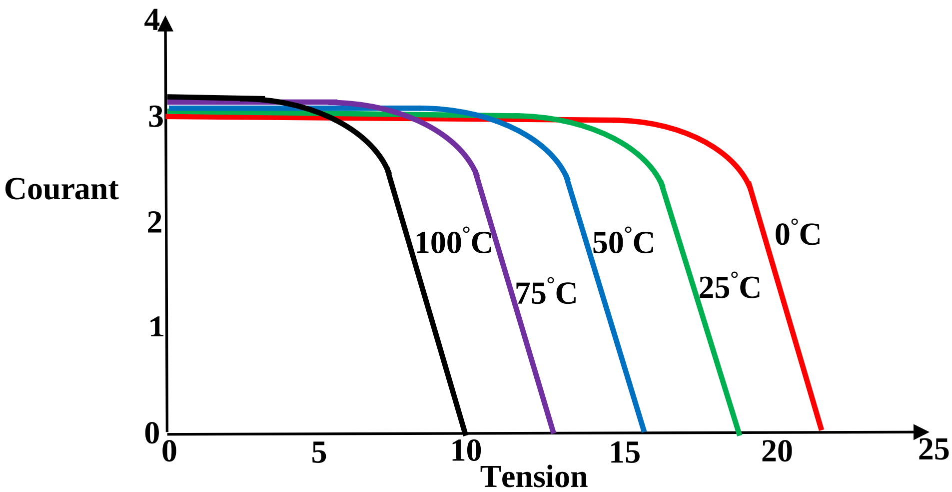

Figure I.3. The Effect of Temperature on Photovoltaic Cell Efficiency

I.5.The influence of Illumination on a photovoltaic cell:

The effects of nonuniform illumination on the performance of a single standard PV cell, at low and medium energy flux concentration ratios, have been investigated, by using of orientation, size, and geometrical shapes as shown in Figure I.4 [09].

From the results we conclude the following for different illuminations (from 0.5kW/m2, 0.8kW/m2to 1 kW/m2) at given temperature of 15°C [10]:

1. The short-circuit current icc varies proportionally to the illumination.

2. The no-load voltage Vco varies little with the illumination. It can be considered as a constant for a given facility

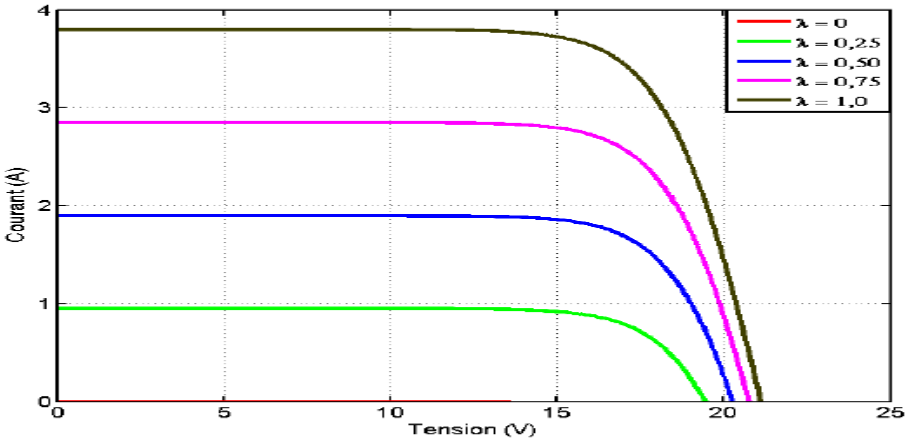

Figure I.4. The Effect of Illumination on a photovoltaic cell Efficiency

I.6.Types of photovoltaic cells:

There are three types of PV cell technologies that dominate the world market be manufactured in many different ways and from a variety of different materials. The most common material for solar panel construction is silicon, which has semiconducting properties.

(monocrystalline silicon, polycrystalline silicon, and thin film.)

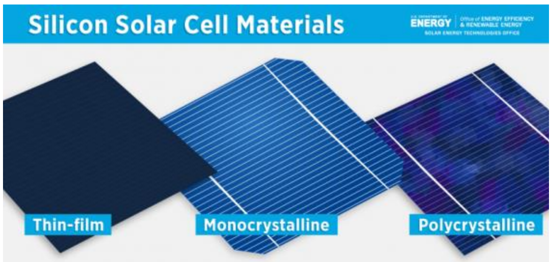

Figure I.5. Types of photovoltaic cells

Matrial	Efficiency (%)
Monocrystalline Silicon	14-17
Polycrystalline Silicon Cell	13-15
Thin Film	5-7

Table I.1. Comparison Of Efficiency Of Solar cells

I.6.1. Monocrystalline Silicon Cell:

Which is an extremely pure form of silicon. To produce these, a seed crystal is pulled out of a mass of molten silicon creating a cylindrical ingot with a single, continuous, crystal lattice structure. This crystal is then mechanically sawn into thin wafers, polished and doped to create the required p-n junction [11, 34].

Monocrystalline silicon cells are highly efficient, and more expensive than their polycrystalline or thin film counterparts.

I.6.2. Polycrystalline Silicon Cell:

Polycrystalline (or multicrystalline) cells contain many small grains of crystals. They can be made by simply casting a cube-shaped ingot from molten silicon, then sawn and packaged similar to monocrystalline cells. Another method known as edge-defined film-fed growth (EFG) involves drawing a thin ribbon of polycrystalline silicon from a mass of molten silicon.

A cheaper but less efficient alternative, polycrystalline silicon PV cells dominate the world market, representing about 70% of global PV production [11, 34].

I.6.3. Thin Film Cells:

One type of thin film PV cell is amorphous silicon (a-Si) which is produced by depositing thin layers of silicon on to a glass substrate. The result is a very thin and flexible cell which uses less than 1% of the silicon needed for a crystalline cell.

Their efficiency, however, is greatly reduced because the silicon atoms are much less ordered than in their crystalline forms leaving 'dangling bonds' that combine with other elements making them electrically inactive [34].

Other types of thin film cells include copper indium gallium diselenide (CIGS) and cadmium telluride (CdTe). These cell technologies offer higher efficiencies than amorphous silicon, but contain rare and toxic elements including cadmium which requires extra precautions during manufacture and eventual recycling [11].

I.7. Connecting cells PV to each other:

This cell constitutes a very low power generator, insufficient for current electrical applications. The modules are therefore produced by association, in series and/or in parallel, of elementary cells. For the electricity generated to be usable for our electrical applications, it is therefore necessary to associate a large number of cells with each other.These modules are then associated in a network (series-parallel) so as to obtain the desired voltages/currents.

I.7.1. Serial association:

By association in series (called "String"), the cells are crossed by the same current and the resulting voltage corresponds to the sum of the voltages generated by each of the cells. as shown in Figure.I.6 (V out =V 1 +V 2 +V 3 +...) [05].

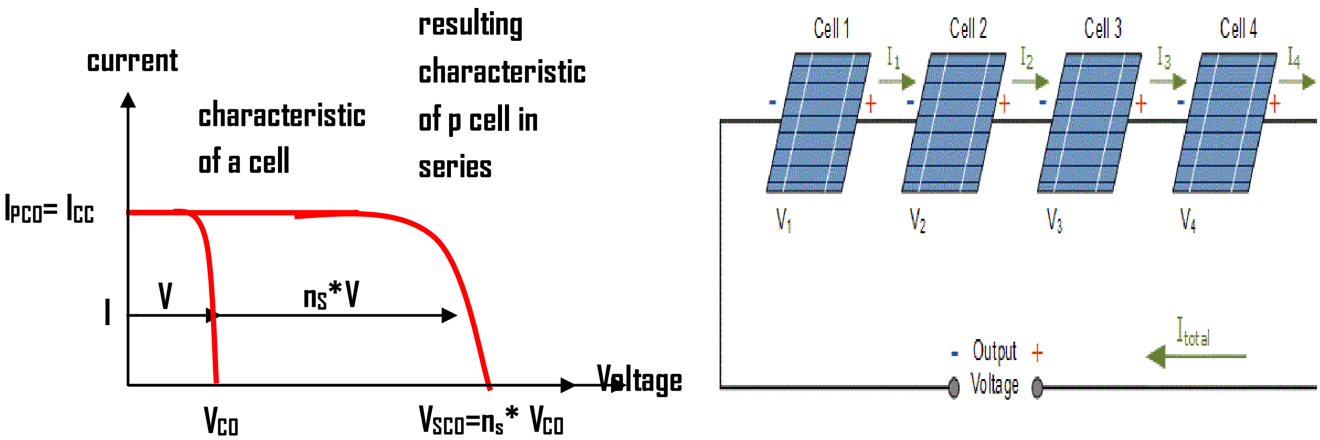

Figure I.6. I-V Characteristics Connecting PV cells in series

I.7.2. Pairing in parallel:

By association in parallel, the cells are subjected to the same voltage and the resulting current corresponds to the sum of the currents generated by each of the cells as shown in Figure I.7 (I out =I 1 +I 2 +I 3 +...) [05].

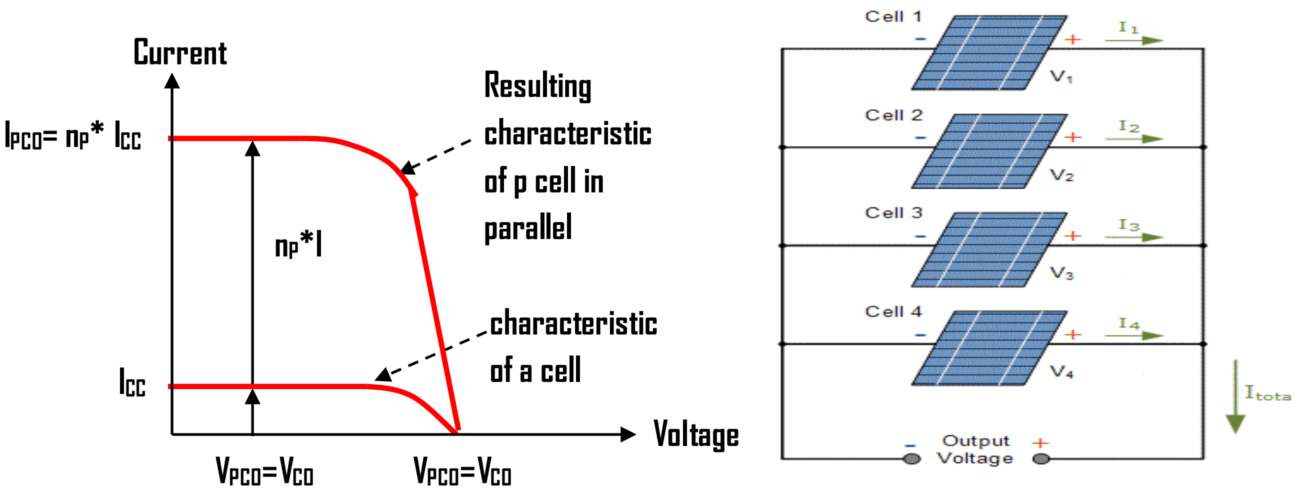

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Figure I.7. I-V Characteristics Connecting PV cells in parallel

I.8. MPPT algorithms:

MPPT or Maximum Power Point Tracking is an electronic DC to DC converter is algorithm that included in charge controllers used for extracting maximum available power from PV module under certain conditions. The voltage at which PV module can produce maximum power is called maximum power point (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature. MPPT is most effective under conditions Cold weather, cloudy or hazy days.

I.9. SOLARPOWER SYSTEMS:

There are basically three kinds of solar power systems through which electricity can be generated. These include:

I.9.1 ON-GRID SOLAR:

If the solar system produces more than required energy which is needed, the excess electricity is sent back to the electricity, and can get paid feed intraffic (Fit).

During night or when the solar power system is not in a proper condition the electricity can be used from the power grid.

The disadvantage of on-grid solar is that during certain climatic conditions or when there is a problem with the electricity grid, we cannot store the electricity for immediate use which becomes a drawback for this system [12].

I.9.2. OFF-GRID SOLAR:

Stand-alone power system has battery storage instead of the connectivity to the electricity grid. After supplying the electricity to the devices if there is any excess amount of electricity that is left out, it is stored in the batteries which act as a backup when there is no support of solar energy. a generator can also be used for backup of power. advantageous for people living in remote areas where there is no accessibility to the utility grid [12].

I.9.3. HYBRID SOLAR:

Hybrid solar is the amalgamation of on grid and off grid solar power systems. The storage of power through batteries for use at any time, without consuming it from the electricity grid makes this system convenient to use and reduces the electricity cost.

When there is neither support of solar energy nor the electricity grid, power can be used from the batteries. Similarly, when there is no sufficient battery backup left and no solar power an uninterrupted flow of electricity can be obtained from the electricity grid and the battery can also be charged [12].

I.10. Solar radiation:

Solar radiation, often called the solar resource or just sunlight, is a general term for the electromagnetic radiation emitted by the sun. Solar radiation can be captured and turned into useful forms of energy, such as heat and electricity, using a variety of technologies.

Solar irradiation is a radiometric quantity that measures the amount of solar energy received per unit area. It can be expressed in kilowatt-hours per square meter (kWh/m^2) or in joules per square meter (J/m^2) in the International System of Units.

I.10.1. Direct radiation:

Sunlight that hits the earth's surface directly is called direct radiation. In contrast to diffuse radiation, the light hits the earth's surface without any obstacles, e.g. clouds, etc. Direct radiation can therefore be defined as any radiation that hits an object by the shortest route, from which it is then partially transmitted as diffuse radiation. PV plants absorb parts of the solar energy and convert it into electrical energy. However, large parts are also reflected and scattered as diffuse radiation. Together with the diffuse radiation, the direct radiation forms the global radiation [13].

I.10.2. Diffuse radiation:

Sunlight that hits the earth's surface does so either directly or indirectly. Indirect solar radiation is called diffuse or scattered radiation. The term "diffuse" means that the light arrives irregularly scattered and without a uniform direction. This is the case, for example, when sunlight penetrates through clouds or changes its direction and/or intensity due to other particles in the air. These particles can be, for example, dust grains, sand or even soot particles. Water - whether in the form of rain or bodies of water - can also be a diffuser. Together with direct radiation, diffuse radiation forms global radiation [13].

I.10.3. Reflected Radiation:

Reflected radiation describes sunlight that has been reflected off of non-atmospheric things such as the ground. Asphalt reflects about 4% of the light that strikes it and a lawn about 25%. However, solar panels tend to be tilted away from where the reflected light is going.

Reflected radiation, or re-radiation from the ground in most cases, is neglected, especially on a surface with inclination b less than 60°. and Care must be taken in using radiation equipment so that no reflected radiation from adjacent walls or ground is present. However, it is difficult to separate this component from diffuse radiation component [14].

I.10.4. Global radiation:

Global radiation is the total solar radiation that falls on a horizontal surface. It is made up of direct radiation and diffuse radiation. Global radiation can be measured with a pyranometer. As a general rule, the radiation is stronger at midday than in the morning and evening, and it is stronger in summer than in winter. In addition, the closer you are to the equator, the stronger the global radiation [13].

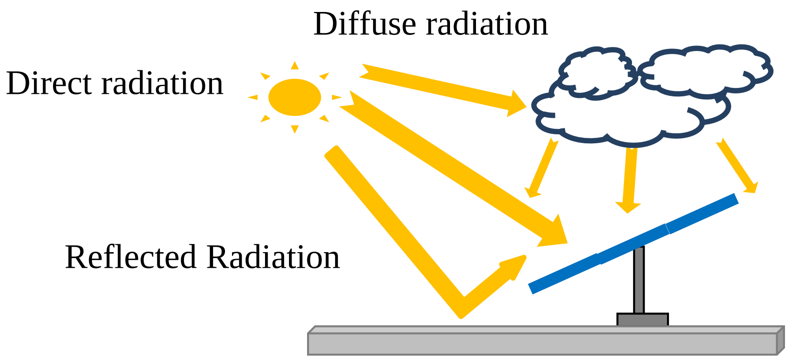


Figure I.8. The three main components of solar radiation

I.11. Tilt Angle:

Every location will have an optimal tilt angle that maximises the total annual irradiation (averaged over the whole year) on the plane of the collector. For fixed tilt grid connected power plants, the theoretical optimum tilt angle may be calculated from the latitude of the site. However, adjustments may need to be made to account for [20].

- **Soiling –** Higher tilt angles have lower soiling losses. The natural flow of rainwater cleans such modules more effectively and snow slides off more easily at higher angles.
- **Shading –** More highly tilted modules provide more shading on modules behind them. As shading impacts energy yield much more than may be expected simply by calculating the proportion of the module shaded, a good option (other than spacing the rows more widely apart) is to reduce the tilt angle. It is usually better to use a lesser tilt angle as a trade-off for loss in energy yield due to inter-row shading.
- **Seasonal irradiation distribution –** If a particular season dominates the annual distribution of solar resource (monsoon rains, for example), it may be beneficial to adjust the tilt angle to compensate for the loss.

I.12. Solar field in Algeria:

Due to its geographical position in the solar belt, Algeria is blessed with an abundance of solar energy and has the opportunity to utilize this bounty of natural energy effectively, a clean environment and developing renewable energy technologies in the region [14].

The country receives direct irradiation estimated at 169,440 kW/m2/year with a potential generation of 3000 kWh/year [15]. Table 1 shows the potential for solar generation in Algeria. The desert in the country is considered to be among the areas with high average solar irradiation and temperature globally. The duration of insolation is around 2000 to 3900 h annually, with horizontal surface radiation of around 3 to 5 kWh/m2. There is a network of 78 meteorological measurement stations operated by the National Meteorological Office (ONM) distributed throughout the country [16, 17, and 35]. Figure I.9. show the country irradiation distribution.

	Location		
	Coastal Area	**Inner Area**	**Desert Area**
Surface (%)	4	10	18
Average of the sunrise (hour/year)	2650	3000	3500
Average energy received (kWh/m2/year)	1700	1900	2650

Table I.2. Solar potential in Algeria [18, 36].

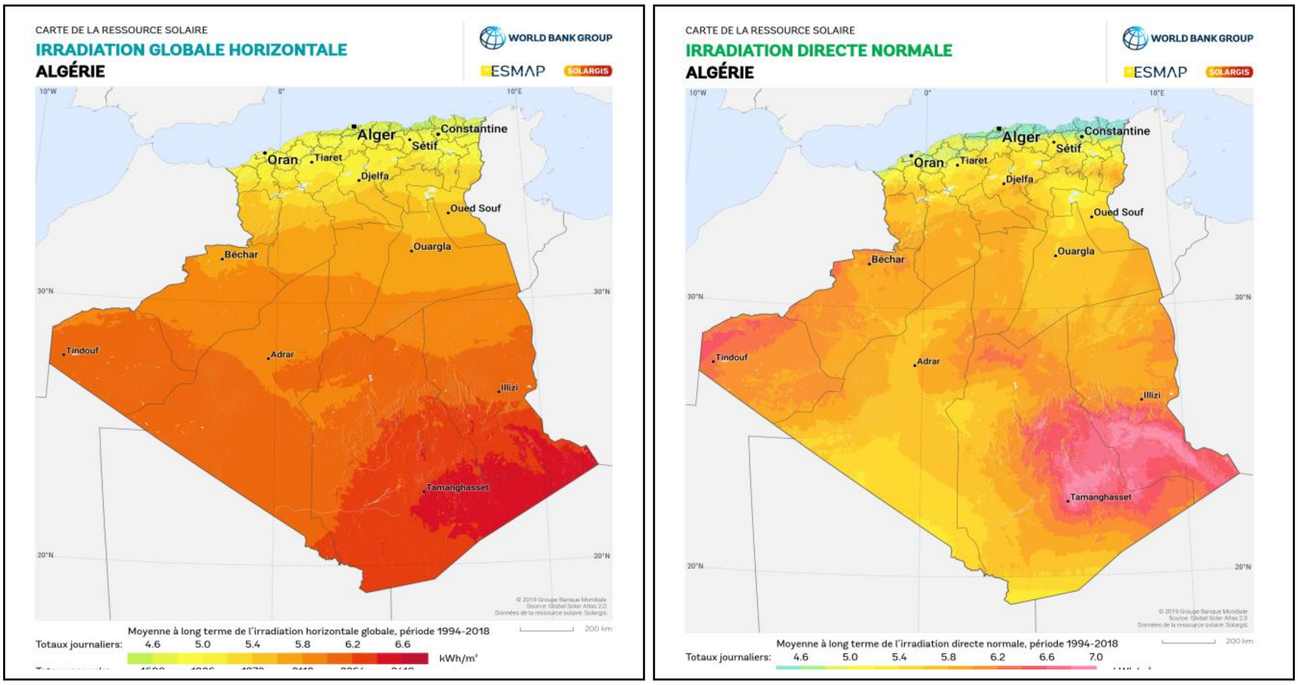


Figure I.9. The solar irradiation in Algeria kW/m2 [19]

II.1. PV Cell Model by Single-diode Electrical Equivalent Circuit:

Generally, the electric characteristics of a PV unit can be expressed with five elements including diode constants (I0, vt), photo current (Iph), series resistance(Rs), and shunt resistance(Rsh) [21]. The variations of these characteristics directly depend on the received solar irradiation and the cell temperature.

Figure.1.5 shows the equivalent electrical and circuit of a typical PV cell

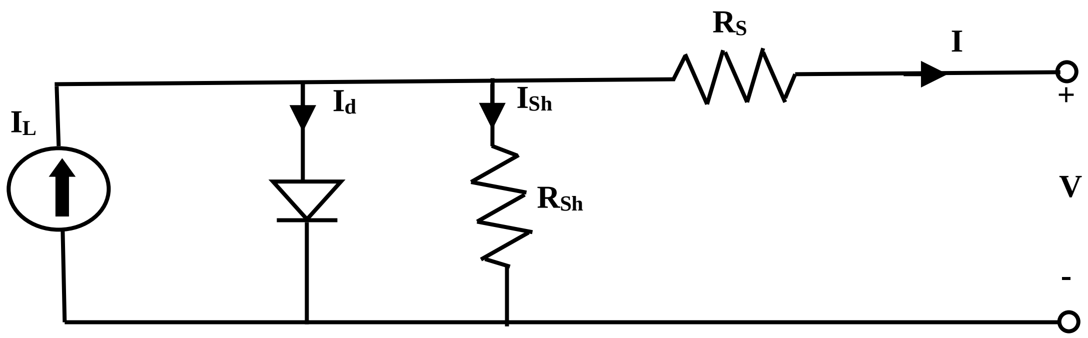


Figure.II.1. Equivalent electrical circuit of a typical PV cell

The values of photo currents can be estimated in proportion to irradiance levels. While, the values of the remaining four elements should be obtained by establishing quaternary first order independent simultaneous equations based on the open circuit voltage (Voc), short circuit current (Isc), and maximum output voltage/current (VMPP /IMPP) which are the 3-operating points provided in the manufacturer's datasheet.

The single exponential equation which models a PV cell is extracted from the physics of the PN junction and is widely agreed as echoing the behavior of the PV cell [22].

$$\boldsymbol{I_{PV} = I_{PH} - I_S * \left[exp\left(\frac{q(V_{PV} + I_{PV} * R_S)}{kT_C A}\right) - 1\right] - \frac{(V_{PV} + I_{PV} * R_S)}{R_{SH}}}$$

- **I_L or I_{PH}**: Current generated by solar energy [A]
- **I_O**: Diode saturation current [A]
- **V_{PV}**: Ideal unit Cell thermal voltage [V]
- **A**: Diode quality factor (1~1.5)
- **k:** Boltzmann's constant (1.381×10-23) [J/K]
- **T**: Kelvin Temperature at standard test condition (=25°C+273.15) [K]
- **q**: Charge of the electron (1.602×10-19) [C]
- **n_s**: Number of PV cells connected in series
- **R_{SH}**: Cell parallel(shunt) resistance [Ω]
- **R_S:** Cell series resistance [Ω]

II.2. PV Module Efficiency as a Function of Operating Temperature:

The solar cell power conversion efficiency can be given as [37]:

$$\eta_C = \frac{P_{max}}{P_{in}} = \frac{I_{max} \times V_{max}}{I(t) \times Ac}$$

- **I(t)** solar intensity
- **A_C** is Area of solar cell.

The effect of temperature on the electrical efficiency of a PV cell/module can be obtained by using the fundamental equations.

The basically effect leads to a relation in the form [37]:

$$\eta_C = \eta_{Tref}[1 - \beta_{ref}(T_C - T_{ref}) + \gamma log_{10} I(t)] \qquad (1)$$

- **η_{Tref} :** is the module's electrical efficiency at the reference temperature T_{ref}, and at solar radiation of 1000W/m2.
- **β_{ref}** : The temperature coefficient.
- γ : The solar radiation coefficient.

The quantities η_{Tref} and β_{ref} are normally given by the PV manufacturer. However, they can be obtained from flash tests in which the module's electrical output is measured at two different temperatures for a given solar radiation flux. The actual value of the temperature coefficient, in particular, depends not only on the PV material but on Tref as well. It is given by the ratio [37]:

$$\beta_{ref} = \frac{1}{T_0 - T_{ref}}$$

- In which T_0 is the (high) temperature at which the PV module's electrical efficiency drops to zero. For crystalline silicon solar cells this temperature is 270 °C.

variations in ambient temperature and irradiance the cell temperature (in °C), can be estimated quite accurately with the linear approximation [37].

$$T_C = T_a + \frac{T_{NOCT} - 20}{0.8 km/m^2} \times I(t) \qquad (2)$$

- T_{NOCT} the Nominal Operating Cell Temperature, and is measured under open-circuit when the ambient temperature is 20◦C, irradiance is 0.8 kW/m2 and wind speed is 1 m/s. TNOCT usually values around 45 °C.

If substitute equation (2) in equation (1) we will obtain important equation (3):

$$\eta_C = \eta_{ref}\left[1 - \beta_{ref} \times \left[T_a - T_{ref} + (T_{NOCT} - 20) \times \frac{I(t)}{I(t)_{NOCT}}\right] + \gamma log_{10} I(t) \times 100\right] \quad (3)$$

Authors usually consider T_{ref} =25°C, average η_{ref} = 12% and average β_{ref} = 0.0045K

II.3. Calculation of the peak power of the panels:

The peak power which is the power supplied by the panels for a sunshine of 1000W/m2 is calculated by the following equation:

$$P_c = \frac{E_J}{E \times K_P \times \eta_{ond} \times \eta_{reg}}$$

- **E_J** :daily energy consumed
- **E :** the irradiation of the place in kWh/m²/day
- **K_P :** called the panel coefficient and equals 0.8
- **η_{ond} :** 90% inverter efficiency
- **η_{reg} :** regulator efficiency 90%

II.4. calculate Annual PV system energy output (kWh/a):

Globally the formula below is followed to estimate the electricity generated in output of a photovoltaic system [31, 32, and 33].

E = A x r x H x PR

- **E:** is Energy (kWh),
- **A:** is total Area of the panel (m²),
- **r:** is solar panel yield (%), (electrical power (in kWp) of one solar panel divided by the area of one panel).
- **H:** is annual averag annual average solar radiation on tilted panels.
- **PR**: Performance ratio, constant for losses (range between 0.5 and 0.9, default value = 0.75).

II.5. Open Circuit Voltage Calculation Equation:

modules are measured under standard test conditions that are difficult to be achieved in real life. The real maximum power obtained from the module is mostly less than this value due to high temperature and low irradiation levels. The open circuit voltage values given in Table 3.3 were given at standard temperature of 25 degrees. However, the temperature is variable that can decrease to less than zero or more than 60 at the cell's surface. For this reason, open circuit voltage values are going to be calculated at the highest and lowest temperature limits of the modules that are -40 and 90 degrees. The next relation can be used to give an approximation of the open circuit voltage. Where β is the temperature de-rating factor [23]

$$V(T) = V_{@25^\circ} C \times (1 + \beta \times \Delta T)$$

II.6. Number of modules per subfield:

The design considers the calculations for one field and then generalized for the rest of the fields of project. Given that the maximum power of each module is 250 Wp, the total number of modules to be used in each field can be found easily by [23, 38]:

Number of modules per field = subfield electric power / maximum power module = 1001KV /250V = 4004 PV module

The total number of the PV modules in the project is then given by:

Total number of modules = 4004×20 = 80080 PV module.

II.7. Number of modules per string:

From Table III.3, the maximum permissible DC input voltage is 1120 V, and the maximum power point voltage ranges between 500 and 850 V. It is important to notice that both the open circuit and maximum power point voltages are maximal at the minimum temperature -40°C and minimum at 90°C. These values are important to find the number of series connected modules per each string that can be connected to the inverter. These values are going to be calculated at the minimum acceptable temperature that is -40°C.

$$\textbf{Number of modules per string} = V_{MPPinverter} / V_{MPP-40^\circ C} = 850 / 38.5 = 22$$

The optimum number of modules per string is found to be 22 modules per string. Now it is important to find the maximum possible number of modules per string as follows [20, 23, 38]:

$$\textbf{Modules per string}_{Max} = V_{MAX\ inverter} / V_{OC-40C^\circ} = 1120 / 37.6 = 29.78$$

That means the maximum allowed number of series modules is 29 modules. The optimal design implies that the number of series module will be between 22 and 29 modules as maximum.

II.8. Number of parallel strings:

In order to find the maximum number of parallel strings, it is important to consider the short circuit and maximum power point currents. The number of strings is found as follows [20,23]:

$$\textbf{String}_{\textbf{numbre max inverter}} = \textbf{I}_{\textbf{MAX inverter}} / \textbf{I}_{\textbf{SC module}} = \textbf{1120 / 8.92 = 125 strings}$$

This means that a maximum of 125 parallel strings can be connected at the input of the inverter. For each inverter, taking in consideration the total number of modules per field found previously to be 4004 modules that will be distributed on two inverters. That means each inverter will be connected to a total of 2002 modules. If we accept that each string will contain 22 series modules for better performance and security, the number of parallel string is then given by [23, 38]:

$$\textbf{String}_{\textbf{Number Inverter}} = \textbf{Strings per inverter / Modules per string = 2002 / 22 = 91}$$

From the previous calculation it was found that the design must use 91 strings of 22 modules each respecting the inverter and modules specifications. Figure 3.3 shows the connection of the strings and modules as calculated previously.

II.9. Array yield:

It is equal to the time which the PV plant has to operate with nominal solar generator power Po to generate array DC energy Ea. Its units are kW h/d∗kW p. [24]

$$\textbf{YA = EA / PO}$$

where, Array energy output per day **EA = Idc∗Vdc∗t (kW h),**

- **Idc:** DC current (A)
- **Vdc:** DC voltage (V)
- **P0**: Nominal Power at STC.

II.10. Reference yield:

The reference yield is the total in-plane irradiance H divided by the PV's reference irradiance G. It represents the under ideal conditions obtainable energy. If G equals 1 kW/m2, then Y_R is the number of peak sun hours or the solar radiation in units of kW h/m2. The Yr defines the solar radiation resource for the PV system. It is a function of the location, orientation of the PV array, and month-to month and year-to-year whether variability [24]. Its units are h/d.

$$Y_R = [kW\ h/m^2] / 1\ kW/m2.$$

$$Y_R = H_t/G_o$$

Where,

- H_t: Total Horizontal irradiance on array plane (Wh/m2),
- G_o: Global irradiance at STC (W/m2).

II.11. Final yield:

The final yield is defined as the annual, monthly or daily net AC energy output of the system divided by the peak power of the installed PV array at standard test conditions (STC) of 1000 W/m2 solar irradiance and 25 °C cell temperature. Its units are kW h/d∗kW p [24].

$$Y_F = E_{PV,\ AC} / P_{maxG\ ,\ STC}$$

II.12. Performance ratio:

The performance ratio is the final yield divided by the reference yield. Performance ratio can be defined as comparison of plant output compared to the output of the plant could have achieved by taking into account irradiation, panel temperature, availability of grid, size of the aperture area, nominal power output, temperature correction values [20,24].

$$P_R = Y_F/Y_R$$

II.13. Capacity utilization factor:

It is defined as real output of the plant compared to theoretical maximum output of the plant.

CUF = Energy measured (kW h)/ (365 ∗ 24 ∗ installed capacity of the plant).

II.14. Inverter efficiency:

Efficiency is given by the ratio of AC power generated by the inverter to the DC power generated by the PV array system. The instantaneous inverter efficiency is given by:

$$\eta_{inv} = P_{AC}/P_{DC}$$

II.15. System efficiency:

The instantaneous daily system efficiency is given as PV module efficiency multiplied by inverter efficiency.

$$\eta_{sys,T} = \eta_{PV,T} + \eta_{inv,T}$$

II.16. Specific plant losses:

Energy losses occur in various components in a grid connected SPV Power plant under real operating conditions. These losses are evaluated using the monitored data [24].

II.17. Array capture losses (LC): These are of two types.

- Thermal capture loss (LCT): Losses caused by cell temperature higher than 25 °C are called thermal losses. Thermal capture loss (LCT) is the difference between reference field and corrected reference field.
- Miscellaneous capture loss (LCM): Losses that are caused by wiring, string diodes, low irradiance, partial shadowing, mismatching, maximum power tracking errors, limitation through dust, losses generated by energy conduction in the photovoltaic modules [24].

$$\mathbf{L_{CT} = Y_R - Y_{CR}}$$
$$\mathbf{L_{CM} = Y_{CR} - Y_A}$$
$$\mathbf{L_C = Y_R - Y_A}$$

II.18. System losses (LS):

These losses are caused by inverter, conduction and losses of passive circuit elements.

$$\mathbf{L_S = Y_A - Y_F}$$

II.19. Sizing of the center distance between two PV panels:

The center distance between two rows of sensors is defined by the following formula:

We have $\sin\beta = \frac{H}{L}$ *and* $\cos\beta = \frac{d}{L}$

And also $\tan\alpha = \frac{H}{b}$

Then $b = \frac{L \times \sin\beta}{\tan\alpha}$ *and* $a = L \times \cos\beta$

On the other hand

$P = a + b$

So $\boldsymbol{P = L \times \left[\frac{\sin\beta}{\tan\alpha} + \cos\beta\right]}$

Where,

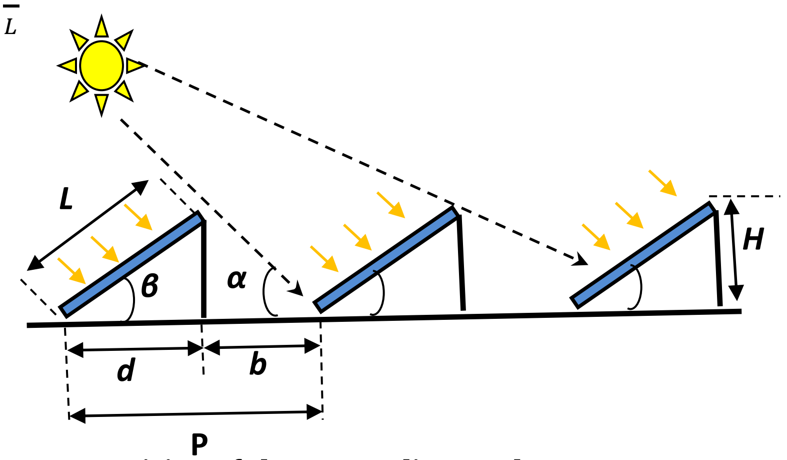


Figure.II.2. Sizing of the center distance between two PV panels

- **L**: size of the sensor.
- **P**: total distance occupied by each panel
- **α**: sun elevation angle (usually taken on December 21, i.e. an angle of 16°).
- **β**: inclination of the panels.

  Then we can easily deduce that the total distance occupied by each panel and proportional to the inverse of the angle of elevation of the sun

III.1. Description of Ain El Melh photovoltaic plant with a capacity of 20megawatts:

The Ain El Melh power plant is a power generation plant from photovoltaic solar panels with an overall capacity of 20MW, an injection voltage of 60 kV, and an area of 41.16 hectares, and whose realization required the mobilization of an investment of nearly 3.9 billion dinars [25]

This station is located 120 km southwest of the Wilayat of M'Sila. Established on January 25, 2017. As shown in Figure III.1. It is an area very rich in potential solar energy due to its topography. It is one of the facilities built by the renewable energy company of the public energy supplier Sonelgaz (SKTM).

The site comprises 20 photovoltaic subfields of 1MWp, and each branch has two inverters and one step-up transformer. Power plant equipment and major components, they are presented below in Table III.1.

Equipment	Number
255 Wp modules	80080
Number of underfield panels	4004
Nombre de chaine/sous champ	91
Number of panel/chain	44
junction boxes	40
1 MW subfields	20
500kw Inverters	40
315v/31.5kv/1MW transformers elevator	20
MT evacuation station (31.5kv/60kv/20MW transformer)	01
control room	01

Table III.1 Configuration of the Ain El Melh 20 MWp power plant

Figure III.1. Aerial view of the Ain El Melh 20 MVp solar (photovoltaic) power plant

III.2. Geographical location of the site:

The AIN EL MELH 20 MW solar power plant is located at a latitude 34,86109° or 34° 51' 40" North, longitude of 4,20407° or 4° 12' 15" East. and at an altitude of 915 m [19, 39]. as it located at geographically good location where it can absorb more solar radiation for the entire year as power generated by solar plant completely depends up on its sun's insolation.

III.3. Description of the 1 MW subfields:

Each sub-field is equipped with 4004 solar panels optimally spaced to avoid shadowing. and are spread over two inverters that convert DC into AC (output voltage 315 VAC) and send it through AC cables to a 1,250 kVA step-up transformer bringing the voltage to 31.5 kVA. and the direct current from the solar panels is collected through the collector boxes in order to reduce the overall length of the DC cables and ohmic losses in them and improve energy efficiency. and the 20 subfields are connected to the 60 kV step-up transformer and discharge the electricity produced to the national grid. The characteristics of the 1 MW subfield equipment of the PV power plant are summarized in Table.III.2. And the schematic diagram is in Figure III.2.

DESIGN PARAMETER	CHARACTERISTICS
Module type	Poly-crystalline silicon
Photovoltaic module efficiency	15%
Orientation and tilt	26.5°, south
Installation type	Fixed
Distance between photovoltaic rows	8 m
Inverters	500 kW
Transformers	1.250 kVA, 47–52 Hz, 315 V/31.5 kV

Table III.2. The characteristics of the 1 MW subfield equipment of the PV power plant

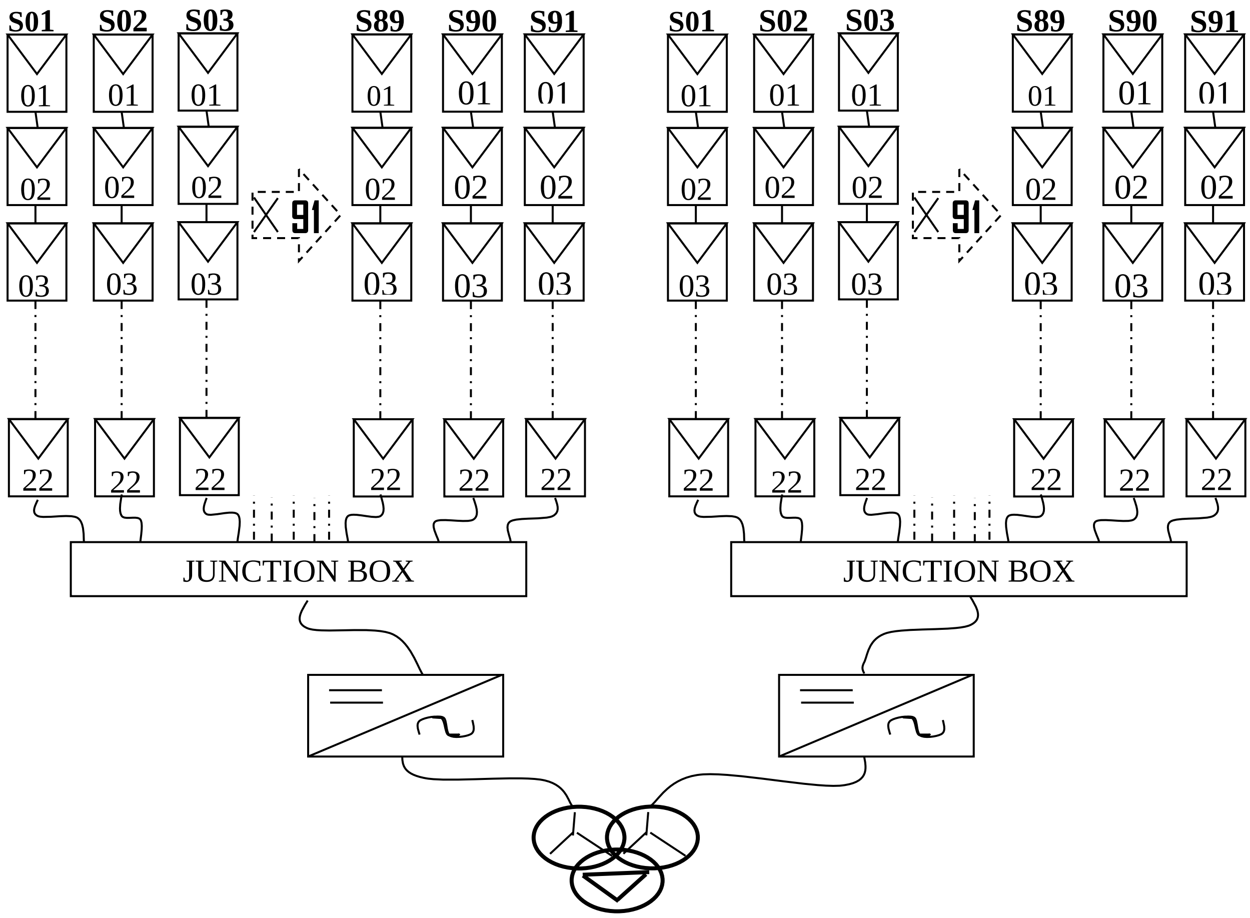


Figure III.2. Schematic outline of a 1 MW subfield in the Ain El Melh photovoltaic power plant.

III.4. Description of the Photovoltaic modules:

The panels identified by SKTM contain China-made Yingli series solar cells made from blocks of polycrystalline silicon. The cost of manufacturing these cells is less than Monocrystalline, but its energy loss is large in heat

The characteristics of the solar modules are shown in Table III.3.

Module type	Characteristics
The Brand	YINGLI SOLAR
Module Type	YL250-29b
Measured Power	250 W (0/+5 W)
Measured Voltage	29.8 V
Measured Current	8.39 A
Open-Circuit Voltage	37.6 V
Short Circuit Current	8.92 A
An Irradiance	1000 W/M2
Fire Resistance Class	C
Application Class	A
The Cell Temperature	25 °C
Tension Système Max	1000 V

Table III.3 Power plant panel characteristics (SKTM, 2017).

III.5. Inverters:

The inverter is an electronic device that converts direct current produced by photovoltaic modules to alternating current using control and protection circuitry. It can accept the maximal current and voltage produced by the photovoltaic field.

The efficiency corresponds to the ratio between the output power and the input power, it is expressed as a percentage. Too high a temperature decreases the efficiency of the inverter.

The power station is equipped with 40 Chinese-made inverters of the brand SUNGROW of 500 kW DC/AC, 2 per subfield.The ~520–820 VDC input range ensures AC output voltage stability with a maximal current of 1008 A at high efficiency 98%. The DC side of the inverters has 4 twopolarity inputs each equipped with direct current fuse protection, a general disconnect switch and a DC lightning arrester. The technical specifications of the inverters are shown in Table III.4.

Inverter	Specification
The Brand	SUNGROW
Type Of	SG500MX
Operating Temperature	-30 C / 50 C
IP Protection	IP 21
DC Input	
Max Voltage	1000V
Isc	1344A
Voltage Vmppmin	500V
Voltage Vmppmax	850V
Max Input Current	1120A
Overvoltage Category	II
AC Output	
Rated Output Power	500KW
Rated Output Voltage	3-315V
Rated Output Frequency	50Hz
Max Output Current	1008A
Power Factor	-0.9/0.9
Overvoltage Category	///

Table III.4. Technical Specifications of the inverters

III.6. MW step-up transformer:

Used transformers are state-of-the-art machines specifically ordered by SKTM whose installation required large capital expenditures, due to complex manufacturing processes. It also requires lengthy expenditures to monitor and maintain these transformers. The failure of a single unit may result in interruption of service and significant loss of revenue as well as replacement costs and other additional costs [26]. It is a very important electrical equipment for AC transformer and transmission system. It transforms LV voltage into HV. The equipment is surrounded by a shelter envelope, equipped on the four sides with heat radiation fans, operating according to the temperature [27]. The technical characteristics of the transformers chosen by the company SKTM are indicated in table III.5.

The Brand	**SUNTEN**
Type Of	ZBW10N 1250/31.5/0.315-0.135
Rated Capacity	1250KVA
Rated Voltage	31.5KV /0.315KV
Rated Frequency	50Hz
Aspect Dimensions	4700*2438*2896mm
Cooling Mode	AN/AF
Rated Input Voltage	315V/315V
Rated Input Current	1146/1146
Rated Output Voltage	30000V
Rated Output Current	24.1A

Table III.5. Technical Specifications of the transformer

III.7. the measuring devices used in the Ain El Melh station:

The Ain El Melh station is equipped with meteorological measuring equipment to predict the weather situation Shown in Figure.III.3. Solar radiation, temperature sensors, humidity sensors, anemometers, rain gauges and lightning protection. The collected data is recorded in one of the factory data acquisition computers installed in the control room.

Humidity Sensor **Rain Sensor** **Pyranometer** **5 Element Sensor (T, P, H, DW,SW)**

Figure III.3. The measuring devices used in the Ain El Melh station

III.8. General Scheme of Ain El Melh power plant connected to the grid:

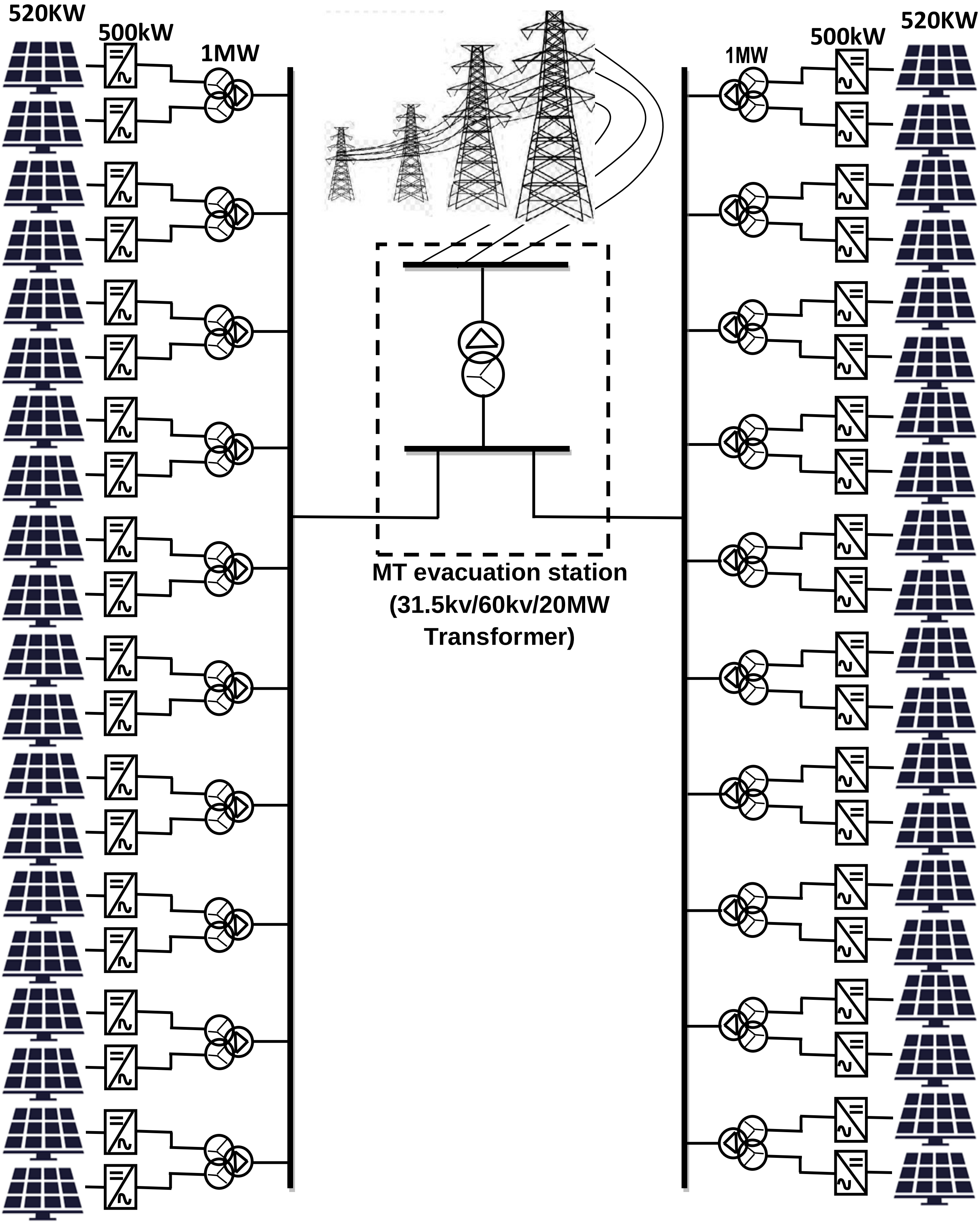


Figure III.4. General Scheme of the Ain El Melh 20 MW power plant connected to the grid.

III.9. The control room:

The control room is a space that facilitates the work of engineers to monitor and control the efficient work flow of all station equipment (inverters, panels, transformers, connectors, etc.). By obtaining the data connected and displayed on a sophisticated computer with an integrated technological program Figure III.5.

It also monitors meteorological data such as solar radiation (G), ambient temperature (Ta), unit temperature (Tm) and wind speed (v)

Which you send the measuring devices Figure III.3. every 15 minutes during the daytime.

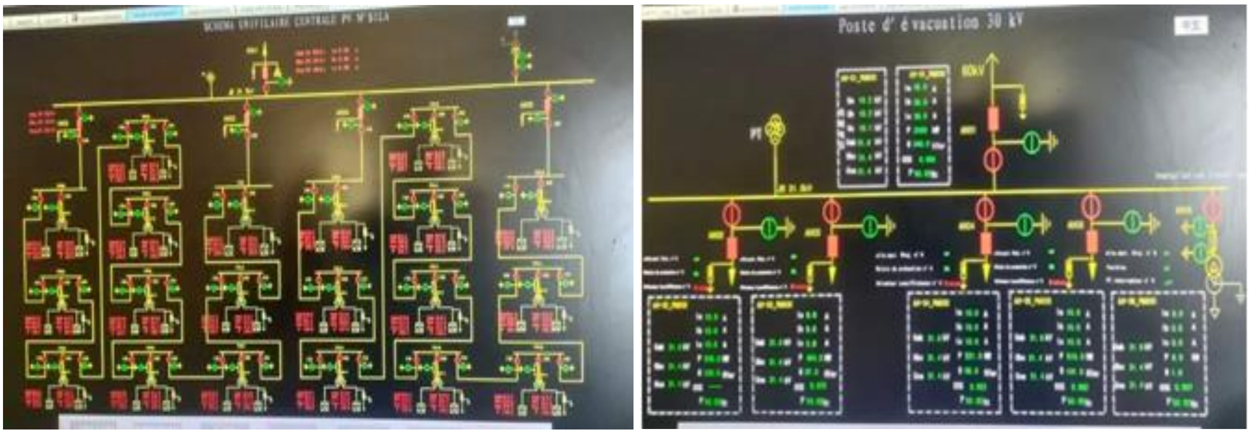


Figure III.5. Shows the optical sign diagram of the AIN EL MELH plant.

III.10. Estimation PV Electricity and Solar Radiation in the Ain el melh station:

- **The first method:**

In order to evaluate the long-term performance of the Ein El Melh solar energy conversion plant systems, knowledge of meteorological and radiative parameters, such as wind, insolation, temperature, relative humidity, pressure, and components of solar radiation, is required with the use of numerical simulation programs.

After analyzing the meteorological data and conducting a comparative study between the values of solar radiation measured at Ain El Melh station and the values estimated by Leo Jordan's theoretical model, the study showed the results obtained that Ain El Melh is a very good area for the photovoltaic project because it has with a favorable climate, and a large influx of solar radiation [28]. results obtained from the estimation of solar radiation for some clear and cloudy days are shown in Figure III.6.

Values of the solar irradiance at ain el melh range from 750kWh/m2 day to 850 kWh/m2 day and the average tilt angle throughout the year was found to be b=30°.

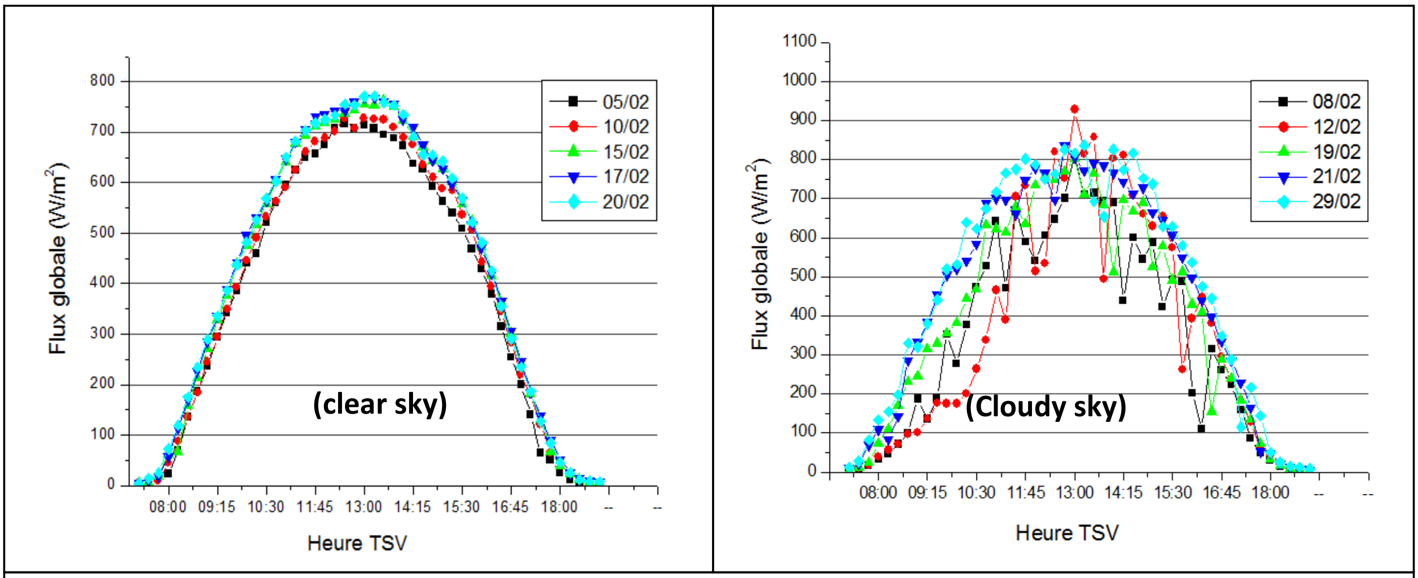


Figure III.6. Estimate of the global solar radiation of the Ain El Melh station on February 2020 [7].

- **The second method:**

This report (the “Work”) is automatically generated and Sun brightness data collect. On the site (Ain El Melh, M'Sila). That obtained from the Global Solar Atlas online app [19], prepared by Solargis under contract to The World Bank, based on a solar resource database that Solargis owns and maintains. It provides the estimated solar resource, air temperature data and potential solar power output for the selected location and input parameters of a photovoltaic (PV) power system.

The site-specific solar energy yield estimates available via the Global Solar Atlas are suitable for preliminary studies, as they consider default values for many factors that are important for a design of a photovoltaic system. For more detailed estimates it is recommended to work with tools that allow configuration of a photovoltaic power project in more detail, and also use more detailed solar and weather data as inputs to the simulation. Monthly global solar insolation and daily average bright sunshine hours in AIN EL MELH city. are presented in the report

GLOBAL SOLAR ATLAS
BY WORLD BANK GROUP

Aïn El Melh

34.859965°,004.202421°
RN 70, Ain El Melh, M'Sila, Algeria
Time zone: UTC+01, Africa/Algiers [CET]

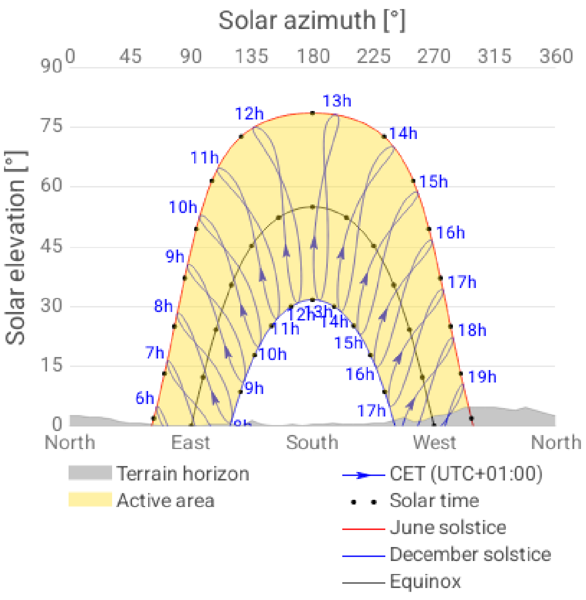
Report generated: 16 Jun 2022

SITE INFO

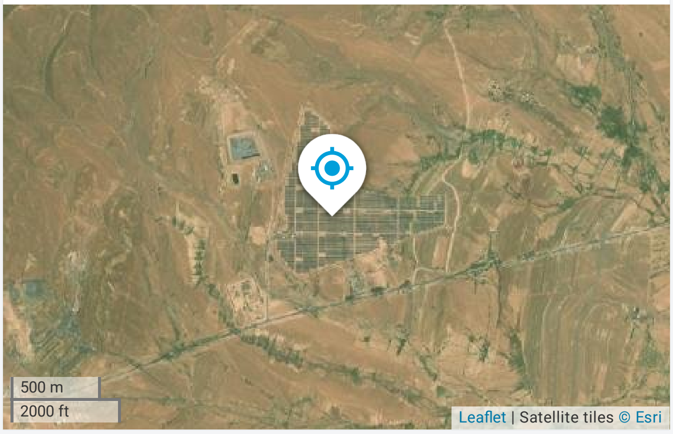
Map data

		Per year	
Direct normal irradiation	DNI	**2079.5**	kWh/m²
Global horizontal irradiation	GHI	**1937.0**	kWh/m²
Diffuse horizontal irradiation	DIF	**678.2**	kWh/m²
Global tilted irradiation at optimum angle	GTI opta	**2254.5**	kWh/m²
Optimum tilt of PV modules	OPTA	**35 / 180**	°
Air temperature	TEMP	**16.9**	°C
Terrain elevation	ELE	**912**	m

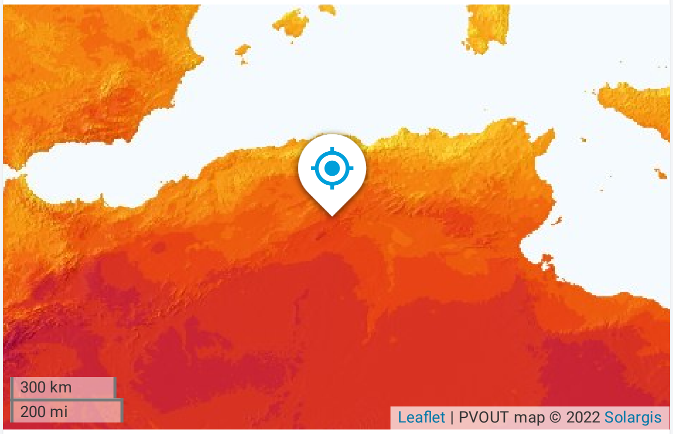
Horizon and sunpath



Map



PVOUT map



PVOUT: Long-term average of annual totals of PV power potential

kWh/kWp: 600 800 1000 1200 1400 1600 1800 2000 2200 2400

PV ELECTRICITY AND SOLAR RADIATION

PV system configuration

Pv system: **Ground-mounted large scale**
Azimuth of PV panels: **Default** (180º)
Tilt of PV panels: **35º**
Installed capacity: **1000 kWp**

Annual averages

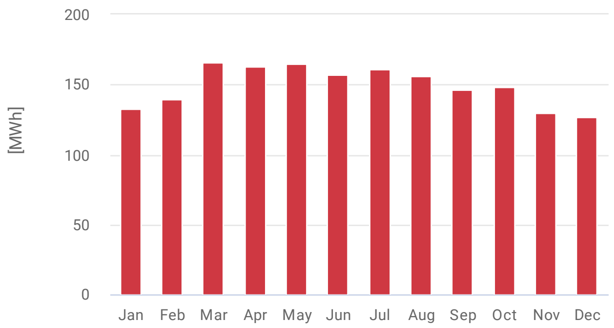
Total photovoltaic power output and Global tilted irradiation

1.792 GWh per year

2250.7 kWh/m² per year

Monthly averages

Total photovoltaic power output



Average hourly profiles

Total photovoltaic power output [kWh]

Average hourly profiles

Total photovoltaic power output [kWh]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5					0	1						
5 - 6				8	32	38	31	12	1			
6 - 7		5	46	117	143	140	125	113	98	63	8	
7 - 8	81	184	260	307	319	307	289	285	287	297	226	117
8 - 9	377	410	458	488	487	466	453	454	460	470	440	398
9 - 10	526	566	611	626	614	596	580	588	585	602	567	536
10 - 11	627	674	711	712	691	670	663	673	665	682	643	621
11 - 12	673	737	762	745	720	698	695	706	700	710	680	659
12 - 13	655	730	743	718	682	673	675	677	665	667	635	627
13 - 14	579	654	660	639	600	593	598	574	569	562	529	536
14 - 15	453	529	533	509	483	470	480	446	435	422	389	407
15 - 16	283	374	379	359	336	328	336	313	283	255	194	181
16 - 17	27	130	178	182	175	179	190	169	117	46	3	2
17 - 18		0	10	31	49	64	67	41	5			
18 - 19					1	9	7	0				
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	4,282	4,993	5,351	5,440	5,332	5,232	5,189	5,051	4,869	4,779	4,315	4,085

PV ELECTRICITY AND SOLAR RADIATION

Annual averages

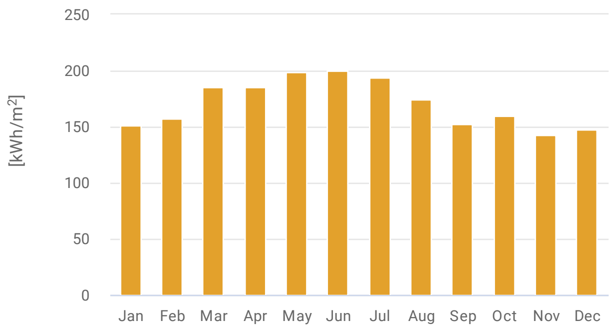
Direct normal irradiation

2047.3

kWh/m² per year

Monthly averages

Direct normal irradiation



Average hourly profiles

Direct normal irradiation [Wh/m²]

Average hourly profiles

Direct normal irradiation [Wh/m²]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6				39	158	177	118	43	1			
6 - 7		19	134	323	370	374	322	284	221	134	24	
7 - 8	183	353	460	480	490	498	458	428	412	442	359	282
8 - 9	525	548	572	574	586	591	563	535	508	538	537	531
9 - 10	597	621	640	637	645	668	638	607	563	598	594	600
10 - 11	644	671	684	673	677	703	678	650	602	636	632	636
11 - 12	664	699	703	683	682	708	687	658	611	645	651	654
12 - 13	641	690	677	662	651	677	665	621	587	616	617	627
13 - 14	595	649	635	617	604	617	602	541	526	554	549	568
14 - 15	533	586	574	544	538	538	525	456	451	485	478	507
15 - 16	431	521	507	470	459	454	435	383	369	388	312	329
16 - 17	79	253	346	374	360	360	337	294	228	102	5	6
17 - 18			27	106	198	253	207	112	11			
18 - 19					1	41	20					
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	4893	5610	5960	6180	6419	6657	6254	5613	5089	5140	4759	4741

IV.1. Presentation of Electrical Transient Analyzer Program (ETAP):

ETAP is a full spectrum analytical engineering software developed by Operation Technology Inc. (OTI). The software specializing in the analysis, simulation, monitoring, control, optimization, and automation of electrical power systems [29].

ETAP is the abbreviation of the 'Electrical Transient Analyzer Program'. Its model-driven architecture provides the faster and real time data to its users, which helps the operator to estimate the forecasting behavior, preventive action, and situational aptitude [30].

ETAP software offers the most comprehensive and integrated suite of power system enterprise solution that spans from modeling to operation.

ETAP is a powerful, user friendly and easy to use tool with trusted output data and calculations.

ETAP is a great help in running and performing complex analysis on power system especially Transmission system.

ETAP is developed under an established quality assurance program and is used worldwide as high impact software.

ETAP is the complete guide for electrical engineers and it offers a complete solution to all the electrical problems such as the power flow, arc flash & short circuit analysis, transient stability, relay coordination, cable selection, and best possible power flow.

One of the most important analyzes that must be performed on the power system is the study of load flow (or power flow analysis) that the results of Load Flow help in maintaining the proper operation of the power system and also in the design and expansion of the existing power system

IV.2. ETAP Toolbars:

ETAP software is intelligently divided into different toolbars according to their functionality. User can easily access each toolbar while creating one-line diagram of a power system model. Besides toolbars. there are 13 study different options in ETAP available to perform analyses on the system model through study cases, configurations, edit toolbars. as depicted in Figure IV.1. Each one of them is briefly described in the list table.IV.1.

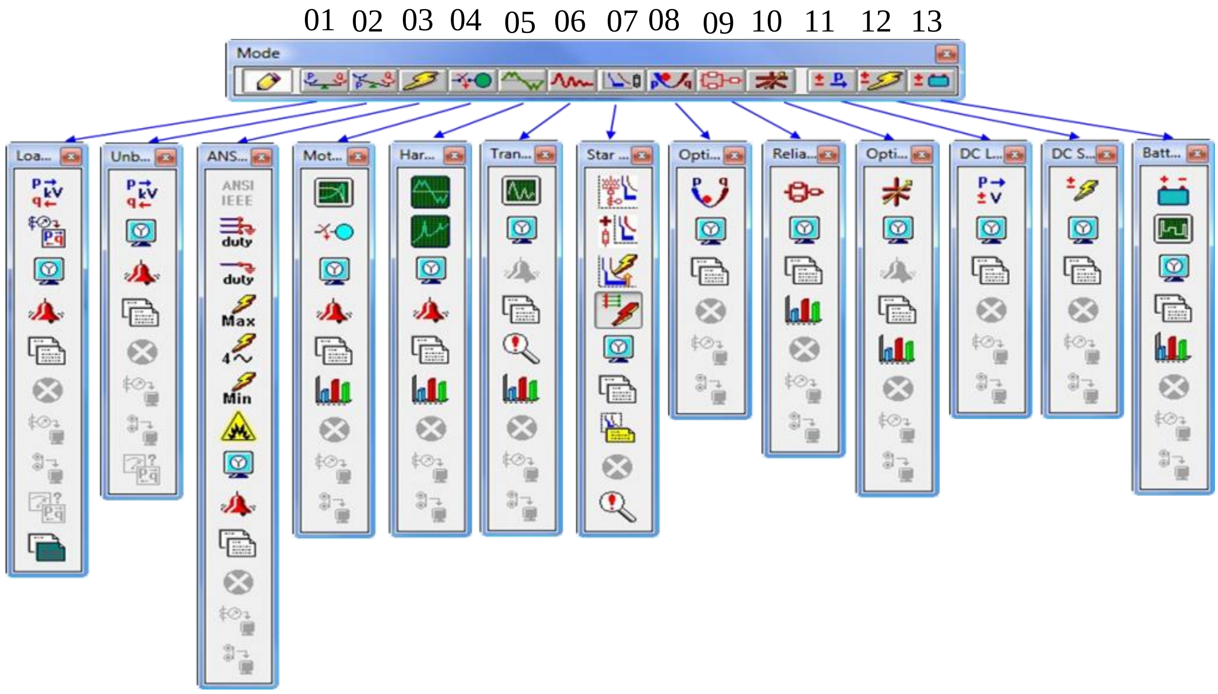


Figure IV.1: ETAP Mode Toolbars for various Power System Analyses

01	Load Flow	08	Optimal Load Flow
02	Unbalanced Load Flow	09	Reliability Analysis
03	ANSI Short Circuit Analysis	10	Optimal Capacitor Placement
04	Motor Starting Analysis	11	DC Load Flow
05	Harmonic Analysis	12	DC Short Circuit Analysis
06	Transient Analysis	13	Battery Sizing Analysis
07	Star Protection Coordination		

Table IV.1. ETAP various Power System Analyses

IV.3. A Detailed Study for Load Flow Analysis in Power System of Ain El Melh plant:

Load Flow (or Power Flow Analysis) is one of the most important analysis to be performed on a Power System.

In the research of the graduation memory, we study in detail the analysis and simulation of pregnancy flow of the actual power distribution network of Ain El Melh photovoltaic plant with a capacity of 20megawatts. is implemented with the electrical transient analyzer program (ETAP) software (version: 19.0.1).

The capability and effectiveness of load flow assessment are demonstrated according to the simulation results obtained (total generation, loading, demand, system losses, and critical report of load flow). Where Load Flow results help in maintaining proper operation of a Power System and also to design and extend the existing Power System. At the end, conclusions are drawn on the basis of performed analysis.

To build and simulate a photovoltaic power plant network in Ain El Melh using the ETAP program, we follow the following steps station schematic diagram Enter data for each item Connect the items together

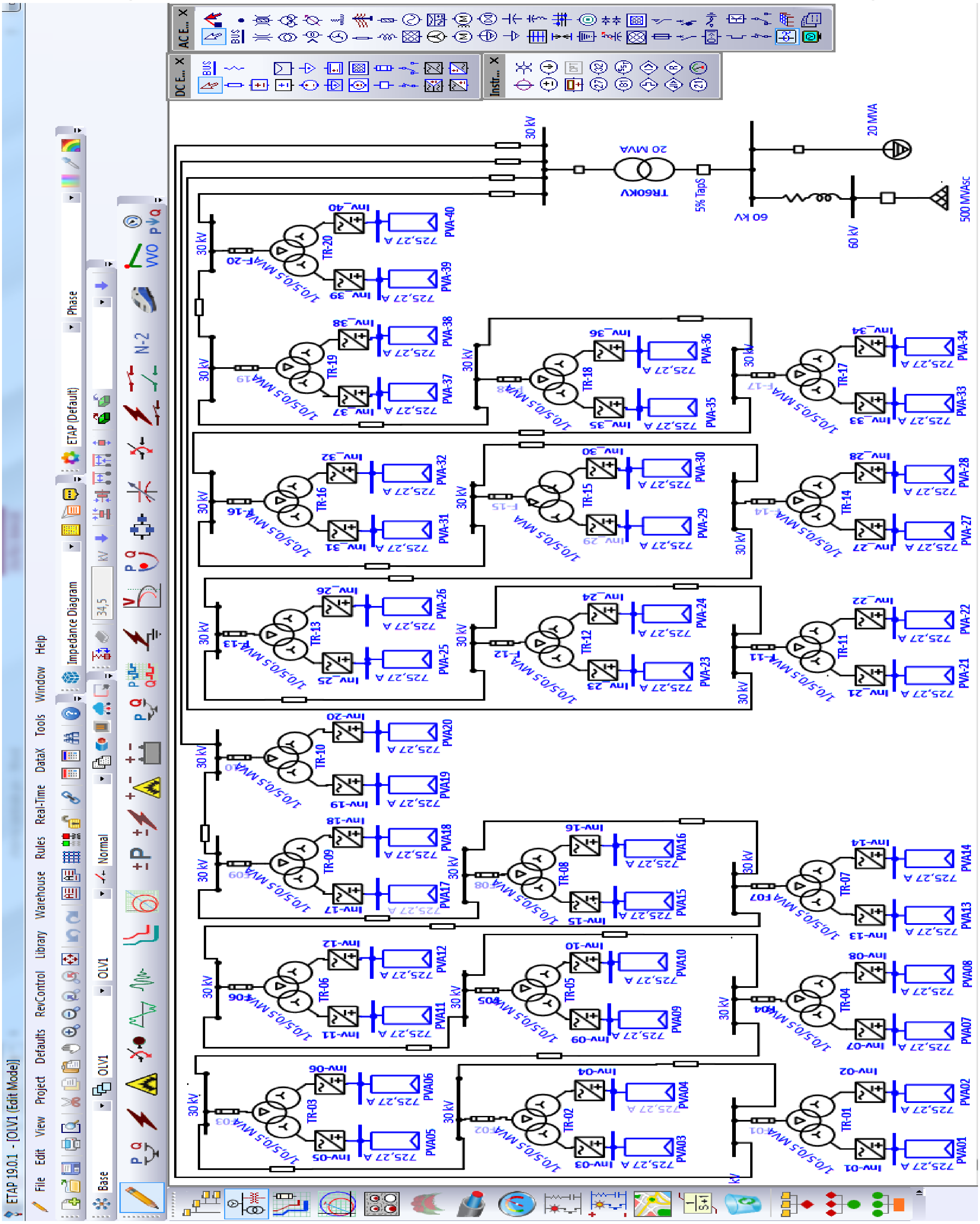
IV.4. Design Procedure of the PV Station:

This section introduces the design procedure before the integration of solar PV power system into an existing grid with power generation of 20 MW. The main system design is undertaken based on the amount of generated power (20 MW). The generated voltage is 0.315 kV and it will be stepped up to 60 kV. It is stepped up through two stages:

- First stage: voltage step-up from 0.315 kV to 30 kV by twenty step-up distribution transformers with 1 MVA rating each.
- Second stage: voltage step-up from 30 kV to 60 kV by one step-up power transformer with 20 MVA rating.

The output voltage of the power transformer is synchronized to the national grid at Ain El Melh main substation. To achieve the power ratings, 20 PV arrays with 1 MW for each array resulting at 20 MW generated power will be used.

IV.5. Diagram of the system the Ain El Melh Photovoltaic Power Plant By Using ETAP

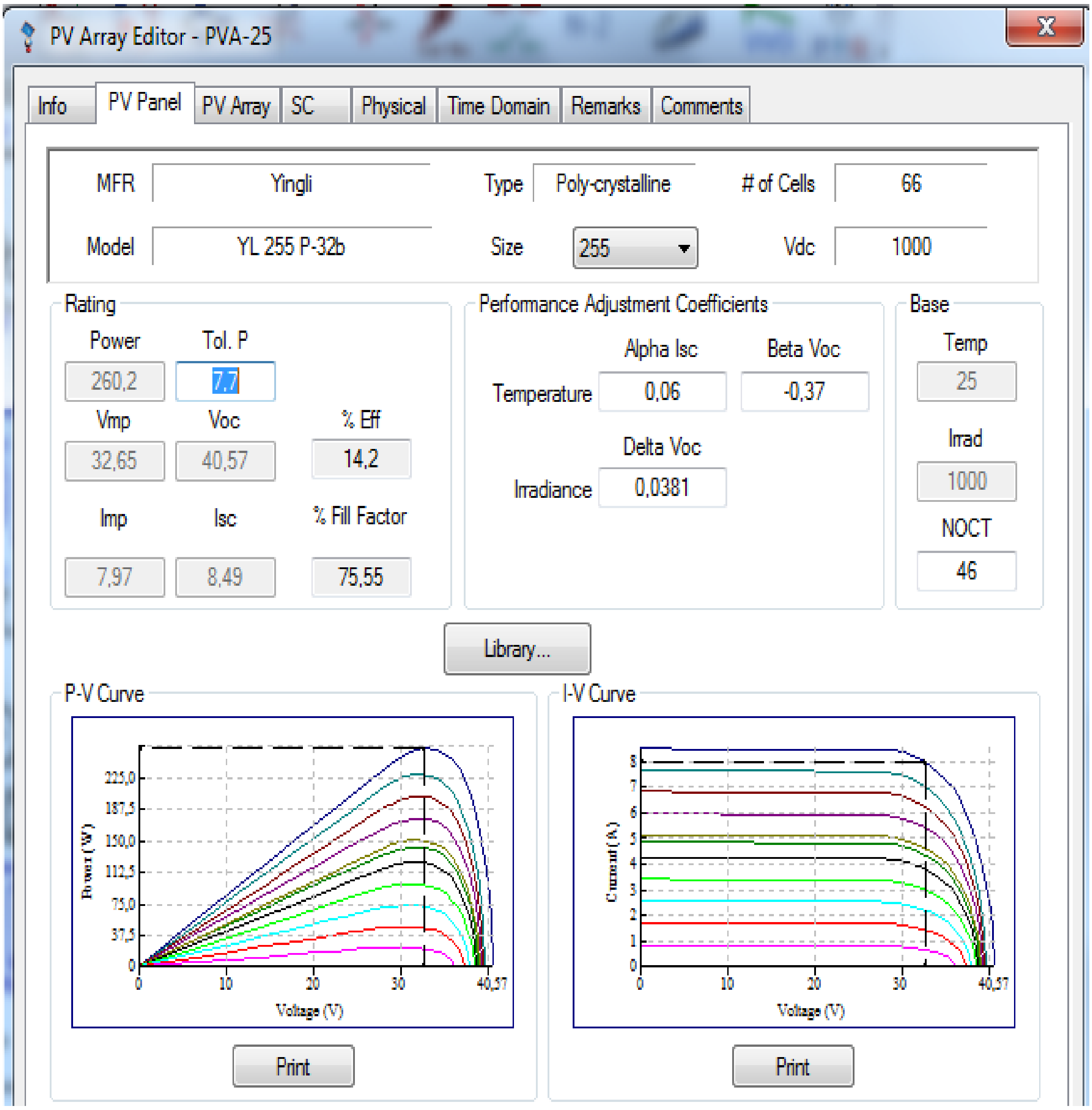


IV.6. Data entry photovoltaic plant equipment Aïn El Melh:

IV.6.1. PV Panel Page - PV Array & Solar Panel Modeling:

On this page, you can bring existing data from the Library page. with available PV array manufacturers. And bring the data for simulation. photovoltaic characteristics including P-V and I-V curves are defined in the user-configurable ETAP Photovoltaic Library or specifying the maximum peak power voltage (Vmpp), maximum peak power current (Impp), open circuit voltage (Voc) and short circuit current (Isc).

ETAP considers the effect of performance coefficients (α, β, γ) that define ranges in irradiance and cell temperature to automatically calculate the expected power output from the photovoltaic array.



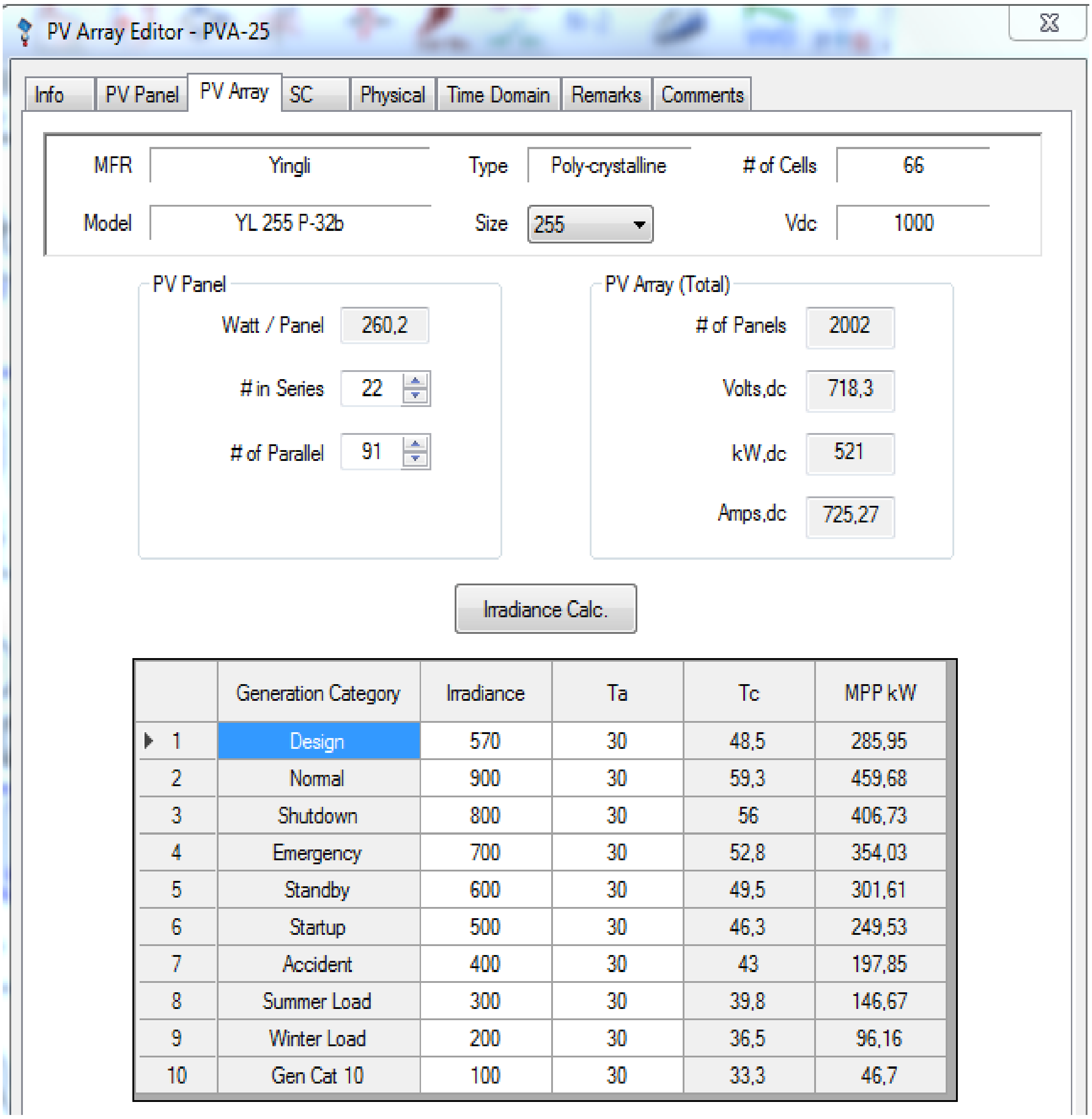
IV.6.2. PV Array Page - PV Array Editor:

On this page, this allows the user to enter the number of PV panels connected in series and parallel. and shows the calculated total number of panels:

- The total DC voltage in Volts calculated based on the number of panels in series.
- The total DC current in Amps calculated based on the number of panels in parallel.
- The total DC power in kW calculated based on the number of panels in series and parallel that make up the PV array.

The ambient temperature Ta in degrees Celsius can be user entered

As irradiance and ambient temperature Ta are changed, the cell temperature Tc is recalculated. Higher the Tc the lower the efficiency and power output from the panel.



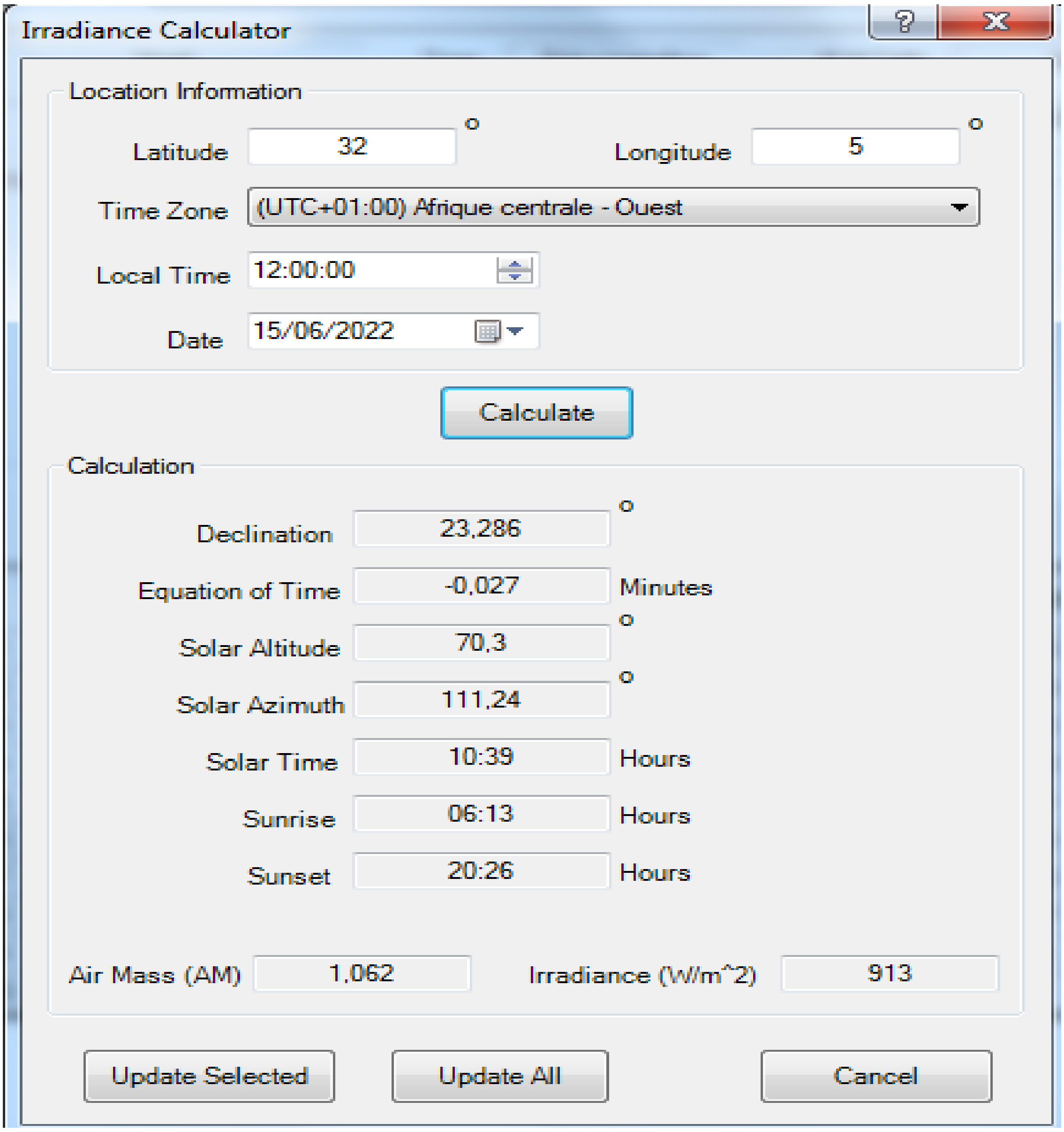
	Generation Category	Irradiance	Ta	Tc	MPP kW
1	Design	570	30	48,5	285,95
2	Normal	900	30	59,3	459,68
3	Shutdown	800	30	56	406,73
4	Emergency	700	30	52,8	354,03
5	Standby	600	30	49,5	301,61
6	Startup	500	30	46,3	249,53
7	Accident	400	30	43	197,85
8	Summer Load	300	30	39,8	146,67
9	Winter Load	200	30	36,5	96,16
10	Gen Cat 10	100	30	33,3	46,7

IV.6.3. PV Array Page - Irradiance Calc:

Solar Irradiance Calculator

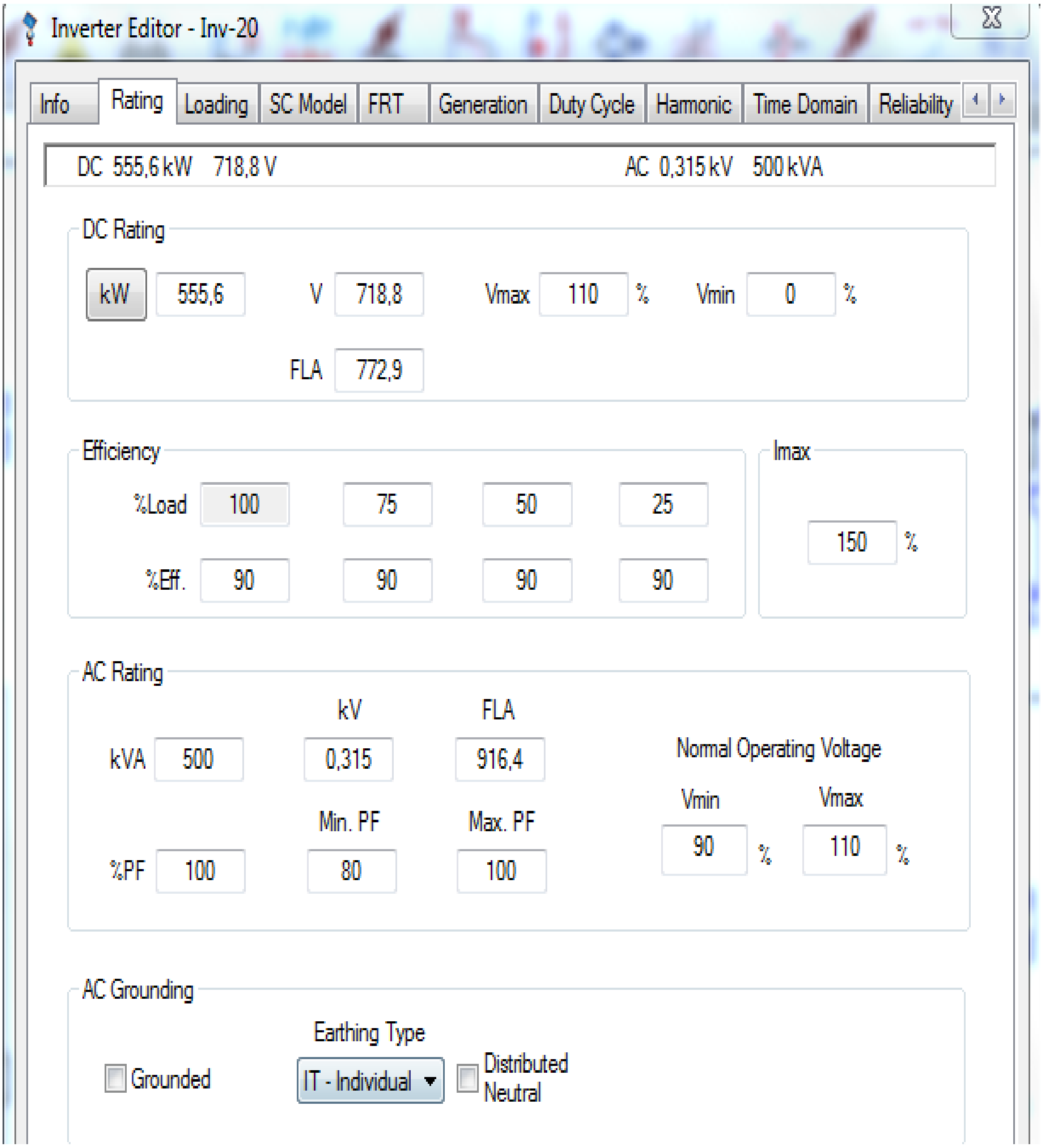
Photovoltaic Array element includes a built-in Solar Irradiance Calculator based on sun position to estimate solar irradiance incident upon a location, and they are especially useful when designing or estimating electrical power output from the panels without knowledge of the entire network.

Based on the user specified location information (Latitude, Longitude, date, and Time Zone, and Local Time), and the calculator will determine the theoretical irradiance (direct component) in W/m2. All calculation results are given at sea level (Declination, Solar Altitude, Solar Azimuth, Solar Time, Sunrise, Sunset, Air Mass, Irradiance.)



IV.6.4. Rating Page - Inverter Editor:

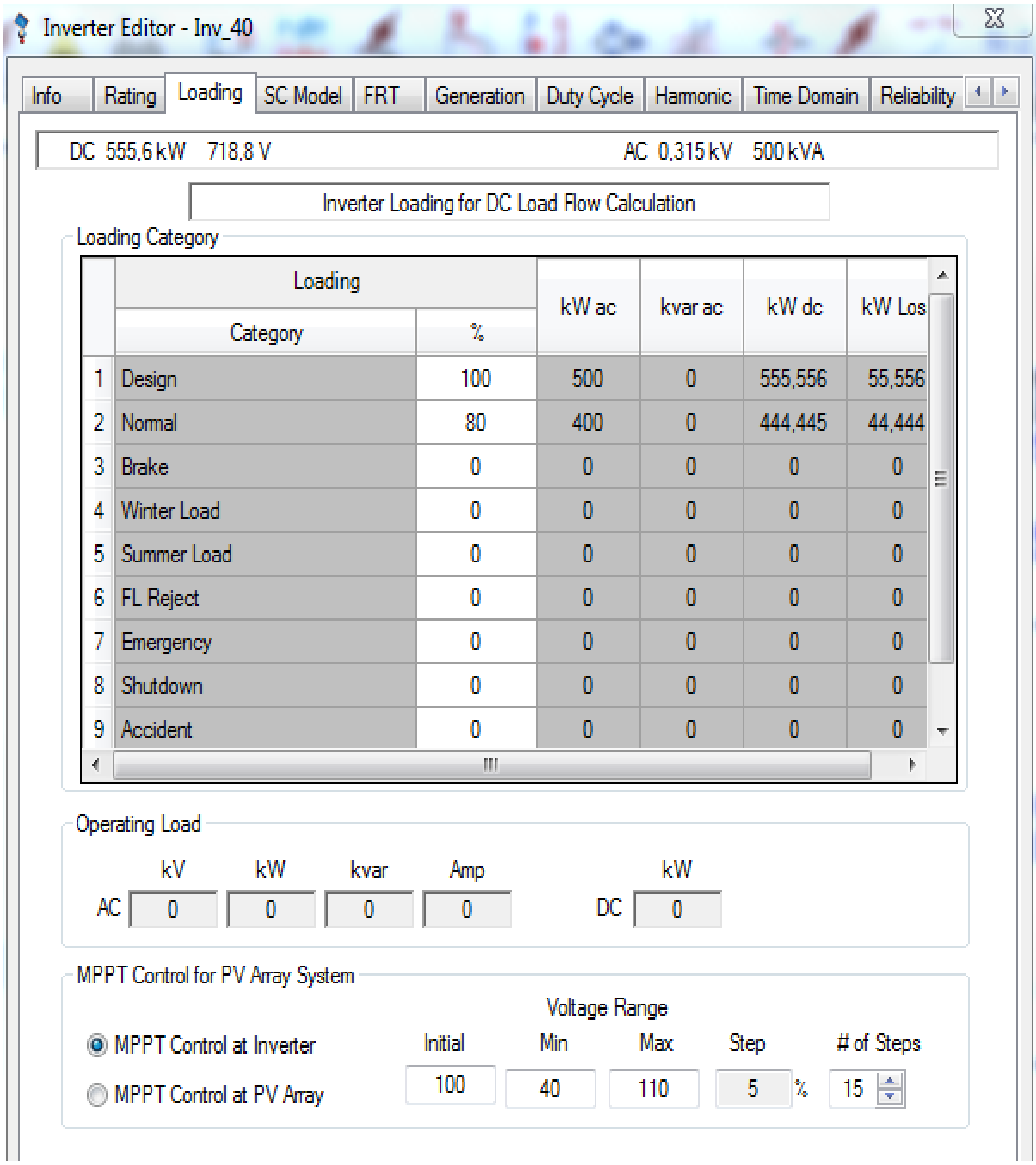
we can specify the inverter ratings, short-circuit current to a fault in the AC system, and AC grounding parameter in this page. And we enter DC Rating settings (kW, FLA, Vmax, Vmin) and AC Rating settings (kVA, kV, FLA, %PF, K).



IV.6.5. AC Loading - Inverter Editor:

In this page, we specify the loading percent of the inverter for all loading categories, and we view updated DC and AC operating load from AC load flow studies.

When option is selected (MPPT Control at Inverter), we can specify the inverter MPPT voltage correction range, step size and as well as the number of steps available. This is the typical option for a central inverter configuration.

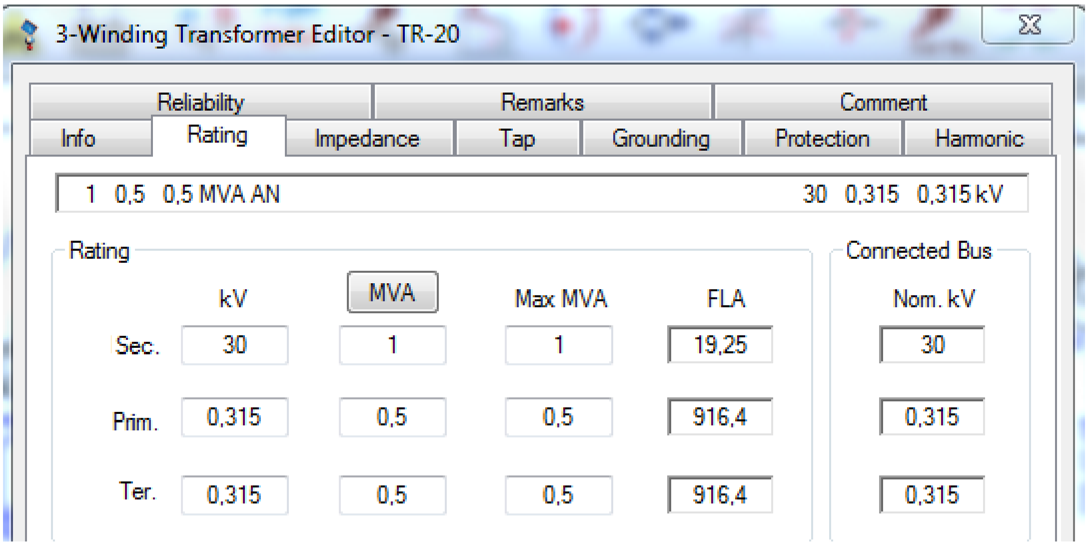


IV.6.6. Rating Page - 3-Winding Transformer Editor:

In this page, we enter primary, secondary, and tertiary voltage and MVA or kVA ratings of the 3-winding transformer.

ETAP uses the voltage at the lowest-numbered swing system as the base voltage and calculates the other base voltages using the transformer ratios. ETAP gives an error message when it detects inconsistent voltage bases in parallel or looped systems during system analysis.

Max MVA Capability values, are used to calculate the percent overload of the transformer windings, and this value is also used as a base for the transformer flow constraint in the optimal power flow studies.

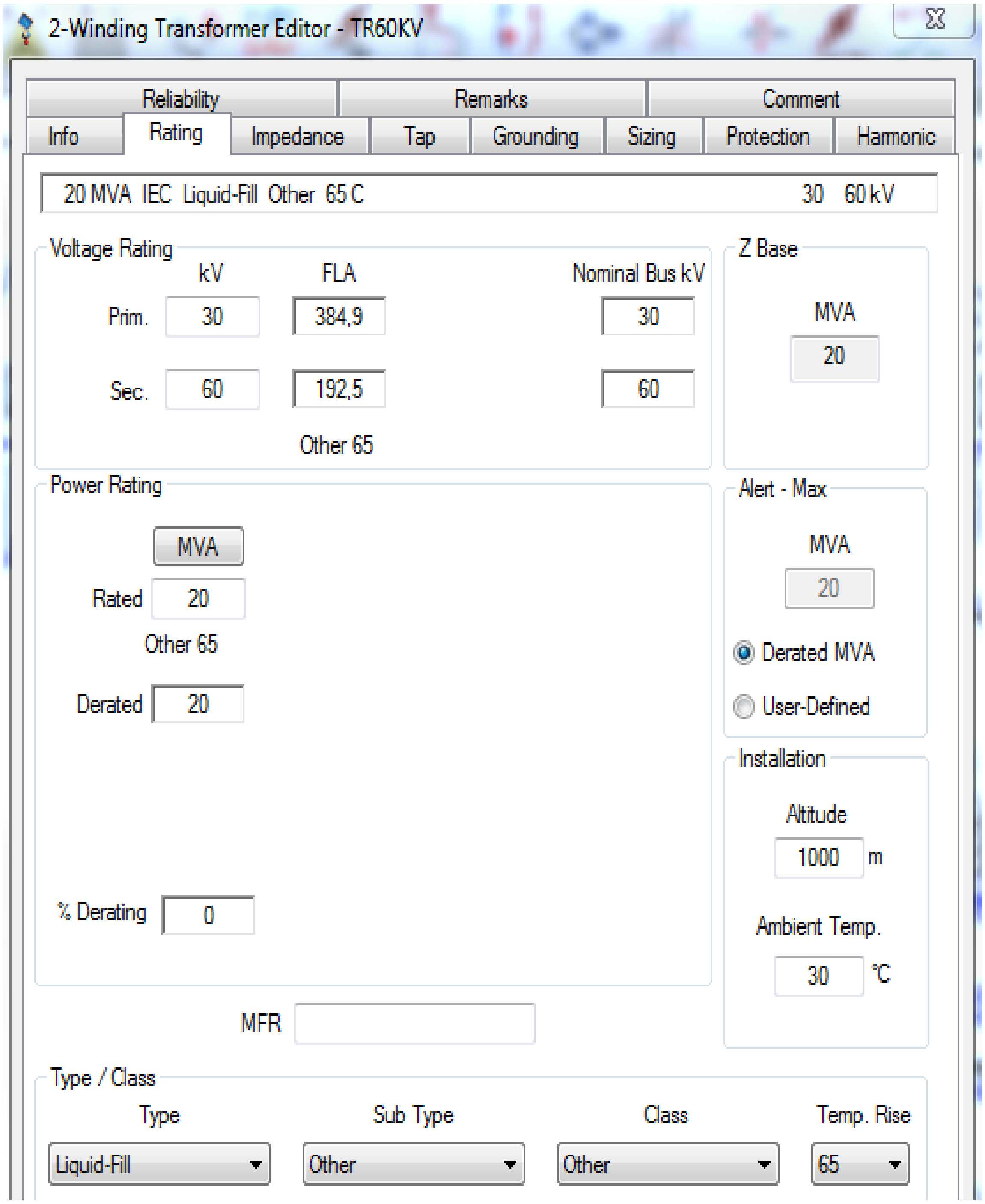


IV.6.7. Rating Page - 2-Winding Transformer Editor:

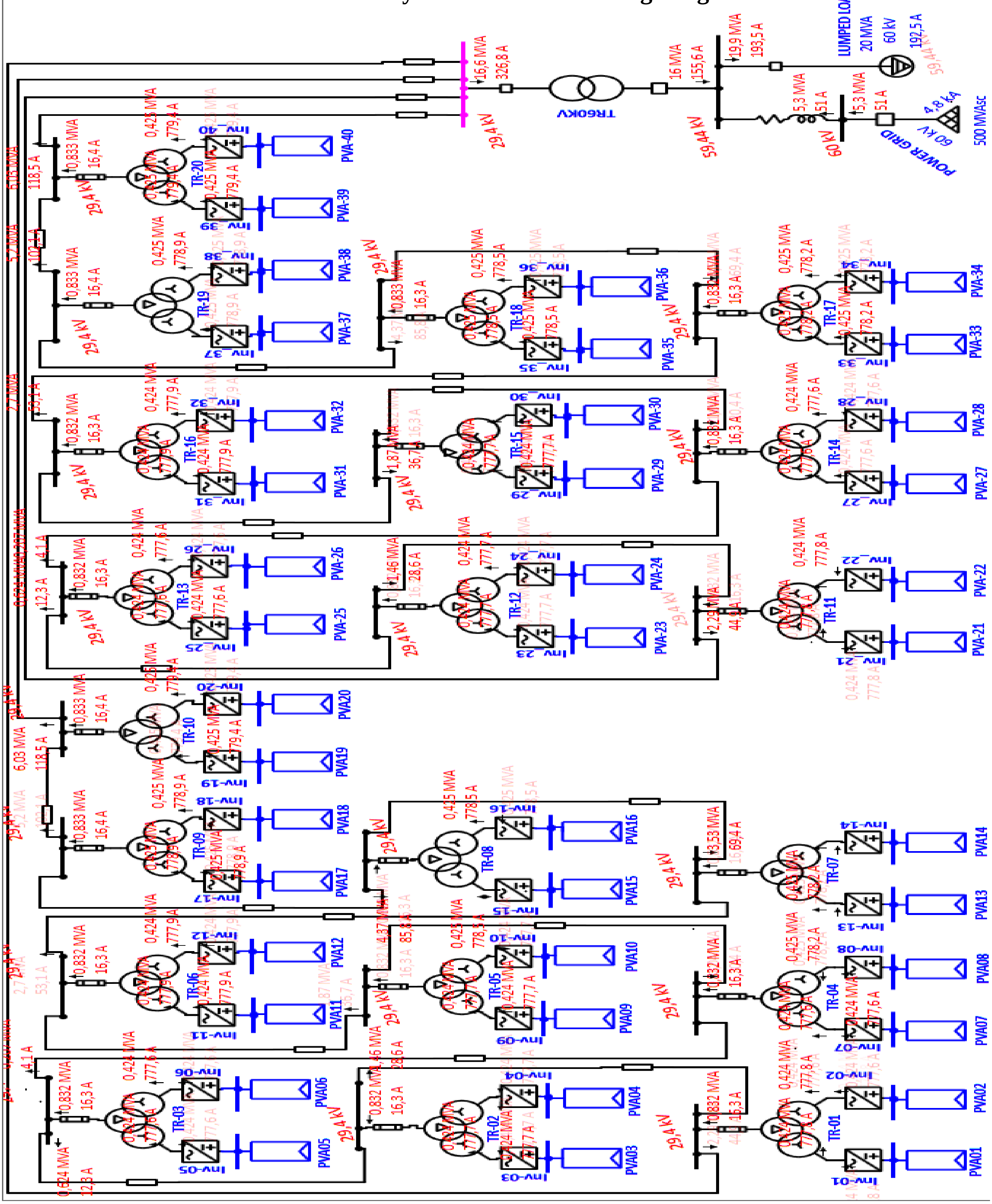
Rating Page - 2-Winding Transformer Editor

On the Rating page, we specify the 2-winding transformer rating (Prim & Sec), and we enter primary and secondary voltage and power ratings.

we select the transformer type from the Type list box. The following transformer types are available for both ANSI and IEC Standards (Liquid-Fill or Dry)



IV.7. Simulation Load Flow Analysis of Substation Using Program ETAP:



a. Electrical Transient Analyzer Program

Load Flow Analysis

Loading Category (1): Design

Generation Category (1): Design

Load Diversity Factor: None

	Swing	V-Control	Load	Total
Number of Buses:	41	0	22	63

	XFMR2	XFMR3	Reactor	Line/Cable/ Busway	Impedance	Tie PD	Total
Number of Branches:	1	20	0	23	0	0	44

Method of Solution:	Adaptive Newton-Raphson Method
Maximum No. of Iteration:	99
Precision of Solution:	0.0001000
System Frequency:	50.00 Hz
Unit System:	Metric
Project Filename:	Simulation **Aïn El Melh photovoltaic plant 20MW**
Output Filename:	C:\Users\adel.saada\Desktop\PROJET ETAP MEMOIRE FIN DETUDE\PROJET ETAP-MODEL-15_06_2022_12H00\Untitled.lfr

b. Adjustments

Tolerance	Apply Adjustments	Individual /Global	Percent
Transformer Impedance:	Yes	Individual	
Reactor Impedance:	Yes	Individual	
Overload Heater Resistance:	No		
Transmission Line Length:	No		
Cable / Busway Length:	No		

Temperature Correction	Apply Adjustments	Individual /Global	Degree C
Transmission Line Resistance:	Yes	Individual	
Cable / Busway Resistance:	Yes	Individual	

c. Bus Input Data

Bus			Initial Voltage		Load: Constant kVA		Load: Constant Z		Load: Constant I		Load: Generic	
ID	kV	Sub-sys	% Mag.	Ang.	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar
Bus7	0.315	1	100.0	0.0								
Bus_21	30.000	1	100.0	0.0								
Bus96	0.315	1	100.0	0.0								
Bus_Power Grid	60.000	1	100.0	0.0								
Bus_TR01	30.000	1	100.0	0.0								
Bus_TR02	30.000	1	100.0	0.0								
Bus_TR03	30.000	1	100.0	0.0								
Bus_TR04	30.000	1	100.0	0.0								
Bus_TR05	30.000	1	100.0	0.0								
Bus_TR06	30.000	1	100.0	0.0								
Bus_TR07	30.000	1	100.0	0.0								
Bus_TR08	30.000	1	100.0	0.0								
Bus_TR09	30.000	1	100.0	0.0								
Bus_TR10	30.000	1	100.0	0.0								
Bus_TR11	30.000	1	100.0	0.0								
Bus_TR12	30.000	1	100.0	0.0								
Bus_TR13	30.000	1	100.0	0.0								
Bus_TR14	30.000	1	100.0	0.0								
Bus_TR15	30.000	1	100.0	0.0								
Bus_TR16	30.000	1	100.0	0.0								
Bus_TR17	30.000	1	100.0	0.0								
Bus_TR18	30.000	1	100.0	0.0								
Bus_TR19	30.000	1	100.0	0.0								
Bus_TR20	30.000	1	100.0	0.0								
Bus_TR60KV	60.000	1	90.0	0.0	13.600	8.429	3.400	2.107				
INV01	0.315	1	100.0	0.0								
INV02	0.315	1	100.0	0.0								
INV03	0.315	1	100.0	0.0								
INV04	0.315	1	100.0	0.0								
INV05	0.315	1	100.0	0.0								
INV06	0.315	1	100.0	0.0								
INV07	0.315	1	100.0	0.0								
INV09	0.315	1	100.0	0.0								

Bus			Initial Voltage		Load							
					Constant kVA		Constant Z		Constant I		Generic	
ID	kV	Sub-sys	% Mag.	Ang.	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar
INV10	0.315	1	100.0	0.0								
INV11	0.315	1	100.0	0.0								
INV12	0.315	1	100.0	0.0								
INV13	0.315	1	100.0	0.0								
INV14	0.315	1	100.0	0.0								
INV15	0.315	1	100.0	0.0								
INV16	0.315	1	100.0	0.0								
INV17	0.315	1	100.0	0.0								
INV18	0.315	1	100.0	0.0								
INV19	0.315	1	100.0	0.0								
INV20	0.315	1	100.0	0.0								
INV21	0.315	1	100.0	0.0								
INV22	0.315	1	100.0	0.0								
INV23	0.315	1	100.0	0.0								
INV24	0.315	1	100.0	0.0								
INV25	0.315	1	100.0	0.0								
INV26	0.315	1	100.0	0.0								
INV27	0.315	1	100.0	0.0								
INV28	0.315	1	100.0	0.0								
INV29	0.315	1	100.0	0.0								
INV31	0.315	1	100.0	0.0								
INV32	0.315	1	100.0	0.0								
INV33	0.315	1	100.0	0.0								
INV34	0.315	1	100.0	0.0								
INV35	0.315	1	100.0	0.0								
INV36	0.315	1	100.0	0.0								
INV37	0.315	1	100.0	0.0								
INV38	0.315	1	100.0	0.0								
INV39	0.315	1	100.0	0.0								
INV40	0.315	1	100.0	0.0								
Total Number of Buses: 63					13.600	8.429	3.400	2.107	0.000	0.000	0.000	0.000

Generation Bus				Voltage		Generation			Mvar Limits	
ID	kV	Type	Sub-sys	% Mag.	Angle	MW	Mvar	% PF	Max	Min

Generation Bus				Voltage		Generation			Mvar Limits	
ID	kV	Type	Sub-sys	% Mag.	Angle	MW	Mvar	% PF	Max	Min
Bus7	0.315	Swing	1	100.0	0.0					
Bus96	0.315	Swing	1	100.0	0.0					
Bus_Power Grid	60.000	Swing	1	100.0	0.0					
INV01	0.315	Swing	1	100.0	0.0					
INV02	0.315	Swing	1	100.0	0.0					
INV03	0.315	Swing	1	100.0	0.0					
INV04	0.315	Swing	1	100.0	0.0					
INV05	0.315	Swing	1	100.0	0.0					
INV06	0.315	Swing	1	100.0	0.0					
INV07	0.315	Swing	1	100.0	0.0					
INV09	0.315	Swing	1	100.0	0.0					
INV10	0.315	Swing	1	100.0	0.0					
INV11	0.315	Swing	1	100.0	0.0					
INV12	0.315	Swing	1	100.0	0.0					
INV13	0.315	Swing	1	100.0	0.0					
INV14	0.315	Swing	1	100.0	0.0					
INV15	0.315	Swing	1	100.0	0.0					
INV16	0.315	Swing	1	100.0	0.0					
INV17	0.315	Swing	1	100.0	0.0					
INV18	0.315	Swing	1	100.0	0.0					
INV19	0.315	Swing	1	100.0	0.0					
INV20	0.315	Swing	1	100.0	0.0					
INV21	0.315	Swing	1	100.0	0.0					
INV22	0.315	Swing	1	100.0	0.0					
INV23	0.315	Swing	1	100.0	0.0					
INV24	0.315	Swing	1	100.0	0.0					
INV25	0.315	Swing	1	100.0	0.0					
INV26	0.315	Swing	1	100.0	0.0					
INV27	0.315	Swing	1	100.0	0.0					
INV28	0.315	Swing	1	100.0	0.0					
INV29	0.315	Swing	1	100.0	0.0					
INV31	0.315	Swing	1	100.0	0.0					
INV32	0.315	Swing	1	100.0	0.0					
INV33	0.315	Swing	1	100.0	0.0					
INV34	0.315	Swing	1	100.0	0.0					
INV35	0.315	Swing	1	100.0	0.0					
INV36	0.315	Swing	1	100.0	0.0					

Generation Bus				Voltage		Generation			Mvar Limits	
ID	kV	Type	Sub-sys	% Mag.	Angle	MW	Mvar	% PF	Max	Min
INV37	0.315	Swing	1	100.0	0.0					
INV38	0.315	Swing	1	100.0	0.0					
INV39	0.315	Swing	1	100.0	0.0					
INV40	0.315	Swing	1	100.0	0.0					
						0.000	0.000			

d. Line/Cable/Busway Input Data

ohms or siemens/1000 m per Conductor (Cable) or per Phase (Line/Busway)

Line/Cable/Busway			Length						
ID	Library	Size	Adj. (m)	% Tol.	#/Phase	T (°C)	R	X	Y
Cable00	30NCUS3	120	200.0	0.0	1	75	0.186940	0.117000	
Cable000	30NCUS3	120	200.0	0.0	1	75	0.186940	0.117000	
Cable01	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable02	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable03	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable04	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable05	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable06	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable07	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable08	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable09	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable10	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable11	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable12	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable13	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable14	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable15	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable_16	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable17	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable_18	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable19	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Cable20	30NCUS3	120	20.0	0.0	1	75	0.186940	0.117000	
Line1		307	70000.0	0.0	1	75	0.137001	0.362525	0.0000031

Line / Cable / Busway resistances are listed at the specified temperatures.

e. 2-Winding Transformer Input Data

Transformer		Rating					Z Variation			% Tap Setting		Adjusted	Phase Shift	
ID	Phase	MVA	Prim. kV	Sec. kV	% Z1	X1/R1	+ 5%	- 5%	% Tol.	Prim.	Sec.	% Z	Type	Angle
TR60KV	3-Phase	20.000	30.000	60.000	5.00	3.50	0	0	0	0	5.000	5.0000	YNd	0.000

f. 3-Winding Transformer Input Data

Transformer	Rating			Tap	Impedance					Z Variation		Phase Shift	
ID	Winding	MVA	kV	%		% Z1	X1/R1	MVAb	% Tol.	+ 5%	- 5%	Type	Angle
TR-01	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-02	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-03	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-04	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-05	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-06	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-07	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-08	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000

3-Winding Transformer Input Data

Transformer	Rating			Tap	Impedance					Z Variation		Phase Shift	
ID	Winding	MVA	kV	%		% Z1	X1/R1	MVAb	% Tol.	+ 5%	- 5%	Type	Angle
TR-09	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-10	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-11	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-12	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-13	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-14	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-15	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-16	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-17	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-18	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000

3-Winding Transformer Input Data

Transformer	Rating			Tap	Impedance					Z Variation		Phase Shift	
ID	Winding	MVA	kV	%		% Z1	X1/R1	MVAb	% Tol.	+ 5%	- 5%	Type	Angle
TR-19	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
TR-20	Secondary:	1.000	30.000	0	Zps =	4.00	8.00	1.000	0	0	0		
	Primary:	0.500	0.315	0	Zpt =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000
	Tertiary:	0.500	0.315	0	Zst =	4.00	8.00	1.000	0			Std Pos. Seq.	0.000

g. Branch Connections

CKT/Branch		Connected Bus ID		% Impedance, Pos. Seq., 100 MVA Base			
ID	Type	From Bus	To Bus	R	X	Z	Y
TR60KV	2W XFMR	Bus_21	Bus_TR60KV	7.21	25.24	26.25	
TR-01	3W Xfmr	Bus_TR01	INV01	74.42	595.37	600.00	
	3W Xfmr	Bus_TR01	INV02	74.42	595.37	600.00	
	3W Xfmr	INV01	INV02	74.42	595.37	600.00	
TR-02	3W Xfmr	Bus_TR02	INV03	74.42	595.37	600.00	
	3W Xfmr	Bus_TR02	INV04	74.42	595.37	600.00	
	3W Xfmr	INV03	INV04	74.42	595.37	600.00	
TR-03	3W Xfmr	Bus_TR03	INV05	74.42	595.37	600.00	
	3W Xfmr	Bus_TR03	INV06	74.42	595.37	600.00	
	3W Xfmr	INV05	INV06	74.42	595.37	600.00	
TR-04	3W Xfmr	Bus_TR04	INV07	74.42	595.37	600.00	
	3W Xfmr	Bus_TR04	Bus96	74.42	595.37	600.00	
	3W Xfmr	INV07	Bus96	74.42	595.37	600.00	
TR-05	3W Xfmr	Bus_TR05	INV09	74.42	595.37	600.00	
	3W Xfmr	Bus_TR05	INV10	74.42	595.37	600.00	
	3W Xfmr	INV09	INV10	74.42	595.37	600.00	
TR-06	3W Xfmr	Bus_TR06	INV11	74.42	595.37	600.00	
	3W Xfmr	Bus_TR06	INV12	74.42	595.37	600.00	
	3W Xfmr	INV11	INV12	74.42	595.37	600.00	
TR-07	3W Xfmr	Bus_TR07	INV13	74.42	595.37	600.00	
	3W Xfmr	Bus_TR07	INV14	74.42	595.37	600.00	
	3W Xfmr	INV13	INV14	74.42	595.37	600.00	
TR-08	3W Xfmr	Bus_TR08	INV15	74.42	595.37	600.00	
	3W Xfmr	Bus_TR08	INV16	74.42	595.37	600.00	
	3W Xfmr	INV15	INV16	74.42	595.37	600.00	
TR-09	3W Xfmr	Bus_TR09	INV17	74.42	595.37	600.00	
	3W Xfmr	Bus_TR09	INV18	74.42	595.37	600.00	
	3W Xfmr	INV17	INV18	74.42	595.37	600.00	
TR-10	3W Xfmr	Bus_TR10	INV19	74.42	595.37	600.00	
	3W Xfmr	Bus_TR10	INV20	74.42	595.37	600.00	
	3W Xfmr	INV19	INV20	74.42	595.37	600.00	
TR-11	3W Xfmr	Bus_TR11	INV21	74.42	595.37	600.00	
	3W Xfmr	Bus_TR11	INV22	74.42	595.37	600.00	
	3W Xfmr	INV21	INV22	74.42	595.37	600.00	
TR-12	3W Xfmr	Bus_TR12	INV23	74.42	595.37	600.00	
	3W Xfmr	Bus_TR12	INV24	74.42	595.37	600.00	

CKT/Branch		Connected Bus ID		% Impedance, Pos. Seq., 100 MVA Base			
ID	Type	From Bus	To Bus	R	X	Z	Y
	3W Xfmr	INV23	INV24	74.42	595.37	600.00	
TR-13	3W Xfmr	Bus_TR13	INV25	74.42	595.37	600.00	
	3W Xfmr	Bus_TR13	INV26	74.42	595.37	600.00	
	3W Xfmr	INV25	INV26	74.42	595.37	600.00	
TR-14	3W Xfmr	Bus_TR14	INV27	74.42	595.37	600.00	
	3W Xfmr	Bus_TR14	INV28	74.42	595.37	600.00	
	3W Xfmr	INV27	INV28	74.42	595.37	600.00	
TR-15	3W Xfmr	Bus_TR15	INV29	74.42	595.37	600.00	
	3W Xfmr	Bus_TR15	Bus7	74.42	595.37	600.00	
	3W Xfmr	INV29	Bus7	74.42	595.37	600.00	
TR-16	3W Xfmr	Bus_TR16	INV31	74.42	595.37	600.00	
	3W Xfmr	Bus_TR16	INV32	74.42	595.37	600.00	
	3W Xfmr	INV31	INV32	74.42	595.37	600.00	
TR-17	3W Xfmr	Bus_TR17	INV33	74.42	595.37	600.00	
	3W Xfmr	Bus_TR17	INV34	74.42	595.37	600.00	
	3W Xfmr	INV33	INV34	74.42	595.37	600.00	
TR-18	3W Xfmr	Bus_TR18	INV35	74.42	595.37	600.00	
	3W Xfmr	Bus_TR18	INV36	74.42	595.37	600.00	
	3W Xfmr	INV35	INV36	74.42	595.37	600.00	
TR-19	3W Xfmr	Bus_TR19	INV37	74.42	595.37	600.00	
	3W Xfmr	Bus_TR19	INV38	74.42	595.37	600.00	
	3W Xfmr	INV37	INV38	74.42	595.37	600.00	
TR-20	3W Xfmr	Bus_TR20	INV39	74.42	595.37	600.00	
	3W Xfmr	Bus_TR20	INV40	74.42	595.37	600.00	
	3W Xfmr	INV39	INV40	74.42	595.37	600.00	
Cable00	Cable	Bus_TR01	Bus_21	0.42	0.26	0.49	
Cable000	Cable	Bus_21	Bus_TR11	0.42	0.26	0.49	
Cable01	Cable	Bus_TR01	Bus_TR02	0.04	0.03	0.05	
Cable02	Cable	Bus_TR03	Bus_TR02	0.04	0.03	0.05	
Cable03	Cable	Bus_TR04	Bus_TR03	0.04	0.03	0.05	
Cable04	Cable	Bus_TR04	Bus_TR05	0.04	0.03	0.05	
Cable05	Cable	Bus_TR05	Bus_TR06	0.04	0.03	0.05	
Cable06	Cable	Bus_TR06	Bus_TR07	0.04	0.03	0.05	
Cable07	Cable	Bus_TR07	Bus_TR08	0.04	0.03	0.05	
Cable08	Cable	Bus_TR08	Bus_TR09	0.04	0.03	0.05	
Cable09	Cable	Bus_TR09	Bus_TR10	0.04	0.03	0.05	
Cable10	Cable	Bus_TR10	Bus_21	0.04	0.03	0.05	
Cable11	Cable	Bus_TR11	Bus_TR12	0.04	0.03	0.05	
Cable12	Cable	Bus_TR12	Bus_TR13	0.04	0.03	0.05	

CKT/Branch		Connected Bus ID		% Impedance, Pos. Seq., 100 MVA Base			
ID	Type	From Bus	To Bus	R	X	Z	Y
Cable13	Cable	Bus_TR13	Bus_TR14	0.04	0.03	0.05	
Cable14	Cable	Bus_TR14	Bus_TR15	0.04	0.03	0.05	
Cable15	Cable	Bus_TR15	Bus_TR16	0.04	0.03	0.05	
Cable_16	Cable	Bus_TR16	Bus_TR17	0.04	0.03	0.05	
Cable17	Cable	Bus_TR17	Bus_TR18	0.04	0.03	0.05	
Cable_18	Cable	Bus_TR18	Bus_TR19	0.04	0.03	0.05	
Cable19	Cable	Bus_TR19	Bus_TR20	0.04	0.03	0.05	
Cable20	Cable	Bus_21	Bus_TR20	0.04	0.03	0.05	
Line1	Line	Bus_TR60KV	Bus_Power Grid	26.64	70.49	75.36	0.7916393

h. LOAD FLOW REPORT

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
* Bus7	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR15	0.301	0.299	777.7	71.0	
								&INV29					
Bus_21	30.000	97.997	-0.9	0.000	0.000	0.000	0.000	Bus_TR01	-1.649	-1.586	44.9	72.1	
								Bus_TR11	-1.649	-1.586	44.9	72.1	
								Bus_TR10	-4.346	-4.185	118.5	72.0	
								Bus_TR20	-4.346	-4.185	118.5	72.0	
								Bus_TR60KV	11.990	11.540	326.8	72.1	
* Bus96	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR04	0.301	0.299	777.6	71.0	
								&INV07					
* Bus_Power Grid	60.000	100.000	0.0	5.218	-0.941	0.000	0.000	Bus_TR60KV	5.218	-0.941	51.0	-98.4	
Bus_TR01	30.000	98.008	-0.9	0.000	0.000	0.000	0.000	Bus_21	1.649	1.586	44.9	72.1	
								Bus_TR02	-1.049	-1.009	28.6	72.1	
								INV01	-0.600	-0.577	16.3	72.1	
								&INV02					
Bus_TR02	30.000	98.009	-0.9	0.000	0.000	0.000	0.000	Bus_TR01	1.049	1.009	28.6	72.1	
								Bus_TR03	-0.450	-0.433	12.3	72.0	
								INV03	-0.600	-0.576	16.3	72.1	
								&INV04					
Bus_TR03	30.000	98.009	-0.9	0.000	0.000	0.000	0.000	Bus_TR02	0.450	0.433	12.3	72.0	
								Bus_TR04	0.150	0.143	4.1	72.3	
								INV05	-0.600	-0.576	16.3	72.1	
								&INV06					
Bus_TR04	30.000	98.009	-0.9	0.000	0.000	0.000	0.000	Bus_TR03	-0.150	-0.143	4.1	72.3	
								Bus_TR05	0.750	0.719	20.4	72.1	
								INV07	-0.600	-0.576	16.3	72.1	
								&Bus96					
Bus_TR05	30.000	98.009	-0.9	0.000	0.000	0.000	0.000	Bus_TR04	-0.750	-0.719	20.4	72.1	
								Bus_TR06	1.349	1.296	36.7	72.1	
								INV09	-0.600	-0.576	16.3	72.1	
								&INV10					
Bus_TR06	30.000	98.008	-0.9	0.000	0.000	0.000	0.000	Bus_TR05	-1.349	-1.296	36.7	72.1	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
								Bus_TR07	1.949	1.872	53.1	72.1	
								INV11	-0.600	-0.577	16.3	72.1	
								&INV12					
Bus_TR07	30.000	98.007	-0.9	0.000	0.000	0.000	0.000	Bus_TR06	-1.949	-1.872	53.1	72.1	
								Bus_TR08	2.548	2.450	69.4	72.1	
								INV13	-0.600	-0.577	16.3	72.0	
								&INV14					
Bus_TR08	30.000	98.005	-0.9	0.000	0.000	0.000	0.000	Bus_TR07	-2.548	-2.450	69.4	72.1	
								Bus_TR09	3.148	3.027	85.8	72.1	
								INV15	-0.600	-0.578	16.3	72.0	
								&INV16					
Bus_TR09	30.000	98.003	-0.9	0.000	0.000	0.000	0.000	Bus_TR08	-3.148	-3.027	85.8	72.1	
								Bus_TR10	3.747	3.606	102.1	72.1	
								INV17	-0.599	-0.578	16.4	72.0	
								&INV18					
Bus_TR10	30.000	98.000	-0.9	0.000	0.000	0.000	0.000	Bus_TR09	-3.747	-3.605	102.1	72.1	
								Bus_21	4.347	4.185	118.5	72.0	
								INV19	-0.599	-0.579	16.4	71.9	
								&INV20					
Bus_TR11	30.000	98.008	-0.9	0.000	0.000	0.000	0.000	Bus_21	1.649	1.586	44.9	72.1	
								Bus_TR12	-1.049	-1.009	28.6	72.1	
								INV21	-0.600	-0.577	16.3	72.1	
								&INV22					
Bus_TR12	30.000	98.009	-0.9	0.000	0.000	0.000	0.000	Bus_TR11	1.049	1.009	28.6	72.1	
								Bus_TR13	-0.450	-0.433	12.3	72.0	
								INV23	-0.600	-0.576	16.3	72.1	
								&INV24					
Bus_TR13	30.000	98.009	-0.9	0.000	0.000	0.000	0.000	Bus_TR12	0.450	0.433	12.3	72.0	
								Bus_TR14	0.150	0.143	4.1	72.3	
								INV25	-0.600	-0.576	16.3	72.1	
								&INV26					
Bus_TR14	30.000	98.009	-0.9	0.000	0.000	0.000	0.000	Bus_TR13	-0.150	-0.143	4.1	72.3	
								Bus_TR15	0.750	0.719	20.4	72.1	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
								INV27 &INV28	-0.600	-0.576	16.3	72.1	
Bus_TR15	30.000	98.009	-0.9	0.000	0.000	0.000	0.000	Bus_TR14	-0.750	-0.719	20.4	72.1	
								Bus_TR16	1.349	1.296	36.7	72.1	
								INV29 &Bus7	-0.600	-0.576	16.3	72.1	
Bus_TR16	30.000	98.008	-0.9	0.000	0.000	0.000	0.000	Bus_TR15	-1.349	-1.296	36.7	72.1	
								Bus_TR17	1.949	1.872	53.1	72.1	
								INV31 &INV32	-0.600	-0.577	16.3	72.1	
Bus_TR17	30.000	98.007	-0.9	0.000	0.000	0.000	0.000	Bus_TR16	-1.949	-1.872	53.1	72.1	
								Bus_TR18	2.548	2.450	69.4	72.1	
								INV33 &INV34	-0.600	-0.577	16.3	72.0	
Bus_TR18	30.000	98.005	-0.9	0.000	0.000	0.000	0.000	Bus_TR17	-2.548	-2.450	69.4	72.1	
								Bus_TR19	3.148	3.027	85.8	72.1	
								INV35 &INV36	-0.600	-0.578	16.3	72.0	
Bus_TR19	30.000	98.003	-0.9	0.000	0.000	0.000	0.000	Bus_TR18	-3.148	-3.027	85.8	72.1	
								Bus_TR20	3.747	3.606	102.1	72.1	
								INV37 &INV38	-0.599	-0.578	16.4	72.0	
Bus_TR20	30.000	98.000	-0.9	0.000	0.000	0.000	0.000	Bus_TR19	-3.747	-3.605	102.1	72.1	
								Bus_21	4.347	4.185	118.5	72.0	
								INV39 &INV40	-0.599	-0.579	16.4	71.9	
Bus_TR60KV	60.000	99.068	-2.2	0.000	0.000	16.937	10.497	Bus_Power Grid	-5.145	0.350	50.1	-99.8	
								Bus_21	-11.792	-10.847	155.6	73.6	5.000
* INV01	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV02 &Bus_TR01	0.301	0.299	777.8	71.0	
* INV02	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR01 &INV01	0.301	0.299	777.8	71.0	
* INV03	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV04	0.301	0.299	777.7	71.0	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
								&Bus_TR02					
* INV04	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR02	0.301	0.299	777.7	71.0	
								&INV03					
* INV05	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV06	0.301	0.299	777.6	71.0	
								&Bus_TR03					
* INV06	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR03	0.301	0.299	777.6	71.0	
								&INV05					
* INV07	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus96	0.301	0.299	777.6	71.0	
								&Bus_TR04					
* INV09	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV10	0.301	0.299	777.7	71.0	
								&Bus_TR05					
* INV10	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR05	0.301	0.299	777.7	71.0	
								&INV09					
* INV11	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV12	0.301	0.299	777.9	71.0	
								&Bus_TR06					
* INV12	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR06	0.301	0.299	777.9	71.0	
								&INV11					
* INV13	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV14	0.301	0.299	778.2	70.9	
								&Bus_TR07					
* INV14	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR07	0.301	0.299	778.2	70.9	
								&INV13					
* INV15	0.315	100.000	0.0	0.301	0.300	0.000	0.000	INV16	0.301	0.300	778.5	70.9	
								&Bus_TR08					
* INV16	0.315	100.000	0.0	0.301	0.300	0.000	0.000	Bus_TR08	0.301	0.300	778.5	70.9	
								&INV15					
* INV17	0.315	100.000	0.0	0.301	0.300	0.000	0.000	INV18	0.301	0.300	778.9	70.8	
								&Bus_TR09					
* INV18	0.315	100.000	0.0	0.301	0.300	0.000	0.000	Bus_TR09	0.301	0.300	778.9	70.8	
								&INV17					
* INV19	0.315	100.000	0.0	0.301	0.300	0.000	0.000	INV20	0.301	0.300	779.4	70.8	
								&Bus_TR10					
* INV20	0.315	100.000	0.0	0.301	0.300	0.000	0.000	Bus_TR10	0.301	0.300	779.4	70.8	
								&INV19					

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
* INV21	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV22 &Bus_TR11	0.301	0.299	777.8	71.0	
* INV22	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR11 &INV21	0.301	0.299	777.8	71.0	
* INV23	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV24 &Bus_TR12	0.301	0.299	777.7	71.0	
* INV24	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR12 &INV23	0.301	0.299	777.7	71.0	
* INV25	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV26 &Bus_TR13	0.301	0.299	777.6	71.0	
* INV26	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR13 &INV25	0.301	0.299	777.6	71.0	
* INV27	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV28 &Bus_TR14	0.301	0.299	777.6	71.0	
* INV28	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR14 &INV27	0.301	0.299	777.6	71.0	
* INV29	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus7 &Bus_TR15	0.301	0.299	777.7	71.0	
* INV31	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV32 &Bus_TR16	0.301	0.299	777.9	71.0	
* INV32	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR16 &INV31	0.301	0.299	777.9	71.0	
* INV33	0.315	100.000	0.0	0.301	0.299	0.000	0.000	INV34 &Bus_TR17	0.301	0.299	778.2	70.9	
* INV34	0.315	100.000	0.0	0.301	0.299	0.000	0.000	Bus_TR17 &INV33	0.301	0.299	778.2	70.9	
* INV35	0.315	100.000	0.0	0.301	0.300	0.000	0.000	INV36 &Bus_TR18	0.301	0.300	778.5	70.9	
* INV36	0.315	100.000	0.0	0.301	0.300	0.000	0.000	Bus_TR18 &INV35	0.301	0.300	778.5	70.9	
* INV37	0.315	100.000	0.0	0.301	0.300	0.000	0.000	INV38 &Bus_TR19	0.301	0.300	778.9	70.8	
* INV38	0.315	100.000	0.0	0.301	0.300	0.000	0.000	Bus_TR19	0.301	0.300	778.9	70.8	

Bus		Voltage		Generation		Load		Load Flow					XFMR
ID	kV	% Mag.	Ang.	MW	Mvar	MW	Mvar	ID	MW	Mvar	Amp	%PF	%Tap
								&INV37					
* INV39	0.315	100.000	0.0	0.301	0.300	0.000	0.000	INV40	0.301	0.300	779.4	70.8	
								&Bus_TR20					
* INV40	0.315	100.000	0.0	0.301	0.300	0.000	0.000	Bus_TR20	0.301	0.300	779.4	70.8	
								&INV39					

* Indicates a voltage regulated bus (voltage controlled or swing type machine connected to it)

\# Indicates a bus with a load mismatch of more than 0.1 MVA

i. Bus Loading Summary Report

Bus			Directly Connected Load								Total Bus Load			
			Constant kVA		Constant Z		Constant I		Generic					Percent
ID	kV	Rated Amp	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar	MVA	% PF	Amp	Loading
Bus7	0.315										0.424	71.0	777.7	
Bus_21	30.000										16.642	72.1	326.8	
Bus96	0.315										0.424	71.0	777.6	
Bus_Power Grid	60.000										5.302	98.4	51.0	
Bus_TR01	30.000										2.288	72.1	44.9	
Bus_TR02	30.000										1.456	72.1	28.6	
Bus_TR03	30.000										0.832	72.1	16.3	
Bus_TR04	30.000										1.039	72.1	20.4	
Bus_TR05	30.000										1.871	72.1	36.7	
Bus_TR06	30.000										2.703	72.1	53.1	
Bus_TR07	30.000										3.535	72.1	69.4	
Bus_TR08	30.000										4.367	72.1	85.8	
Bus_TR09	30.000										5.200	72.1	102.1	
Bus_TR10	30.000										6.034	72.0	118.5	
Bus_TR11	30.000										2.288	72.1	44.9	
Bus_TR12	30.000										1.456	72.1	28.6	
Bus_TR13	30.000										0.832	72.1	16.3	
Bus_TR14	30.000										1.039	72.1	20.4	
Bus_TR15	30.000										1.871	72.1	36.7	
Bus_TR16	30.000										2.703	72.1	53.1	
Bus_TR17	30.000										3.535	72.1	69.4	
Bus_TR18	30.000										4.367	72.1	85.8	
Bus_TR19	30.000										5.200	72.1	102.1	
Bus_TR20	30.000										6.034	72.0	118.5	
Bus_TR60KV	60.000		13.600	8.429	3.337	2.068					20.113	84.2	195.4	
INV01	0.315										0.424	71.0	777.8	
INV02	0.315										0.424	71.0	777.8	
INV03	0.315										0.424	71.0	777.7	
INV04	0.315										0.424	71.0	777.7	
INV05	0.315										0.424	71.0	777.6	
INV06	0.315										0.424	71.0	777.6	
INV07	0.315										0.424	71.0	777.6	
INV09	0.315										0.424	71.0	777.7	
INV10	0.315										0.424	71.0	777.7	
INV11	0.315										0.424	71.0	777.9	
INV12	0.315										0.424	71.0	777.9	
INV13	0.315										0.425	70.9	778.2	
INV14	0.315										0.425	70.9	778.2	
INV15	0.315										0.425	70.9	778.5	

Bus			Directly Connected Load								Total Bus Load			
			Constant kVA		Constant Z		Constant I		Generic					Percent
ID	kV	Rated Amp	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar	MVA	% PF	Amp	Loading
INV16	0.315										0.425	70.9	778.5	
INV17	0.315										0.425	70.8	778.9	
INV18	0.315										0.425	70.8	778.9	
INV19	0.315										0.425	70.8	779.4	
INV20	0.315										0.425	70.8	779.4	
INV21	0.315										0.424	71.0	777.8	
INV22	0.315										0.424	71.0	777.8	
INV23	0.315										0.424	71.0	777.7	
INV24	0.315										0.424	71.0	777.7	
INV25	0.315										0.424	71.0	777.6	
INV26	0.315										0.424	71.0	777.6	
INV27	0.315										0.424	71.0	777.6	
INV28	0.315										0.424	71.0	777.6	
INV29	0.315										0.424	71.0	777.7	
INV31	0.315										0.424	71.0	777.9	
INV32	0.315										0.424	71.0	777.9	
INV33	0.315										0.425	70.9	778.2	
INV34	0.315										0.425	70.9	778.2	
INV35	0.315										0.425	70.9	778.5	
INV36	0.315										0.425	70.9	778.5	
INV37	0.315										0.425	70.8	778.9	
INV38	0.315										0.425	70.8	778.9	
INV39	0.315										0.425	70.8	779.4	
INV40	0.315										0.425	70.8	779.4	

* Indicates operating load of a bus exceeds the bus critical limit (100.0% of the Continuous Ampere rating).
# Indicates operating load of a bus exceeds the bus marginal limit (95.0% of the Continuous Ampere rating).

j. Branch Loading Summary Report

CKT / Branch		Busway / Cable & Reactor			Transformer				
					Capability (MVA)	Loading (input)		Loading (output)	
ID	Type	Ampacity (Amp)	Loading Amp	%		MVA	%	MVA	%
TR60KV	Transformer				20.000	16.642	83.2	16.022	80.1
TR-01	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		
	3W XFMR t				0.500	0.424	84.9		
TR-02	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		
	3W XFMR t				0.500	0.424	84.9		
TR-03	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		
	3W XFMR t				0.500	0.424	84.9		
TR-04	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		
	3W XFMR t				0.500	0.424	84.9		
TR-05	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		
	3W XFMR t				0.500	0.424	84.9		
TR-06	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		
	3W XFMR t				0.500	0.424	84.9		
TR-07	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.425	84.9		
	3W XFMR t				0.500	0.425	84.9		
TR-08	3W XFMR p				1.000	0.833	83.3		
	3W XFMR s				0.500	0.425	84.9		
	3W XFMR t				0.500	0.425	84.9		
TR-09	3W XFMR p				1.000	0.833	83.3		
	3W XFMR s				0.500	0.425	85.0		
	3W XFMR t				0.500	0.425	85.0		
TR-10	3W XFMR p				1.000	0.833	83.3		
	3W XFMR s				0.500	0.425	85.0		
	3W XFMR t				0.500	0.425	85.0		
TR-11	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		

CKT / Branch		Busway / Cable & Reactor			Transformer				
						Loading (input)		Loading (output)	
ID	Type	Ampacity (Amp)	Loading Amp	%	Capability (MVA)	MVA	%	MVA	%
TR-11	3W XFMR t				0.500	0.424	84.9		
TR-12	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		
	3W XFMR t				0.500	0.424	84.9		
TR-13	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		
	3W XFMR t				0.500	0.424	84.9		
TR-14	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		
	3W XFMR t				0.500	0.424	84.9		
TR-15	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		
	3W XFMR t				0.500	0.424	84.9		
TR-16	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.424	84.9		
	3W XFMR t				0.500	0.424	84.9		
TR-17	3W XFMR p				1.000	0.832	83.2		
	3W XFMR s				0.500	0.425	84.9		
	3W XFMR t				0.500	0.425	84.9		
TR-18	3W XFMR p				1.000	0.833	83.3		
	3W XFMR s				0.500	0.425	84.9		
	3W XFMR t				0.500	0.425	84.9		
TR-19	3W XFMR p				1.000	0.833	83.3		
	3W XFMR s				0.500	0.425	85.0		
	3W XFMR t				0.500	0.425	85.0		
TR-20	3W XFMR p				1.000	0.833	83.3		
	3W XFMR s				0.500	0.425	85.0		
	3W XFMR t				0.500	0.425	85.0		

* Indicates a branch with operating load exceeding the branch capability.

k. Branch Losses Summary Report

Branch ID	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop
	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag
Cable_16	1.949	1.872	-1.949	-1.872	0.0	0.0	98.0	98.0	0.00
Cable_18	3.148	3.027	-3.148	-3.027	0.1	0.1	98.0	98.0	0.00
Cable00	-1.649	-1.586	1.649	1.586	0.2	0.1	98.0	98.0	0.01
Cable000	-1.649	-1.586	1.649	1.586	0.2	0.1	98.0	98.0	0.01
Cable01	-1.049	-1.009	1.049	1.009	0.0	0.0	98.0	98.0	0.00
Cable02	-0.450	-0.433	0.450	0.433	0.0	0.0	98.0	98.0	0.00
Cable03	0.150	0.143	-0.150	-0.143	0.0	0.0	98.0	98.0	0.00
Cable04	0.750	0.719	-0.750	-0.719	0.0	0.0	98.0	98.0	0.00
Cable05	1.349	1.296	-1.349	-1.296	0.0	0.0	98.0	98.0	0.00
Cable06	1.949	1.872	-1.949	-1.872	0.0	0.0	98.0	98.0	0.00
Cable07	2.548	2.450	-2.548	-2.450	0.1	0.0	98.0	98.0	0.00
Cable08	3.148	3.027	-3.148	-3.027	0.1	0.1	98.0	98.0	0.00
Cable09	3.747	3.606	-3.747	-3.605	0.1	0.1	98.0	98.0	0.00
Cable10	-4.346	-4.185	4.347	4.185	0.2	0.1	98.0	98.0	0.00
Cable11	-1.049	-1.009	1.049	1.009	0.0	0.0	98.0	98.0	0.00
Cable12	-0.450	-0.433	0.450	0.433	0.0	0.0	98.0	98.0	0.00
Cable13	0.150	0.143	-0.150	-0.143	0.0	0.0	98.0	98.0	0.00
Cable14	0.750	0.719	-0.750	-0.719	0.0	0.0	98.0	98.0	0.00
Cable15	1.349	1.296	-1.349	-1.296	0.0	0.0	98.0	98.0	0.00
Cable17	2.548	2.450	-2.548	-2.450	0.1	0.0	98.0	98.0	0.00
Cable19	3.747	3.606	-3.747	-3.605	0.1	0.1	98.0	98.0	0.00
Cable20	-4.346	-4.185	4.347	4.185	0.2	0.1	98.0	98.0	0.00
Line1	5.218	-0.941	-5.145	0.350	73.3	-590.3	100.0	99.1	0.93
TR-01	-0.600	-0.577	0.301	0.299	2.7	21.4	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-02	-0.600	-0.576	0.301	0.299	2.7	21.4	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-03	-0.600	-0.576	0.301	0.299	2.7	21.4	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-04	-0.600	-0.576	0.301	0.299	2.7	21.4	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-05	-0.600	-0.576	0.301	0.299	2.7	21.4	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-06	-0.600	-0.577	0.301	0.299	2.7	21.4	98.0	100.0	1.99

Branch ID	From-To Bus Flow		To-From Bus Flow		Losses		% Bus Voltage		Vd % Drop
	MW	Mvar	MW	Mvar	kW	kvar	From	To	in Vmag
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-07	-0.600	-0.577	0.301	0.299	2.7	21.5	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-08	-0.600	-0.578	0.301	0.300	2.7	21.5	98.0	100.0	2.00
	0.000	0.000	0.301	0.300			98.0	100.0	2.00
TR-09	-0.599	-0.578	0.301	0.300	2.7	21.5	98.0	100.0	2.00
	0.000	0.000	0.301	0.300			98.0	100.0	2.00
TR-10	-0.599	-0.579	0.301	0.300	2.7	21.5	98.0	100.0	2.00
	0.000	0.000	0.301	0.300			98.0	100.0	2.00
TR-11	-0.600	-0.577	0.301	0.299	2.7	21.4	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-12	-0.600	-0.576	0.301	0.299	2.7	21.4	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-13	-0.600	-0.576	0.301	0.299	2.7	21.4	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-14	-0.600	-0.576	0.301	0.299	2.7	21.4	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-15	-0.600	-0.576	0.301	0.299	2.7	21.4	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-16	-0.600	-0.577	0.301	0.299	2.7	21.4	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-17	-0.600	-0.577	0.301	0.299	2.7	21.5	98.0	100.0	1.99
	0.000	0.000	0.301	0.299			98.0	100.0	1.99
TR-18	-0.600	-0.578	0.301	0.300	2.7	21.5	98.0	100.0	2.00
	0.000	0.000	0.301	0.300			98.0	100.0	2.00
TR-19	-0.599	-0.578	0.301	0.300	2.7	21.5	98.0	100.0	2.00
	0.000	0.000	0.301	0.300			98.0	100.0	2.00
TR-20	-0.599	-0.579	0.301	0.300	2.7	21.5	98.0	100.0	2.00
	0.000	0.000	0.301	0.300			98.0	100.0	2.00
TR60KV	11.990	11.540	-11.792	-10.847	198.1	693.2	98.0	99.1	1.07
					326.4	533.0			

* This Transmission Line includes Series Capacitor.

l. Alert Summary Report

	% Alert Settings	
	Critical	**Marginal**
Loading		
Bus	100.0	95.0
Cable / Busway	100.0	95.0
Reactor	100.0	95.0
Line	100.0	95.0
Transformer	100.0	95.0
Panel	100.0	95.0
Protective Device	100.0	95.0
Generator	100.0	95.0
Inverter/Charger	100.0	95.0
Bus Voltage		
OverVoltage	105.0	102.0
UnderVoltage	95.0	98.0
Generator Excitation		
OverExcited (Q Max.)	100.0	95.0
UnderExcited (Q Min.)	100.0	

m. Marginal Report

Device ID	Type	Condition	Rating/Limit	Unit	Operating	% Operating	Phase Type
Bus_21	Bus	Under Voltage	30.000	kV	29.399	98.0	3-Phase

n. SUMMARY OF TOTAL GENERATION , LOADING & DEMAND

	MW	Mvar	MVA	% PF
Source (Swing Buses):	17.263	11.030	20.486	84.27 Lagging
Source (Non-Swing Buses):	0.000	0.000	0.000	
Total Demand:	17.263	11.030	20.486	84.27 Lagging
Total Motor Load:	13.600	8.429	16.000	85.00 Lagging
Total Static Load:	3.337	2.068	3.926	85.00 Lagging
Total Constant I Load:	0.000	0.000	0.000	
Total Generic Load:	0.000	0.000	0.000	
Apparent Losses:	0.326	0.533		
System Mismatch:	0.000	0.000		

Number of Iterations: 5

GENERAL CONCLUSION

Solar energy is variable in the nature and depends on the site, including the Algeria that has tremendous scope of generating solar energy and gains a huge prospective for solar power generation plants, the reason being the geographical location Where it receives solar radiation almost throughout the year, especially in the great desert with its vast area.

Through this project, we touched, in the first chapter, the basics principles photovoltaic panels and solar radiation, and in the second chapter equations and dimensions of how to install photovoltaic panels, and in the third chapter we made a detailed study of the Ain El Melh station, including the design, presenting brief data on the equipment

And through the fourth chapter of the study, we designed the plant 20MW using the simulation program ETAP for monitoring and analyses such as the load flow analysis for different operating scenarios and through it we got a detailed report, and critical information about the system.

The obtained results from the load flow analysis show that the implementation of PV solar generation station of Ain El Melh power distribution station develops the voltage profile and increase the stability of the system. and the analyses have shown that the power station is in good status and its voltage profile is healthy before and after the use of PV generation system.

From the work done in this memory it can be concluded that the addition of support PV power generation of 20 MW increases the efficiency of the electrical network and improves the voltage profile

This simulation can also be helpful for utilities in their planning and development sectors. Once the simulation is performed in ETAP for complete power system.

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