Czech Technical University in Prague
Faculty of Electrical Engineering
Department of Economics, Management & Humanities

Feasibility Study & Optimization of Utility-Scale Photovoltaic Systems with 1000V-1500V string inverters

Master's Thesis

Study Program: Electrical Engineering, Power Engineering & Management

Field of Study: Management of Power Engineering and Electrotechnics

Scientific Adviser: Ing. Jiří Beranovský, Ph.D.

BSc. Oğuzhan GÜNDOĞDU

Prague 2020

MASTER'S THESIS ASSIGNMENT

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Specialisation: **Management of Power Engineering and Electrotechnics**

II. Master's thesis details

Master's thesis title in English:

Photovoltaic System for Company or Household - Feasibility and Optimization

Master's thesis title in Czech:

Fotovoltaický systéma pro firmu nebo domácnost - proveditelnost a optimalizace

Guidelines:

- Prepare general research about Solar PV systems
- Design of installed PV power systems
- Technical and economic analysis of solar photovoltaic power plant
- Comparison and evaluation variants of solutions

Bibliography / sources:

- Djamila Rekioua, Ernest Matagne: Optimization of Photovoltaic Power Systems (Modelization, Simulation and Control). Green Energy and Technology. ISBN: 978-1-4471-2403-0
- Parimita Mohanty, Tariq Muneer, Muhan Kolhe: Solar Photovoltaic System Applications (A Guidebook for Off-Grid Electrification). Green Energy and Technology. ISBN: 978-3-319-14663-8
- Inzunza R., Okuyama R., Tanaka T., Kinoshita M. (2015) Development of a 1500Vdc Photovoltaic Inverter for Utility-Scale PV Power Plants. International Conference on Renewable Research and Applications (ICERA)

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Date of master's thesis assignment: **17.01.2020** Deadline for master's thesis submission: **22.05.2020**

Assignment valid until: **30.09.2021**

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III. Assignment receipt

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Topic Registration Form

Student: Oğuzhan Gündoğdu
Study Program: Electrical Engineering, Power Engineering & Management
Topic: Feasibility Study & Optimization of Utility-Scale Photovoltaic Systems with 1000V-1500V string inverters

Details:

- Prepare general research about Solar PV systems
- Design of 6 MWp utility-scale solar photovoltaic power systems with centralized and distributed 1000V - 1500V string inverters
- Technical and economic analysis of utility-scale solar photovoltaic power systems
- Building optimal variants of solutions

Literatures:

- Djamila Rekioua, Ernest Matagne: Optimization of Photovoltaic Power Systems (Modelization, Simulation and Control). Green Energy and Technology. ISBN: 978-1-4471-2403-0
- Parimita Mohanty, Tariq Muneer, Muhan Kolhe: Solar Photovoltaic System Applications (A Guidebook for Off-Grid Electrification). Green Energy and Technology. ISBN: 978-3-319-14663-8
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I hereby declare that this master's thesis is the product of my own independent work and that I have clearly stated all information sources used in the thesis according to Methodological Instruction No. 1/2009 – "On maintaining ethical principles when working on a university final project, CTU in Prague ".

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Abstract

Design of solar photovoltaic systems plays a crucial role for technical and economic aspects on solar photovoltaic systems. So far as fossil sources becomes limited, many countries focus on renewable energy, especially to the solar energy sector. Many new have already started to establish market with various solar equipment designs due to the rapid growth of the sector. By increasing diversification of equipment, solar photovoltaic system designs become substantial.

The main purpose of this dissertation is to show which steps need to be followed and what to consider in these steps whilst designing a solar power system. Evaluate technical and economic reflections of the design changes to be made especially in the inverter and cabling which are the important parts of the utility-scale solar photovoltaic systems and which effects the efficiency of the system directly.

In the first chapter, the energy consumption amounts throughout the world, the concepts that should be known as basics before designing a solar photovoltaic system, and the based equipment and features used in these systems are included. In the second chapter, a site area was determined. Suitable photovoltaic modules, trackers, cables, inverters, and transformer were selected for four cases. Overloading ratio was determined according to the capacity of the inverters. PV string sizes were calculated for 1000V and 1500V inverters in order to use inverters more efficiently. Trackers were designed, and locations were decided according to optimally incline angle obtained from Solargis platform. Required number of equipment was calculated. Amount of cables were determined with ProgeCad drawing software, and cables size were decided according to current they carry. In addition, the power loss of the systems was calculated to obtain the average annual electricity production report from the Solargis platform. At the end of the second section, four solar photovoltaic systems were designed with two different inverters to be 1000V-centralized, 1000V-distributed, 1500V-centralized, and finally 1500V-distributed. In the third chapter, solar PV plant reports were obtained from the Solargis platform with the data received from the calculations in the second chapter. Technical analysis of these reports has been made, and the efficiency of all systems has been calculated. In the section of economic analysis, the investment cost of the solar PV systems´ equipment was calculated with sales prices and usage amounts of equipment. In the last chapter, NPV analyses were made for all designs and minimum electricity selling prices were calculated to obtain how the location, and inverters with different voltage are affected utility-scale solar photovoltaic systems. Furthermore, four designed projects were compared with each other according to total based equipment costs and average annual electricity production of the projects. Finally, the effects of discount rate and electricity inflation rate on the minimum selling price were examined with sensitivity analyses.

Keywords: Solar System Design, Photovoltaic System Design, Utility-Scale, 1000V String Inverter, 1500V String Inverter

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Acknowledgements

Firstly, I would like to thank to my advisor Ing. Beranovský Jiří Ph.D., MBA for his mentoring.
I would like to thank to my cousin MSc. Burak Gundogdu and my friend MBA Birkan Isik to have exchanged ideas with me.
I also express my thanks to Ing. Tomáš Králík, Ph.D. who played a role on my decision to make technical weighted research and rest of academicians who supported me during my master studies in CVUT.
Finally, I extend my gratitude to my family who supported and motivated me throughout my whole education life.

List of Abbreviations

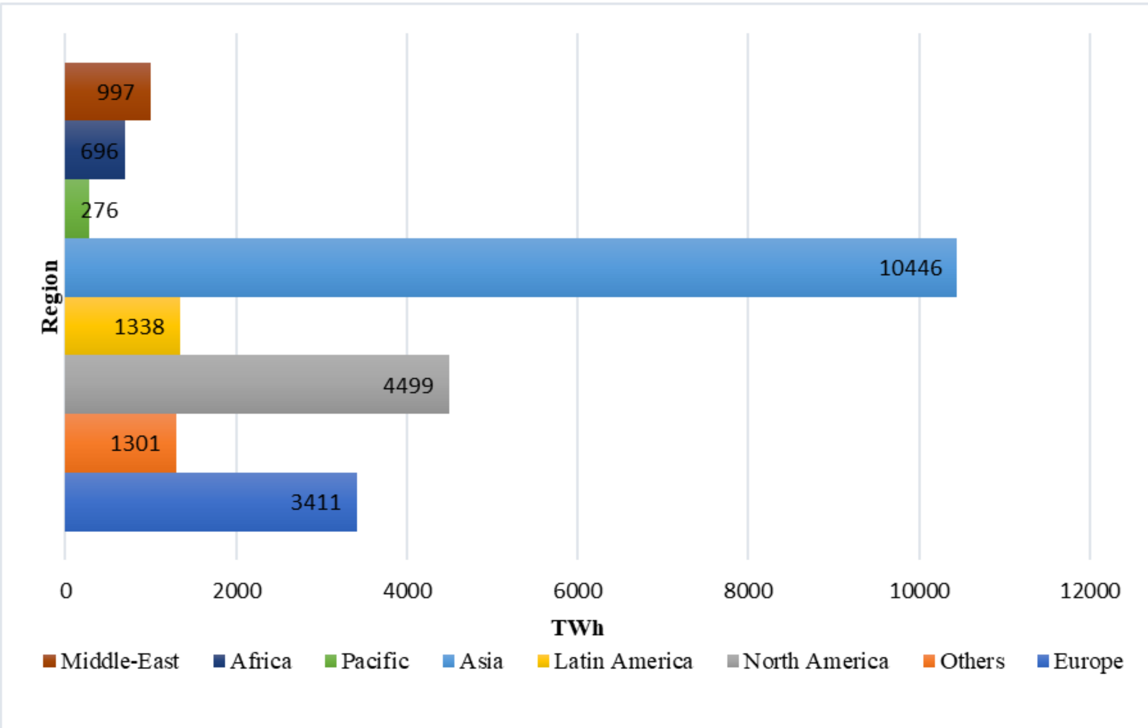
AC	Alternating Current
A-SI	Amorphous Silicon Solar Thin Film
DC	Direct Current
DWG	Drawing file
HVDC	High Voltage Direct Current
KMZ	Zipped keyhole markup language file
LV	Low Voltage
Mono-SI	Monocrystalline Silicon Solar Panel
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
Mtoe	Millions of Tonnes of Oil Equivalent
MV	Medium Voltage
NPV	Net Present Value
N-S	North-South
p-Si	Polycrystalline Silicon Solar Panel
PV	Photovoltaic
SiO_2	Silicon Dioxide (Silica)
STC	Standard Test Conditions
UTM	Universal Transverse Mercator
W-S	West-East
XLPE	Cross-linked Polyethylene

1. Introduction

Energy can be defined as ability to work. In different areas of daily life, we are faced with different types of energy at any moment. These encounters are often forms of energy that is in transformation. Many new electronic devices enter our life's with developing technology. Although the efficiency of these devices increases day by day, it has become almost impossible to survive without energy.

If we take a look at the total energy consumption in the world in 2018 in terms of Mtoe (Millions of tonnes of oil equivalent), Europe 1847 Mtoe, North America 2558 Mtoe, Latin America 822 Mtoe, Asia 5859 Mtoe, Pacific 158 Mtoe, Africa 850 Mtoe, Middle East 803 Mtoe, Others (Armenia, Azerbaijan, Belarus, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Uzbekistan) 1081 Mtoe have consumed energy. The share of electricity consumption in 13978 Mtoe energy consumed is 9% [1].

Global electricity power consumption accelerated again in 2018 (+3.5%). Asia's share of the 3.5% increase in energy consumption is almost 80% due to the development of the industry [2].



Graph 1. Energy consumption by region in 2018 (based on data from [2]).

Today, global warming and environmental pollution have reached a level that threatens vital activities in the world with the predominant use of fossil fuels to generate energy. Since the cost of electricity produced from fossil fuels is lower, its share in electricity generation is about 4 times higher than that of renewable energy sources. Therefore, the production, transmission and consumption of the compulsory electrical energy in a way that causes the least harm to the environment has become one of the most important problems. According to October 2019 data, if fossil fuels are assumed to be consumed at the same rate, estimated years to the end of oil is ≈44, years to the end of natural gas is

≈158, years to the end of coal is ≈408 [3]. Nowadays, although the estimated lifetime of fossil fuels is not very short, toxic gases that are mixed with air during the production of electrical energy negatively affect our life. Demand for renewable energy sources is increasing, both in terms of being sustainable and environmentally friendly. There are many forms of renewable energy. The most common of these; solar energy, wind power, hydroelectric energy, biomass, hydrogen, fuel cells and geothermal power. One of the most remarkable renewable and clean energy technologies is photovoltaic technology, which can be easily installed in any location with a low budget and which enables the generation of electrical energy by using solar irradiation.

Inverters which is one of the based equipment having a 600V (voltage) input value in the past were then introduced to the market as 1000V and 1500V. Thanks to the savings of high voltage, they have started to have more demand in the last years compared to the central inverters. In this project, the thing that encouraged me to work with string inverters the most is that when a string has a problem caused by cable or panels, only the power of that string is lost, and the system continues to run. Besides, in case of a problem with an inverter, other inverters do not experience any disruption in their operation.

String inverters with an input value of 1500V have a significant place in the market in recent years, especially for projects that have a value below 10MW (megawatt). [43]

The technical changes and the economic reflections of these changes will be examined when the 1500V and 1000V string inverters are located in the centre (centralized) and when they are distributed (decentralized) within the site area.

1.1 Photovoltaic Cell Definition

Photovoltaic (PV) cell is a technology that converts solar energy into electrical energy. Some materials, such as silicon, have the property of converting solar energy directly into electrical energy. This is called a photovoltaic effect [4].

1.1.1 Solar Irradiance and Radiation

Solar irradiance (power) is a measurement of solar energy and is defined as the speed at which solar energy falls to the surface. The power unit is watt (W). In solar irradiance, the power per unit area is measured in watts per square meter ($\mathrm{W/m^2}$) or kilowatt per square meter ($\mathrm{kW/m^2}$). The radiation falling on a surface change momentarily. This measurement gives us the rate at energy received [5].

Solar Irradiation (energy) is the area under the solar irradiance (power) curve.

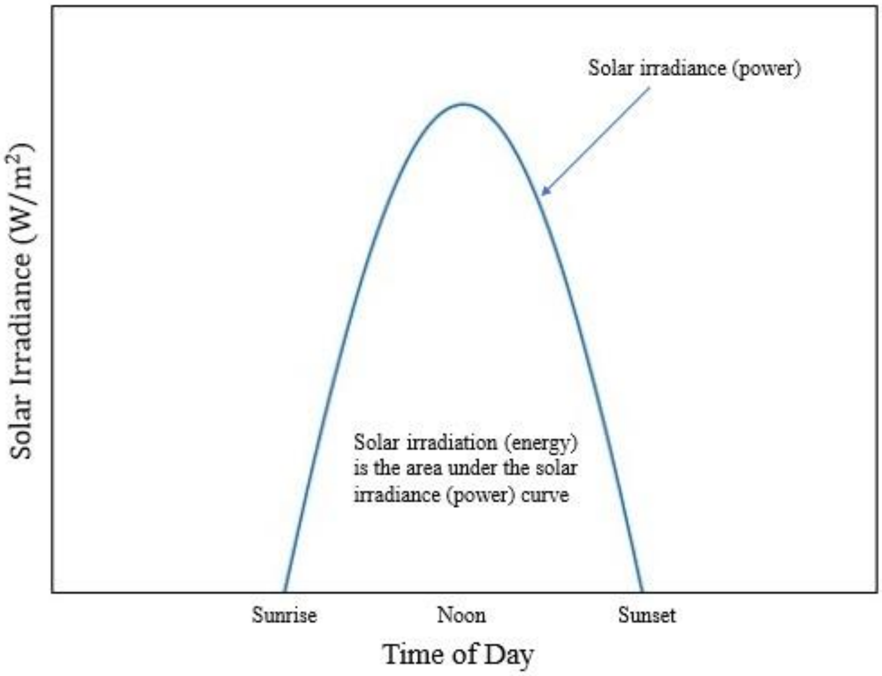


Figure 1. Solar power and solar energy (based on figure from [5]).

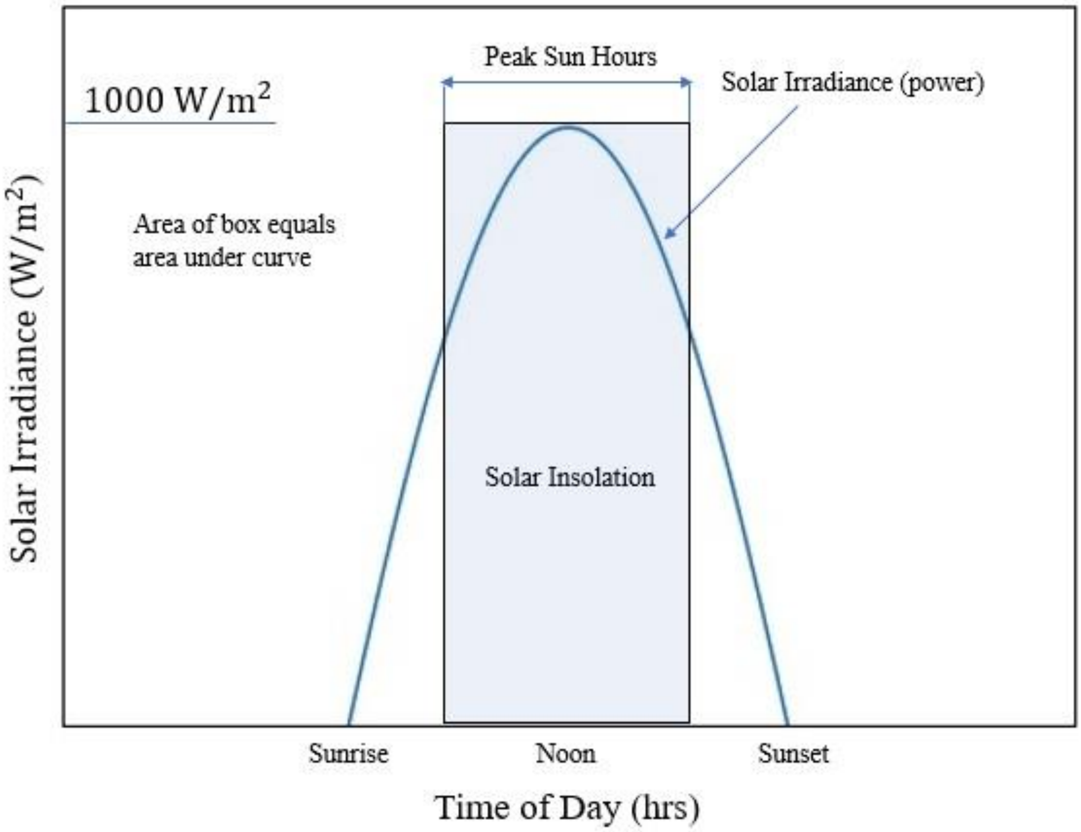


Figure 2. Peak sun hours (based on figure from [5]).

1.1.2 Open Circuit and Short Circuit

The power from a single solar cell is unlikely to operate even a simple power tool. Therefore, in order to obtain high power, the cells are connected in parallel and in series to form the modules. The modules are connected to form the solar panels. The current remains same with the addition of series cells or modules, but the voltage increases in proportion to the number of cells in the series. In modules inserted in parallel, the voltage is the same as that of a module and intensity increases with the number of modules in parallel [7].

Open circuit and short circuit are two special terms that represent opposite extremes of the resistance number line [13].

Short Circuit

If two points are shorted in a circuit, it means that these two points are directly conducting with each other. No matter how much current passes over this connection, the voltage drop over it becomes 0. In case of the V = I×R formula, it is possible that V is equal to 0, but that R is 0, regardless of I. Therefore, the short circuit can be expressed with a resistance of 0Ω [14].

Open Circuit

An open circuit between the two points means that there is no electrical connection between these points. Whichever voltage applied, the current passing through is zero. If we compare the open circuit status to a resistor,

$$I = \frac{V}{R}$$

For all values of V in the formula, I is zero only if R is infinite. Therefore, the open circuit acts as a resistor whose value is infinite [14].

1.1.3 Ideal Solar Panel Characteristic

Figure 3 shows the typical I-V and P-V characteristics of an ideal solar panel.

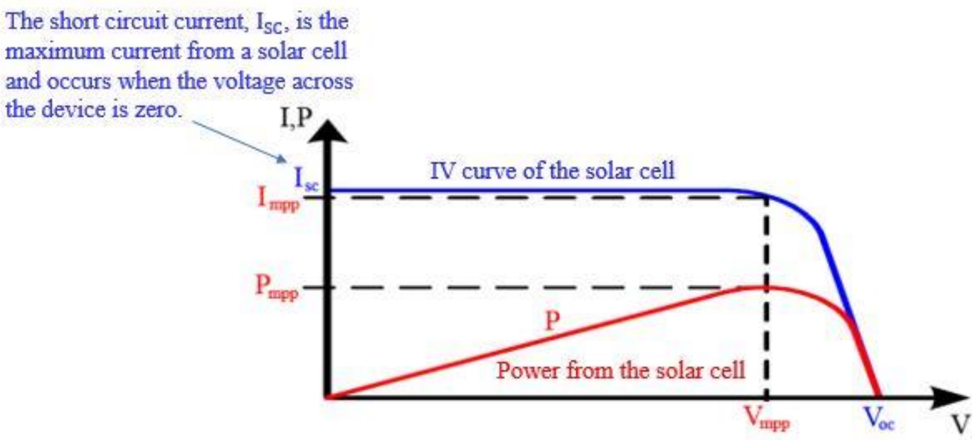


Figure 3. Typical I-V and P-V characteristics of an ideal solar panel (based on information from [15], based on figure from [16])

While the output voltage of an ideal solar panel is constant until the output current reaches a certain value, it starts to decrease rapidly as soon as it exceeds this value. In a real solar panel, the output voltage starts to drop as soon as the current drawn from the panel is different than zero. However, the rate of voltage drop decreases slowly until the current reaches a certain value, accelerates after exceeding this value. Solar panels have five basic parameters as shown in Figure 3 [16].

- V_{OC} Open circuit voltage
- I_{SC} Short circuit current
- P_{mpp} Maximum power rating
- V_{mpp} Maximum power point voltage
- I_{mpp} Maximum power point current

The I-V characteristics of a true solar panel vary depending on temperature and radiation. Thus, a curve as in Figure 3 is valid only for a single temperature and radiation value. Again, the curve in Figure 3 is valid under the condition that the panel surface is completely and homogeneously illuminated and the yield reduction due to shadows and dirt is not considered. In short, the ambient conditions must be considered in order to obtain the correct I-V curve in any case for a solar panel [16].

1.1.3.1 Temperature Effect

Solar panels consist of a large number of small cells. Since each cell is simply an enlarged P-N junction, its parameters vary with temperature, such as those of a diode. As the temperature increases, V_{OC} decreases and Isc increases. Since the amount of reduction in V_{OC} is much greater than the increase in I_{SC}, the maximum power available from the panel decreases as the temperature increases. These effects are shown in Figure 4 and Figure 5 [16].

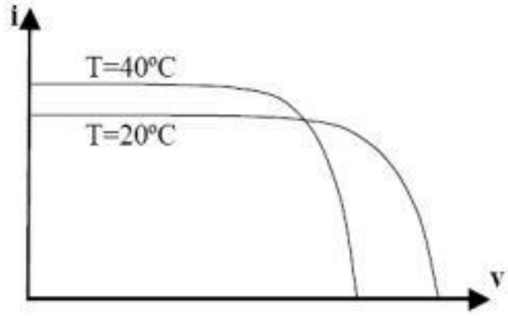


Figure 4. Change of V_{OC} and I_{SC} with temperature [16]

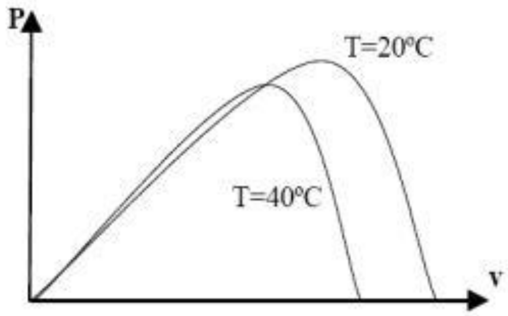


Figure 5. Change of P with temperature [16]

The amount of change in V_{OC} and I_{SC} versus the change in temperature of 1°C is usually given as temperature coefficients that refer to the values in T = 25°C in the technical documentation of solar panels. These coefficients are named V_{tempco} (Temperature coefficient of voltage) and I_{tempco} (Temperature coefficient of current) [16].

1.1.3.2 Irradiance Effect

The short circuit current of a solar panel is directly proportional to radiation. However, the open circuit voltage increases only slightly with increasing radiation. Since the change in V_{OC} is negligible compared to the change in I_{SC}, the maximum output power of a solar is assumed to be directly proportional. Figure 6 shows the I-V curves for three different radiation values of the same module [16].

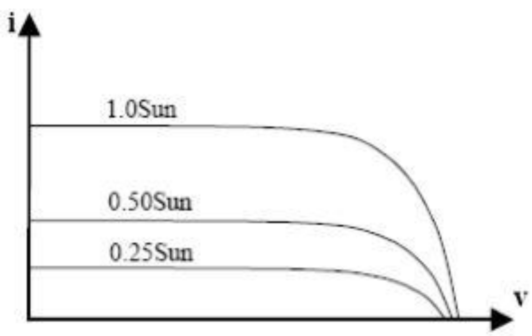


Figure 6. Change of V_{OC} and I_{SC} with irradiance [16]

The effect of a $1W/m^2$ change in radiation on I_{SC} can be easily calculated because I_{SC} is directly proportional to radiation. However, the change in V_{OC} can be estimated approximately because there is no direct correlation between radiation and V_{OC}, and there is usually no coefficient in the technical documentation of the panels that gives the correlation between these two values [16].

1.2 Photovoltaic Systems

Solar systems are the systems that produce electricity result from the combination of multiple solar modules connected in series and in parallel with the inverter.

1.2.1 Types of Photovoltaic Systems

There are three types of power systems. These are on-grid, off-grid and hybrid solar PV systems [18].

On-Grid Solar PV Systems

Grid-tied, on-grid, utility-interactive, grid intertie and grid back-feeding are all terms used to describe a solar system that is connected to the utility power grid [18]. Grid connected solar PV systems can be designed in two ways. In these systems, the DC generated can be directly converted to AC by an inverter, as well as various loads can be fed to the grid by using the bidirectional electric meter after the inverter. The excess energy produced but not used can be supplied to the grid. In the systems which are used generally as a power plant, the connection point varies according to the installed power of the system. [17].

Off-Grid Solar PV Systems

Off-grid or standalone systems are systems that do not interact with the network. In these systems, the electrical energy generated by the solar modules as DC is stored in the batteries. The energy stored in the batteries can be used at any time. Since off-grid systems do not have a grid connection, there may be situations where more electrical energy is needed than stored in batteries. Off-grid systems are usually supported by external generators. It is generally preferred in regions that do not have access to the network because of its high costs [18].

Hybrid Solar PV Systems

Unlike off-grid systems, hybrid systems are connected to the grid in addition to the use of electrical energy stored in the battery. The electrical energy produced in the panels is stored in the batteries. When more electrical energy is needed than stored in batteries, electricity from the grid is used. Costs are cheaper than off-grid systems. However, they are not preferred much because of the high battery costs. To summarize, instead of the generator that supports off-grid systems, support is provided from the grid [18].

Type of Power Lines

Power lines are classified by their voltage level. Voltage levels are changed by country. Table 1 shows the classification of the power lines.

Table 1. Type of power lines [19]

Voltage Level	Value Level Mark	System	Valid Section
Low Voltage Level	< 1000V	AC	Secondary Distribution
Medium Voltage Level	1000V to 69kV	AC	Primary Distribution
High Voltage Level	< 100kV	AC	Secondary Distribution
Extra High Voltage Level	230kV to 800kV	AC, DC both	Primary Distribution
Ultra High Voltage Level	800kV to 1000kV	AC, DC both	Primary Distribution
	>1000kV	HVDC is preferable	Primary Distribution

1.2.2 Based Equipment of Solar Photovoltaic Systems

1.2.2.1 Photovoltaic Cells and Modules

Photovoltaic cells are products which generally produced from silicon material that are used to capture the energy from the sun and convert it into electrical energy. Solar cells are the basic elements of photovoltaic modules. The solar modules are seen most often at homes, businesses, agricultural lands. The cells are flat, dark-coloured and shiny. Cells convert the energy from the sun into electrical energy without the need for anything else. Other components are used to amplify output and convert electricity from DC (Direct Current) to AC (Alternating Current) [6,7].

There are many different types of solar cells and modules. Three most common types of solar cells are Monocrystalline Silicon Solar Cell (Mono-SI), Polycrystalline Silicon Solar Cell (p-Si), and Amorphous Silicon Solar Cell (A-SI).

Monocrystalline Silicon Solar Cell (Mono-SI)

Silicon is the most common element on earth after oxygen. The most common form is sand and quartz. Monocrystalline Silicon Solar cells are made of silicon material. It is produced by the Czochralski process, which bears the name of the Polish scientist. The first stage of the production process begins with the production of silicon crystal from sand because the purity of the sand is very low and is not suitable for direct use. At the end of this process, the silicone still has unwanted impurity. 90% of quartz is silicon and it is processed to obtain 99% silicon dioxide - silica (SiO_2). The processes result in a pure silicone block. And after, this block is divided into square pieces. Then, it is sliced neatly and assembled into a characteristic monocrystalline solar panel pattern [8,9].

Solar cells produced from Monocrystalline Silicon Blocks, which are firstly enlarged and then sliced into thin layers of 200-micron thickness, yield efficiency generally 24% in laboratory conditions and 18% in commercial modules [9].

Figure 7. Monocrystalline silicon solar cell [10]

Polycrystalline Silicon Solar Cell (p-Si)

In comparison, producing polycrystalline is relatively simple. Polycrystalline silicon solar cells also consist of silicon cells, but instead of being formed into a large block and cut into wafers, they are produced by melting multiple silicon crystals together. Many silicon molecules are melted and then reassembled into the panel. Because the exterior cools more quickly, different regions of the silicone cools at different speeds. This irregular cooling pattern causes the panel to form many different crystals which give it a multicoloured appearance and become more sparkly [8,9].

Polycrystalline silicon solar cells obtained by slicing from cast silicon blocks are produced cheaper, but the efficiency is also lower. Generally, the yield efficiency is around 16% in laboratory conditions and 14% in commercial modules [9].

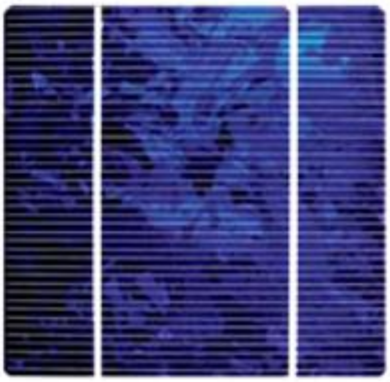


Figure 8. Polycrystalline silicon solar cell [10]

Amorphous Silicon Solar Thin Film (A-SI)

Amorphous silicon solar cells have thin-film solar cells. Since the electrical power output is low, amorphous silicon-based solar cells are often used for small-scale applications, such as calculators. These panels are made by placing materials such as silicon, cadmium or copper on a base. Fewer materials are needed for their productions. Thus, the production costs of Amorphous silicon solar cells are lower than other solar cells. Only 1% amount of silicon used in crystalline silicon solar cells is used in amorphous silicon solar cells. In addition to being affordable, they are flexible. Therefore, they are easy to apply and have low sensitivity to high temperatures [10].

Considering that they are easily manufactured and have low cost, they are known to have low lifespan and efficiency. Generally, the yield efficiency is around 12-13% in laboratory conditions and 6-9% in commercial products [12].

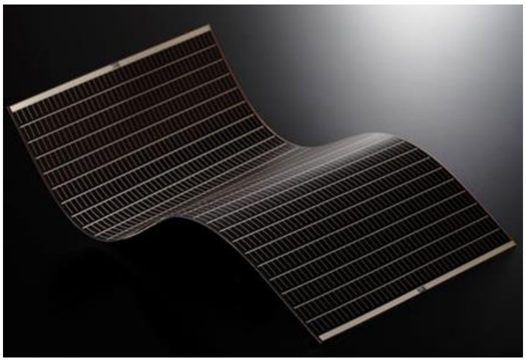


Figure 9. Amorphous silicon solar thin film [11]

Bifacial Solar Photovoltaic Modules

There may be two ways in which solar power plants can be more economically effective. The first way is to reduce the lifetime cost of the plant, especially the initial investment. The second way is to increase amount of electricity the plant generates during its lifetime. The bifacial solar photovoltaic modules give hope for at this point. Ability of these modules is to capture the sun's rays on both sides. As shown in Figure 10, the bifacial solar modules are open on the backside. In this way, they reach the sun rays reflected from the ground or other objects. It is observed that bifacial photovoltaic modules can increase production capacity up to 50% compared to monocrystalline photovoltaic modules under laboratory conditions. This ratio is between 5% and 30% depending on the field conditions [23].

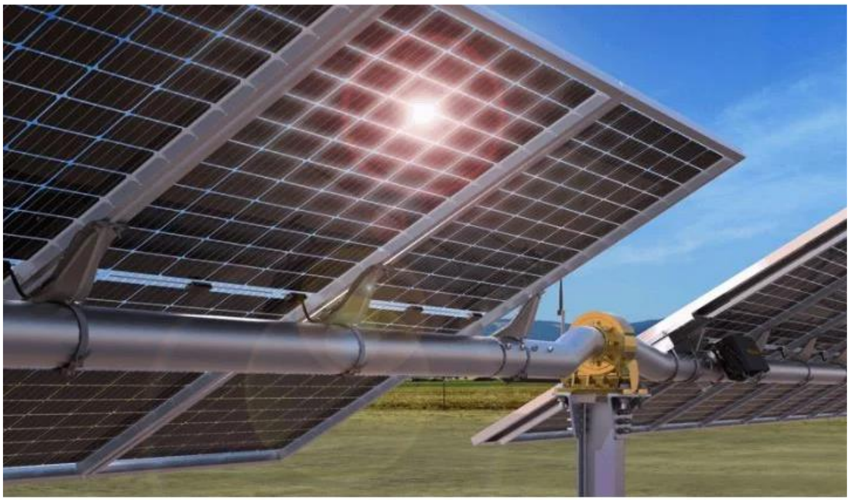
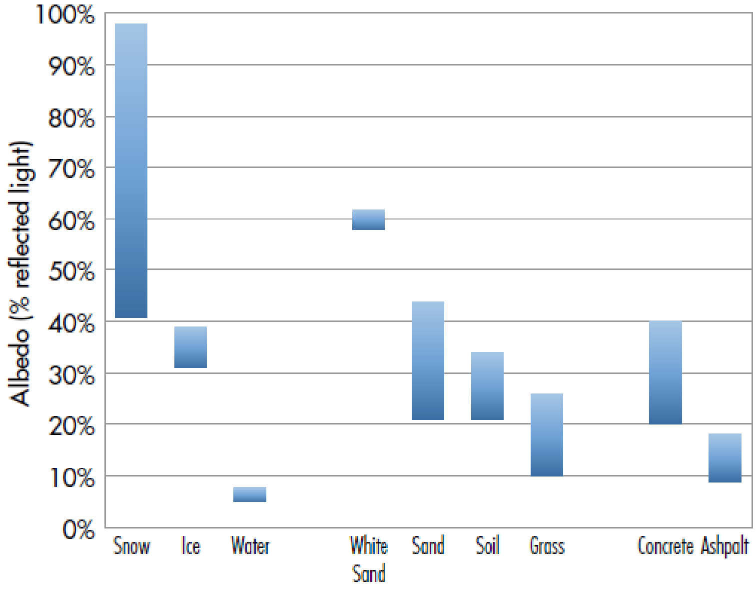


Figure 10. Bifacial solar photovoltaic modules [24]

After the radiation from the sun touches a surface, the word used to describe the amount of percent of radiation reflected from that surface or object is 'albedo' [25]. Graph 2 shows the albedo ranges of various surfaces.



Graph 2. Albedo ranges for a variety of surfaces [23]

When the percentages in Graph 2 are 0%, it means that the surface does not reflect any reflections, and when 100% it completely reflects the incoming radiation. Demand for bifacial solar photovoltaic modules is increasing. Until recently, the cost of silicon cells was being approximately %66 of the solar modules. Thanks to developing technologies, the ratio of silicon cells in the total module cost is around 50%. To further reduce the cost of solar photovoltaic modules, manufacturers work to reduce the cost of extracellular modules. This has resulted in more efficient solar photovoltaic modules 'bifacial' with lower cost of extracellular modules [23].

Back surface of the Mono-SI and A-SI PV cells are covered with metal. This feature includes metal contact for reduced series resistance and is cost-effective to manufacture. It contains a low amount of metal as it should allow light to leak through the bifacial modules. This situation affects the optimization performance of the cells which covered with less metal material. This requires the use of tighter silicone and thin films and increases series resistance concerns. Furthermore, bifacial cells may need to be used in different materials such as copper and nickel. This leads to a more complex and expensive production process. Therefore, the amount of energy obtained from reflection must meet these newly formed costs [23].

1.2.2.2 Fixed Mount and Tracking Systems

Fixed Mount Systems

As the name implies, fixed systems are systems that are mounted on a surface and do not move. These systems are generally used on roofs of houses or solar systems installed on small terrains. It is mounted in a fixed place with the optimally incline angle that the most intense sun rays will reach in order to get the best rays from the sun. Although these systems perform quite well, their performance is lower compared to tracking systems, as the angle of incidence of the sun's rays is constantly changing [20].

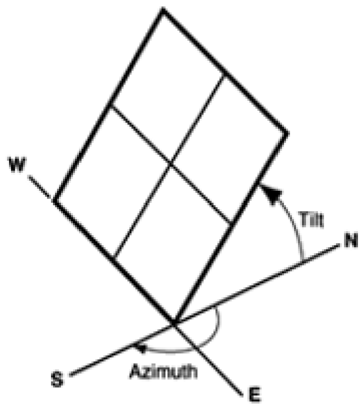


Figure 11. PV array facing south at fixed tilt [21]

Tracking Systems

Solar power tracking systems are the systems designed to monitor the sun continuously usually by means of electronic control circuits, sensors and electric motors, and aim to collect the rays from the sun with the best performance [20].

Solar tracking systems has two types which are single-axis tracking systems and dual-axis tracking systems [20].

Single-axis solar tracking systems are systems that designed to follow the sun E-W (east-west) or N-S (north-south) movements during the day and have the ability to move almost parallel to the earth's rotation axis. Single axis tracking systems are suitable system to be used in areas with high wind [20].

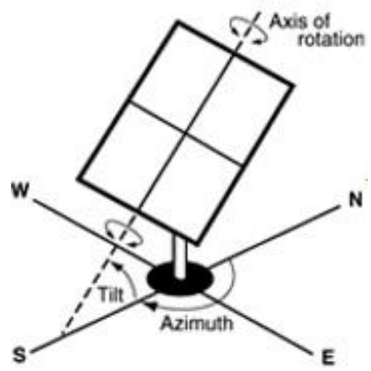


Figure 12. Single axis tracking PV array with axis oriented south [21]

As the name implies, dual-axis tracking systems are capable of tracking both E-W and N-S movements of the sun during the day. They are designed to provide optimum performance throughout the year. These systems show a significant performance increase, especially in the summer months. As a result of the tests conducted in Germany in 2008, on the 15-hour sunlight, the dual-axis tracking system has a power output of close to 100% for 9 hours, while the single-axis tracking system can provide maximum 5 hours, and a fixed system can provide only 1 hour [20].

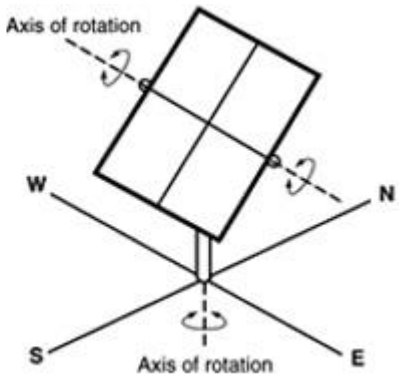


Figure 13. Dual-axis tracking PV array [21]

1.2.2.3 Electrical Wires

A cable is a set of a wire or wires, usually covered with plastic on the outer surface, used to transfer power or data between devices or locations [26].

Generally, three main types of cables are used in solar power plants. First one is the DC power cables used in the process until DC electricity is delivered to the inverter. Second is the AC cables that transfer the electrical power to the inverter and supply it to the distribution and transmission line. Third one is the data cables that are used to monitor the incidents in the plant and used to carry the data to the monitoring systems.

Wiring is critical to the smooth operation of the solar power system. Incorrect selection of specifications and values for the cable may cause the system to malfunction or run irregularly. Power losses and fire risks should also be considered. Cables are mainly classified according to conductor type and current carrying capacity. As shown in Figure 14, if it has a single wire, it is called single stranded conductor. If it has multiple wire, it is called multi-stranded or solid [27].

Figure 14. Single-stranded (Solid) wire vs. Multi-stranded cable [28]

The most important difference between single-stranded wire and multi-stranded cable is that multi-stranded cable shows better performance on vibrating areas because of more flexibility and containing more thin wires [27].

The power cables used in the solar system are rated according to the current carrying capacity. The diameter of the cable must be greater depending on their current carrying capacity. If the cable current carrying capacity is less than required, the voltage will drop, and the cable will become hot. This can cause the cable to catch fire and damage system. Therefore, when calculating current carrying capacity of a cable, maximum current values are taken as a basis [27].

Length is other factor affecting the amperage value. As the length of the cable increases, the risk of voltage drops increases. Therefore, the cable current carrying capacity is taken 30% - 35% higher than calculated. For example; If a cable capable of carrying 100 amps is considered to be required as a result of the calculations, a cable is selected which has current carrying capacity for 130-135 amperes is often used to reduce the risk of voltage drop in sudden system loads [27].

Aluminium and copper are most common materials used for the transmission of electricity in solar systems. Aluminium has 61% of the conductivity of copper, but its weight is 70% of copper [29].

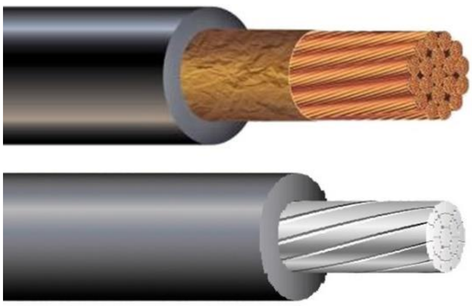


Figure 15. Aluminium cable vs copper cable [30]

The fact that aluminium is light, and costs are cheaper compared to copper causes to come to the forefront in projects requiring long distance electric transmission lines. It can be applied easily, and it saves time when it is applied in projects with excessive curl on the transmission path thanks to flexibility of aluminium. However, aluminium conductors require additional costs since they will be thicker than copper conductors. Also, since the expansion rate is higher than the expansion rate of copper, they can easily heat up and damage the system and cause a fire in an incorrect application [30].

1.2.2.4 Inverters

In almost all of the solar systems, regardless of scale, inverters are used to convert DC electricity to AC to use the generated DC electricity in AC powered devices. The inverters are critical and mandatory components for utility-scale solar power systems. There are various sizes of inverters depending on the production capacity. Figure 16 shows small-scale inverter and Figure 17 shows utility-scale inverter [33, 34].

Figure 16. Small-scale inverter ABB (UNO-DM-6.0-TL-PLUS) [31]

Figure 17. Utility-scale inverter ABB (PVS980-CS) [32]

As with all power system components, inverters also loss energy during energy conversion due to the interferences. Usually, their efficiency varies between 90% and 95%, depending on air temperature, material quality and design used. Their share in total cost of utility-scale solar system cost is around 6-

7% [66]. The energy converted by the inverters can have various wave outputs. Three basic wave outputs are square, modified sine and pure sine wave output. Pure sine waved inverters are used for general applications. These inverters have the highest cost. This corresponds to the best output power quality. Modified sine wave inverters are used for resistive, capacitive and inductive loads. Modified sine waved inverters are neither very cheap nor too expensive. Output power quality of modified sine is lower than pure sine. The square waved inverters are used only for some resistive loads. They have lowest cost, correspondingly they have the lowest efficiency. Since the inverters emit electromagnetic noise, their grounding must be made considering these reasons [33, 34].

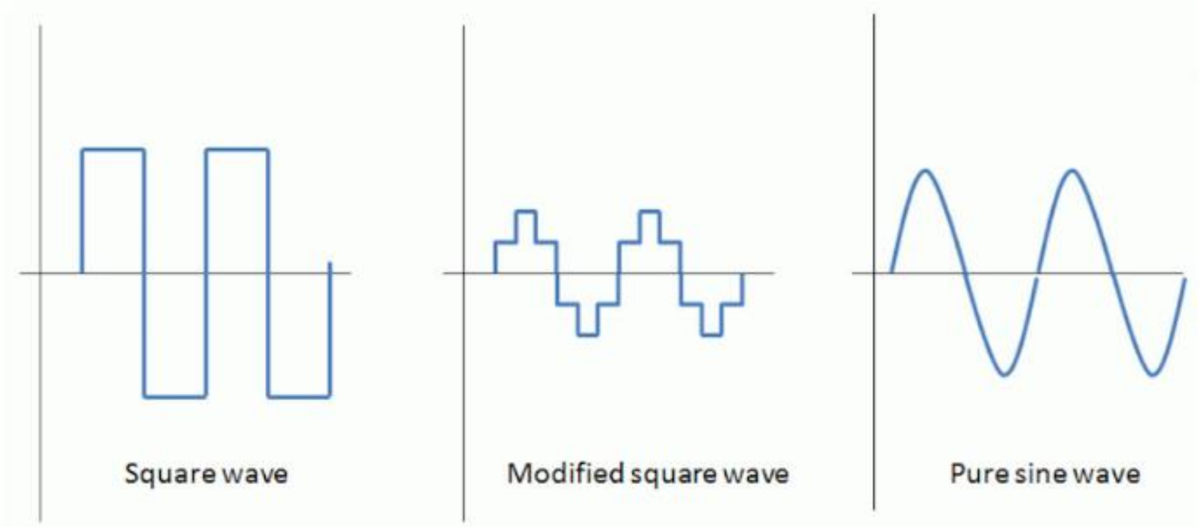


Figure 18. Different types of AC signal produced by inverters [33]

Inverters are used between electrical energy generated on solar PV modules and transformer. They synchronize with the transformer and convert the DC power to AC to transmit to the transformer. Also, thanks to the devices and programs on it, they can disable the connection between grid and power system to prevent system [34].

Especially with the studies on the benefits of renewable energy sources, increasing needs, and demand for these systems, inverter types with higher quality and stability and more features are produced in order to make the energy obtained from solar energy systems suitable for use. Microprocessor or low voltage controlled, alarm and warning outputs, overload protection, static regulation devices are offered by the manufacturers. Since there are no starting currents, the devices that do not harm network operate at the minimum and maximum intervals [35].

The purpose of developing inverters is for saving power loss. Inverter devices that clean the voltage fluctuations and peaks from the grid through the filter circuit reduces engine and mechanical component errors caused by these effects; it minimizes the repair, maintenance costs and extends the service life of these parts. In addition, the inverter reduces the reactive energy and allows savings [35].

1.2.2.5 Transformers

High voltage and low current technique are preferred to prevent losses in the transmission of electrical energy in form of heat. It is crucial to increase or lower the high voltage produced in the plants and carried on the transmission lines according to the need. The circuit element called a transformer is used to serve these needs. Machines that convert electrical energy from one circuit to another circuit with the same frequency but different current and voltage by electromagnetic induction are called transformers [39].

Figure 19. FITformer® – Siemens' fluid-immersed distribution transformers [40]

The magnetic core is used to pass the resulting magnetic flux from one coil to another without dispersing it. The magnetic core is produced from thin silica steel sheets in order to minimize losses. The magnetic flux provides the connection between both windings. First coil, which is connected to the alternating current source from the current coils and where the mains voltage is applied, is called primary (input), and second coil, where the electrical energy is taken at a different voltage, is called secondary (output). Transformer whose secondary winding number is more than the primary winding number is called step-up transformer, and whose secondary winding number is less than the primary winding number is called step-down transformer. Since transformers are stationary electrical machines, there are no moving parts. For this reason, transformers do not have friction and wind losses. The ratio of the power taken from the output of the transformers to the power applied to the input is called efficiency. The efficiency of the transformer is around 99% [39].

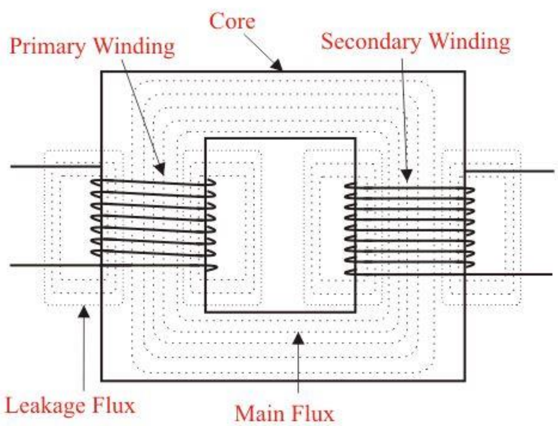


Figure 20. Main transformer parts and flux scheme [41]

2. Design and Optimization of Solar Photovoltaic Systems

Photovoltaic energy system has a complex structure and is not simple to design. Design of grid-connected solar PV systems is more difficult to design than household solar PV systems. It is important to choose the suitable parts and components [36].

There are many ways that can be followed while designing the solar PV systems. Aim of this dissertation is to analyse of 1000V – 1500V inverters on system investment and productivity when placed in different location designs.

This section focuses on what to consider when designing a solar PV plant and what steps to follow. Therefore, the stages may differ for each project. Steps to follow in order:

1. Determining site area
2. Inverter selection
3. Solar PV module selection
4. DC/AC ratio and overloading
5. PV String size calculation
6. Tracker selection and design
7. Determining usable lands in the field
8. Calculating space between trackers
9. Calculating number of inverters
10. Determining location of the string inverters
11. Calculating DC - AC cables length
12. Calculating cable capacity, cable size and selection of cables
13. Power Loss Calculation

2.1 Determining Site Area

Field selection is the first stage of solar PV plant installation. All calculations made after this stage are directly or indirectly related to the site area where the power plant has been established.

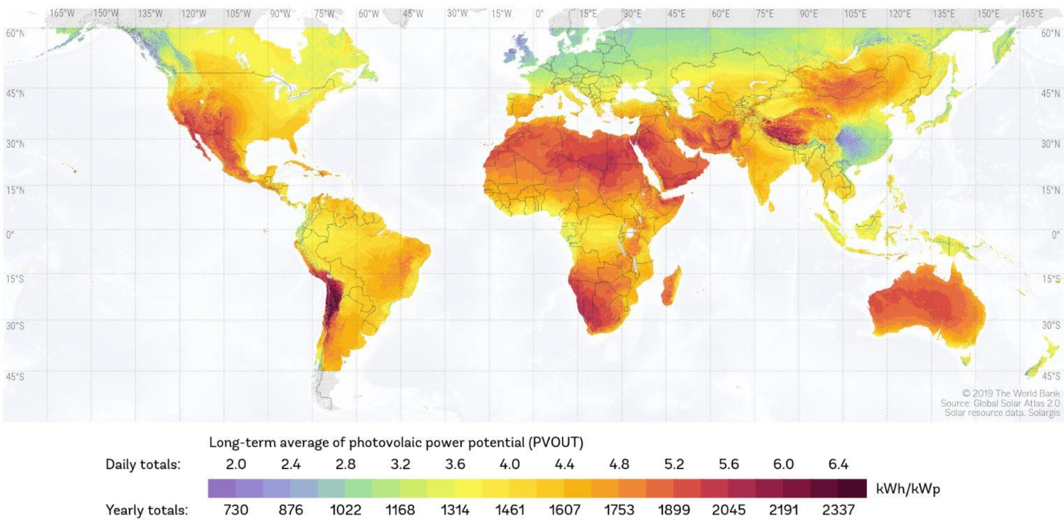


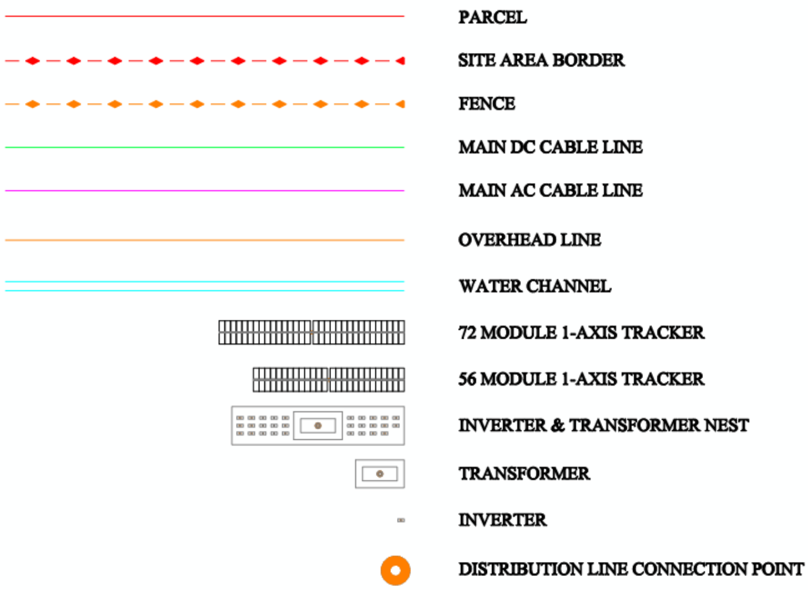
Figure 21. Photovoltaic power potential in the World [42]

The map in Figure 21 shows photovoltaic power potential in the World. In this map, it is seen that Chile has the highest solar PV power potential in the world. Therefore, all our technical and economic calculations regarding this thesis has been in the land near Santiago, detailed below.

Figure 22. Site area geographical view of the project

The areas symbolised by A and B represent a parcel. The land used in this project is the area indicated by the letter A. Figure 22 is obtained from the satellite image taken on 27.04.2019 from Google Earth Pro application.

Table 2. General legend table for drawings



Unless a specific legend table is specified for the figures, the symbolized colours and naming are valid for all drawings in this project according to Table 2.

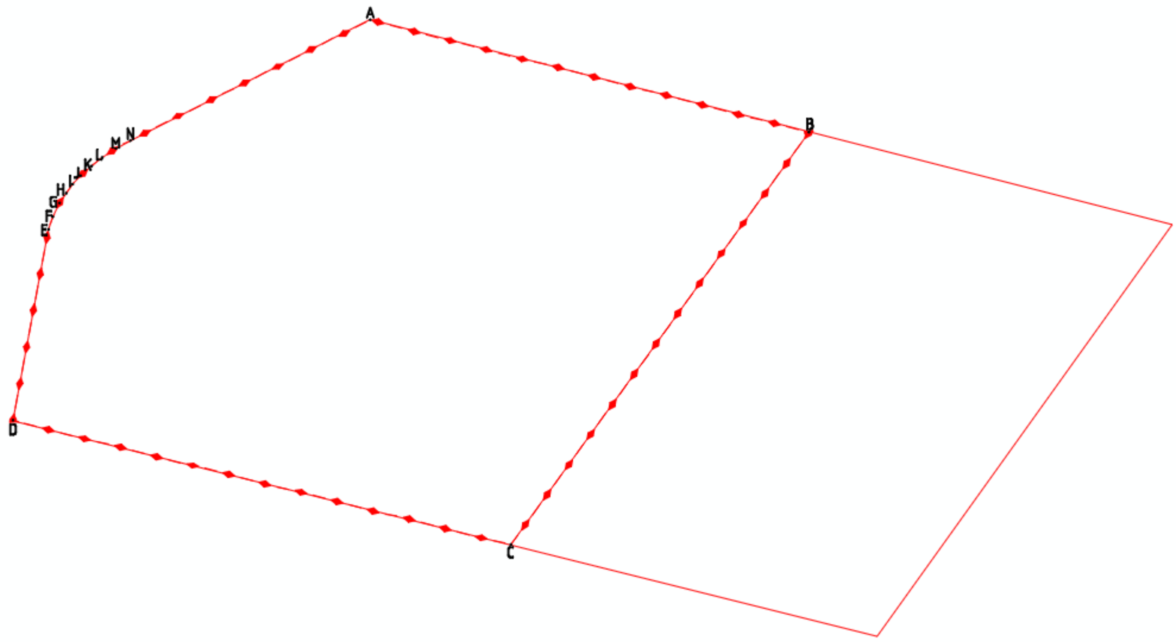


Figure 23. Site area view of the project

Global mapper (version 20.1) program is used to convert KMZ files created in Google Earth to make proper format DWG to use in ProgeCad (professional 2020) drawing program. The obtained view from the drawing program is shown in Figure 23.

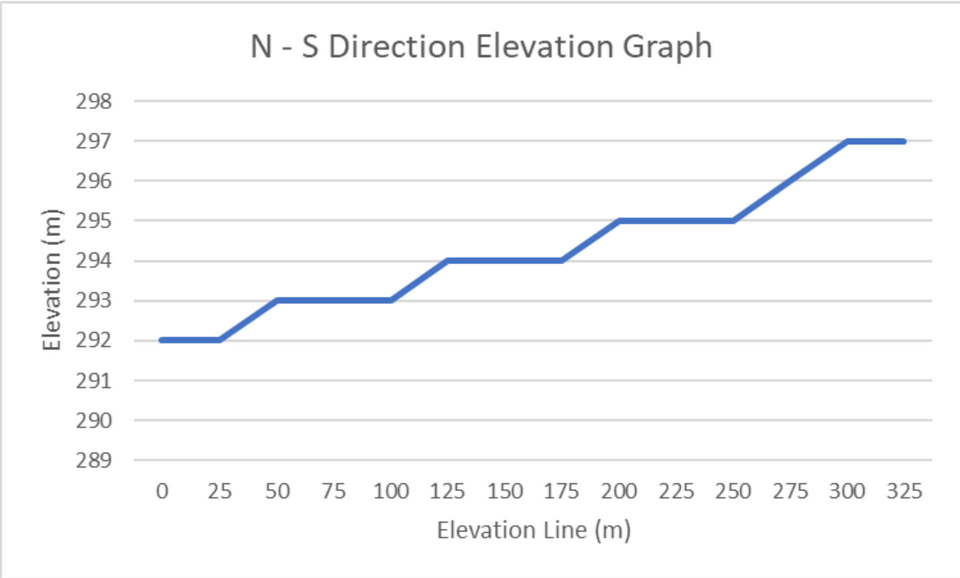
The fence corners are defined by 14 letters according to the English alphabetical order from letter A to the letter N. The coordinates of these points are given on the Table 3 below with Universal Transverse Mercator (UTM).

Table 3. Fence coordinates of the site area

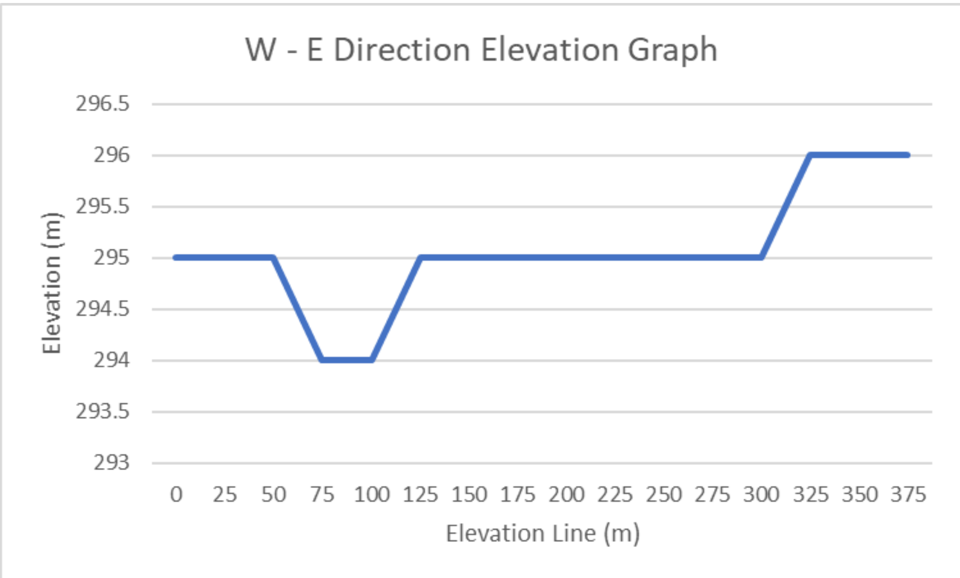
FENCE COORDINATES (UTM) ZONE: 19H		
POINT	X	Y
A	305605.9210	6142370.3458
B	305889.3117	6142297.9347
C	305696.7217	6142031.4780
D	305375.3070	6142111.6951
E	305398.2221	6142235.1048
F	305401.1412	6142243.3060
G	305405.3744	6142252.1194
H	305409.6886	6142258.6790
I	305413.9107	6142264.4375
J	305418.9626	6142269.6952
K	305426.2474	6142276.2885
L	305432.9159	6142281.5815
M	305441.8396	6142287.2447
N	305451.0946	6142292.5935

The elevation line information in the N-S (North-South) direction of the land is shown in Graph 3, and the elevation line information in the W-E (West-East) direction is shown in Graph 4. These data obtained by Google Earth Pro application from the satellite image taken on 27.04.2019

The slope of the terrain affects the distance between the trackers due to the shadows that will occur due to the PV modules. Therefore, the slope is an essential factor for the installation of any types of equipment. In areas with the same square meter but with different inclinations, the installed power capacity could vary.



Graph 3. Elevation of the site area from North to South



Graph 4. Elevation of the site area from West to East

Table 4. Maximum and average slope of terrain

SLOPE OF TERRAIN		
Direction	**Maximum**	**Average**
N-S	4.60%	1.60%
W-E	1.90%, -1.90%	0.6%, -1.5%

2.2 Inverter Selection

In order to obtain technical and economic analysis between string inverters with input values of 1000V and 1500V, PV-175-TL-SX2 and PV-120-TL-SX2 are chosen the models of the Swiss brand ABB. The selection of inverters with the same brand and the same additional features enables us to achieve the most economically correct results.

Figure 24. ABB PV-175-TL-SX2 utility scale sting inverter [44]

Table 5. Important technical data of ABB PVS-175-TL and ABB PVS-120-TL utility scale string inverters [45, 46]

Technical Data	Inverter Type Code	
Input Side	**PVS-175-TL**	**PVS-120-TL**
Absolute maximum DC input voltage (Vmax,abs)	1500 V	1000 V
Start-up DC input voltage (Vstart)	750 V	420 V
Rated DC input power (Pdcr)	177000 W @ 40°C	123000 W @ 40°C
Number of independent MPPT	12	6
Number of DC input pairs for each MPPT	2	4
Operating Performance		
Weighted efficiency (EURO)	98.40%	98.60%

2.3 Solar PV Module Selection

Photovoltaic solar modules are monocrystalline framed modules which have slower power degradation, LONGI LR6-72PH-370M, with a rated output of 370Watt at Standard Test Conditions (STC). All equipment is rated for 1000V and 1500V operation. [48]

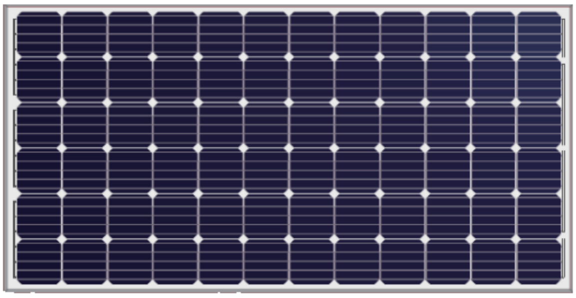


Figure 25. LONGI LR6-72PH solar photovoltaic module [47]

Table 6. Important technical data of LR6-72PH-370M solar PV module [48]

Technical Data	Model Number
	LR6-72PH-370M
Maximum Power (Pmax/W)	370
Open Circuit Voltage (Voc/V)	48.3
Short Circuit Current (Isc/A)	9.84
Voltage at Maximum Power (Vmp/V)	39.4
Current at Maximum Power (Imp/A)	9.39

2.4 DC/AC Ratio and Overloading

While calculating string size input data, the data obtained from the standard test conditions (STC) parameters given in the table below are used. [49]

Table 7. Standard test condition parameters [49]

Standard Test Conditions (STC)	
Solar Irradiation, (Sc)	1000 watt/m2
Temperature, (T)	25°C
Wind Speed, (W)	1 m/sec
Air Mass, (AM)	1.5

Assuming that the above conditions are met and all equipment such as cables and inverters do not experience any power loss, DC / AC ratio is obtained as 1. However, it is not possible to reach the parameters of standard test conditions in real life. Also, there is undoubtedly an energy loss in the equipment used. For this reason, it is better to load more than 100% power to the DC power inputs of inverters in order to approach the maximum value at the AC power output which is 1. Solar design engineers make their designs according to DC > AC by taking a risk the clipping loss caused by overloading the inverters. [51, 77].

DC/AC ratio is given 1.15 for the central regions of Chile on some researches. However, the increase in energy prices throughout the world in recent years and the decrease in prices in solar modules increase DC/AC ratio [50].

In order to increase the DC / AC ratio, the overload rate of according to rated DC input power of inverters is accepted as between 1.15 – 1.20 in this project.

2.5 PV String Size Calculation

One of the most critical questions is how many modules will be connected serially on one string. Firstly, the output powers and types of the selected photovoltaic modules should be the same in order not to make any more complicated designing and calculations and to avoid damaging input connections of inverters. [36].

String size calculation is a calculation that shows how many serial PV module groups can be connected to an inverter. The inverters operate within a specific input voltage range. If the panel group formed does not have enough voltage, enough power cannot be supplied to start the inverter. If the inverter is supplied with a much higher voltage than required by the assembled modules, likely to be damaged. The operating range defines the range in which inverter operates appropriately and efficiently. In this range, the inverter operates, and the desired power is supplied. Not only operation of the inverter is enough, but it is also essential to benefit from the inverter in the most efficient way [36].

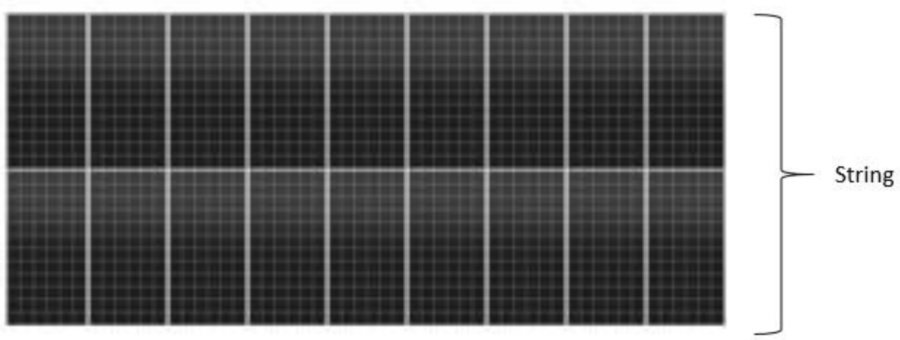


Figure 26. String design with 18 solar panels

The range where output is most efficient is called maximum power point (MPP). This is the narrower range in which the inverter operates at the highest efficiency [36]. I-V curve and MPP values are given in all inverter datasheets.

The purpose in string size calculation is to connect the correct number of panels to the voltage value in the MPP range, which is the most efficient range of the inverter [36].

MPP value has lower and upper limits. Therefore, the string size is calculated according to both the maximum and minimum limit. The following method applies when calculating the minimum string size [37].

Minimum String Size Calculation

All formulas and information used for minimum string size calculation under this subtitle are based on reference [37].

Minimum string size shows the minimum number of photovoltaic modules connected in series that are required for inverter to operate during the hottest summer periods. Firstly, $\text{Module Vmp}_{\text{min}}$ is calculated to find the minimum string size. Then the minimum voltage required of the inverter is divided by this value to find minimum string size for the inverter operation and this result gives us the minimum number of series-connected modules required for the inverter operation.

As the modules heat up, they generate a lower voltage, so this calculation is based on the maximum temperature the module reaches.

$$\text{Module Vmp}_{\text{min}} = \text{Vmp} \times [1 + ((\text{T}_{\text{max}} + \text{T}_{\text{add}} - \text{T}_{\text{STC}}) \times (\text{Tk}_{\text{Vmp}}/100))]$$

(Eq. 1)

where,

$\mathbf{Module\ Vmp_{min}}$: minimum module voltage expected at site high temperature [V].

$\mathbf{Vmp}$: rated module max power voltage [V].
This value is given at the PV panel datasheet.

$\mathbf{T_{max}}$: the ambient high temperature for the installation site [°C]. This value can be taken in many ways. The most commons are:

- The highest temperature ever recorded in the region where the photovoltaic system is located.
- The average temperature of the hottest month, week, or day in the region where the photovoltaic system is located.
- Looking at the past temperature values in the region, high temperatures that can be seen in the future periods.

The region could have various associations and organizations that record this data. This data can be obtained from those organizations. Using the most accurate data ensures the most precise result.
In this project, +38.3°C the highest temperature ever recorded in the region is taken as the ambient high temperature for the installation site. [55]

$\mathbf{T_{add}}$: temperature adjustment for installation method [°C].
Generally, photovoltaic systems installed on the roof of the house are hotter than the ground-mounted photovoltaic systems due to the low air flow.
This value is generally taken at the mild climate regions as +35°C if it is a PV system mounted parallel to the roof, +30°C if the roof is mounted on a rack-type, and +25°C if it is mounted on the ground or pole on the mild condition regions.

$\mathbf{T_{STC}}$: temperature at standard test conditions, 25°C

$\mathbf{Tk_{Vmp}}$: module temperature coefficient of Vmp [%/°C]
This value always expressed as a negative value and is taken from PV panel data sheet.

$$\text{Min String Size} = \frac{\text{Inverter V}_{\text{min}}}{\text{Module Vmp}_{\text{min}}}$$
(Eq. 2)

The value obtained here is rounded to the nearest whole number.

where,

$\mathbf{Module\ Vmp_{min}}$: minimum module voltage expected at site high temperature [V]
This data is obtained from the previous calculation which is above.

$\mathbf{Inverter\ V_{min}}$: minimum MPPT voltage of inverter [V].
This value is taken from the datasheet of the inverter which corresponds the minimum operating voltage of the inverter, to enable the inverter to step in.

The maximum power point tracking (MPPT) function of the inverter can stop the operation of the system. This function is to ensure that the inverter generates the highest power output at any time. Using the MPPT value of the inverter allows the inverter to operate properly and to provide the highest possible output power.

The minimum string size value to be obtained after this calculation is always rounded up to the next whole number to provide the minimum voltage required for the inverter.

Maximum String Size Calculation

All formulas and information used for maximum string size calculation under this subtitle are based on reference [37].

The maximum string size indicates the maximum number of photovoltaic modules connected in series during the coldest period of the inverter. This value is essential for safety as the output power of the modules will increase in cold weather. First, Module Voc_{max} is calculated to find the maximum string size. Then the inverter maximum allowable voltage is divided by this value to find maximum string size for inverter operation. This result shows the maximum number of modules connected in series to the inverter.

$$\text{Module Voc}_{\text{max}} = \text{Voc} \times [1 + (\text{T}_{\text{min}} - \text{T}_{\text{STC}}) \times (\text{Tk}_{\text{Voc}}/100)]$$
(Eq. 3)

where,

$\mathbf{Module\ Voc_{max}}$: maximum module voltage corrected for the site lowest expected ambient temperature [V].

$\mathbf{Voc}$: module rated open current voltage [V].
This data is taken from the PV module datasheet.

$\mathbf{T_{min}}$: lowest expected ambient temperature for site [°C].
The most crucial point here is to estimate the lowest temperature in the region where the photovoltaic system is being located. The lowest measured value in the region can be taken. If the maximum value used in the minimum string size calculation is incorrect, the system will either not work, or the efficiency will be low. However, if the minimum value is taken incorrectly for maximum string size calculation, power can be loaded more than the inverter can handle. The inverter may overheat and damage the system. It may result in a fire.

Since the inverters used in this project have overload protection, the inverter will not be damaged. In order not to be faced with such a situation and to bring an additional burden to the initial investment cost, the value lowest expected ambient temperature for the site used is important.

In this project, -6.8°C the lowest temperature ever recorded in the region is taken as lowest expected ambient temperature for site. [55]

$\mathbf{T_{STC}}$: temperature at standard test conditions, 25°C

$\mathbf{Tk_{Voc}}$: open current voltage of module temperature coefficient [%/°C]
This value always expressed as a negative value and is taken from the PV module datasheet.

$$\text{Max String Size} = \frac{\text{Inverter V}_{\text{max}}}{\text{Module Voc}_{\text{max}}}$$

(Eq.4)

where,

$\mathbf{Module\ Voc_{max}}$: maximum module voltage corrected for the site lowest expected ambient temperature [V].
This data is obtained from the previous calculation which is above.

$\mathbf{Inverter\ V_{max}}$: the inverter maximum allowable voltage [V].
This data is taken from the PV module datasheet.

The maximum string size value to be obtained after this calculation is always rounded down to the next whole number to not to exceed the maximum inverter voltage.

The value obtained from the minimum string size calculation indicates the lowest number of modules that can be connected in series to an input in MPPT to have required voltage for the inverter to activate. The value obtained from the maximum string size calculation indicates the maximum number of modules that can be connected in series to an input in MPPT of the inverter.

String Size Calculation for 1000V String Inverter

In the first equation **(Eq. 1)**, when we put the values given above:

$$\text{Module Vmp}_{\text{min}} = 39.4 \times [1 + ((38.3 + 25 - 25) \times (-0.37/100))]$$

$$\text{Module Vmp}_{\text{min}} = 33.8166\text{V}$$

In the second equation **(Eq. 2)**, when we put the values given above:

$$\text{Min String Size} = \frac{420}{33.8166}$$

$$\text{Min String Size} = 12.4199$$

As mentioned above the value to be obtained is always rounded up to the next whole number to provide the minimum voltage required for the inverter.

The result shows the minimum 13 (LONGI LR6-72PH) 370-watt solar modules must be connected in serial to supply the minimum voltage required for the (PV-120-TL-SX2) 1000V string inverter.

In the third equation **(Eq. 3)**, when we put the values given above:

$$\text{Module Voc}_{\text{max}} = 48.3 \times [1 + (-6.8 - 25) \times (-0.286/100)]$$

$$\text{Module Voc}_{\text{max}} = 52.6928\text{V}$$

In the fourth equation **(Eq. 4)**, when we put the values given above:

$$\text{Max String Size} = \frac{1000}{52.6928}$$

$$\text{Max String Size} = 18.9779$$

As mentioned above the value to be obtained is always rounded down to the next whole number to not exceed the maximum inverter voltage.

The result shows the maximum 18 (LONGI LR6-72PH) 370-watt solar modules can be connected in serial to not exceed the maximum (PV-120-TL-SX2) 1000V string inverter voltage.

The rated DC input power of PVS-120-TL-SX2 model string inverter is 123000 W @ 40°C

The rated DC input power is multiplied by overload ratio range when finding the preferred DC input power range for this project.

$$123000 \times 1.15 \leq \text{DC input power} \leq 123000 \times 1.20$$

$$141450\text{W} \leq \text{DC input power} \leq 147600\text{W}$$

Multiplying of number strings connected to an inverter, number of modules in one string and rated output power of the inverter should be inside of the DC input power range.

There are four variables in this equation, and only rated output power of the panel is not changed. By changing the number strings connected to an inverter and number of modules in one string, a value must be present in the DC input power range.

Considering a string size as high as possible reduces the amount of DC cables used between the tracker and the inverters. Considering the number of connected strings as high as possible reduces the number of inverters that should be used.

In this design, all 24 string inputs of the inverter are used. In order to reach the desired DC input power range, the string size has been taken as 16.

DC input power is equal to multiplying number of PV modules in a string, number of string and rated output power of the panel.

$$\text{DC input power} = 16 \times 24 \times 370\text{W}$$

$$\text{DC input power} = 142080\text{W}$$

$$\text{Overload Ratio} = \frac{\text{loaded DC input power}}{\text{rated DC input power}}$$

$$\text{Overload Ratio} = 142080\text{W}/123000\text{W}$$

$$\text{Overload Ratio} = 1.1551$$

As we can see in the calculation above, when all the string inputs of 24 inverters are used, and there are 16 serial connected PV modules in each string, the overload rate is obtained as 1.1551.

String Size Calculation for 1500V String Inverter

In the first equation **(Eq. 1)**, when we put the values given above:

$$\text{Module Vmp}_{\text{min}} = 39.2 \times [1 + ((38.3 + 25 - 25) \times (-0.37/100))]$$

$$\text{Module Vmp}_{\text{min}} = 33.6450\text{V}$$

In the second equation **(Eq. 2)**, when we put the values given above:

$$\text{Min String Size} = \frac{750}{33.6450}$$

$$\text{Min String Size} = 22.2916$$

As mentioned above the value to be obtained is always rounded up to the next whole number to provide the minimum voltage required for the inverter.

The result shows the minimum 23 (LONGI LR6-72PH) 370-watt solar modules should be connected in serial to supply the minimum voltage required for the (PV-175-TL-SX2) 1500V string inverter.
In the third equation **(Eq. 3)**, when we put the values given above:

$$\text{Module Voc}_{\text{max}} = 47.9 \times [1 + (-6.8 - 25) \times (-0.286/100)]$$

$$\text{Module Voc}_{\text{max}} = 52.2564\text{V}$$

In the fourth equation **(Eq. 4)**, when we put the values given above:

$$\text{Max String Size} = \frac{1500}{52.2564}$$

$$\text{Max String Size} = 28.7046$$

As mentioned above the value to be obtained is always rounded down to the next whole number to not exceed the maximum inverter voltage.

The result shows the maximum 28 (LONGI LR6-72PH) 370-watt solar modules can be connected in serial to not exceed the maximum (PV-175-TL-SX2) 1500V string inverter voltage.

DC input power is equal to multiplying number of PV modules in a string, number of string and rated output power of the panel.

$$\text{DC input power} = 26 \times 22 \times 370\text{W}$$

$$\text{DC input power} = 211640\text{W}$$

$$\text{Overload Ratio} = \frac{\text{loaded DC input power}}{\text{rated DC input power}}$$

$$\text{Overload Ratio} = 211640\text{W}/177000\text{W}$$

$$\text{Overload Ratio} = 1.1957$$

As we can see in the calculation above, when 22 of the inverter's 24 string input is used, and there are 26 serial connected PV modules in each string, the overload rate is obtained as 1.1957 which is inside of preferred range for this project.

2.6 Tracker Selection and Design

In this project, the single-axis Artech Skysmart tracker system is preferred. It provides the opportunity to use two portrait solar modules in one row. In this way, since the number of trackers used decreases, initial investment costs are reduced. One tracker has 90 modules carrying capacity with ±60° tracking range (tilt angle). It is used for up to 20% slope in N/S direction [52].

Figure 27. Arctech Skysmart two portrait single-axis solar tracker (view from below) [54]

Table 8. Important technical specifications of Arctech Skysmart tracker [52]

Tracker Specifications	
Tracking Type	Independent horizontal single - axis
Tracking Range	±60°
Module per Tracker	90
System Voltage	1000V - 1500V
Terrain Adaption	Up to 20% N-S slope
Wind Protection	18m/s

The surface area is more extensive in two portrait trackers. For this reason, wind speed and direction are essential.

The following values obtained from prototype of two portrait single axis solar tracker of the Artech company are taken into consideration while designing the trackers.

- Distance between two PV modules on the column: 0.6 cm
- Distance between portraits: 16 cm
- Distance on a tracker that between N and S groups: 48 cm
- Distance between trackers in the N-S direction (back to back): 90 cm

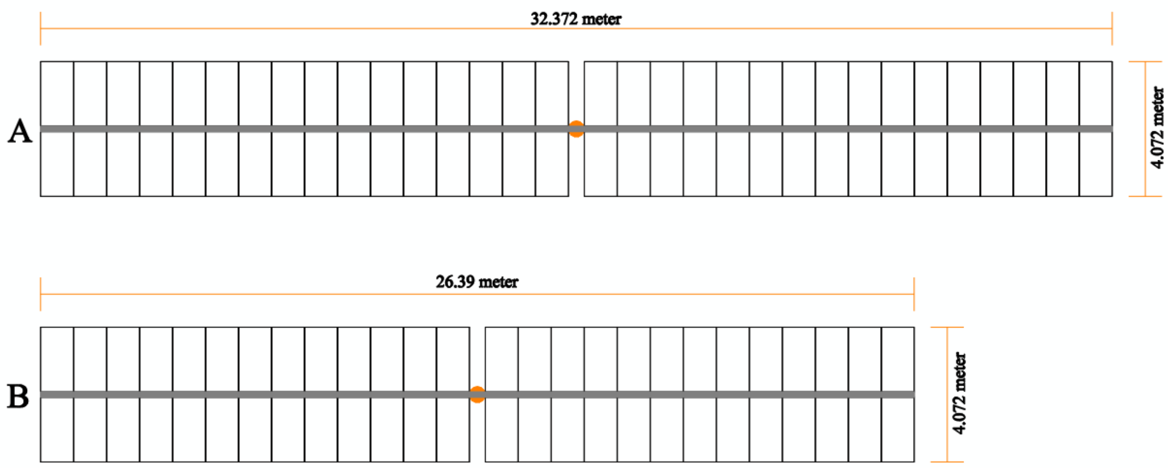


Figure 28. 64-module (A) & 52-module (B) two portrait tracker (top view)

In the upper part (A) of Figure 28 shows the drawing of a 64-module two portrait tracker designed for 1000V inverter with four strings according to LONGI LR6-72PH 370-watt PV module sizes.

In the lower part (B) of Figure 28 shows the drawing of a 52-module two portrait tracker designed for 1500V inverter with two strings according to LONGI LR6-72PH 370-watt PV module sizes.

2.7 Determining Usable Land in the Field

If there are no nonignorable things in the site area, such as a tree, water channel, high tension line, rock or structure, that could cast a shadow for the modules or prevent the installation, the whole area can be used. In site area of this project, none of those as mentioned above obstacles exists. However, it is planned to leave space on the interior to provide access to every part of the site area.

According to Chilean road permits rules, the widest vehicle that can be legally in traffic is 2.60 meters [53]. In this project, the distance between the fence and the trackers is determined as 5.20 meters, which is double the 2.60, to give easy access for any type of vehicle to the site area.

2.8 Calculating Space Between Trackers

The values needed for the calculation of space between trackers in this section are given below.

- Optimally incline angle obtained from the Solargis platform for optimal use of the sun's rays (34°50'39.35"S, 71°07'28.36"W): 27° [56]

Optimally incline angle is the angle between the sun and the horizontal axis of 0°, with the highest irradiation amount of the sun's rays to the earth.

- Width of the tracker with two portraits: 4.072 m

Length of the LR6-72PH PV is given at the datasheet as 1956 mm [48]

When calculating the width of a 2-portrait tracker:

$$\text{Width of the tracker} = (2 \times 1.956\text{m}) + 0.16\text{m}$$

$$\text{Width of the tracker} = 4.072\ \text{meter}$$

- Maximum tilt angle of the tracker: 60° [52]

- Maximum W-E slope of the site area: 1.9% (1.088°)[1] (Table 4)

In order to find the shortest distance between two trackers in the most inclined region, the maximum slope of the site area at W-E direction is accepted in this project.

Table 9. Legend table for Figure 29

	0° HORIZONTAL AXIS
	IRRADIATION
	SOLAR PV MODULE
	-1.088° HORIZONTAL AXIS
	SPACE BETWEEN TRACKERS

1 arctan (0.019) = 1.088488842°

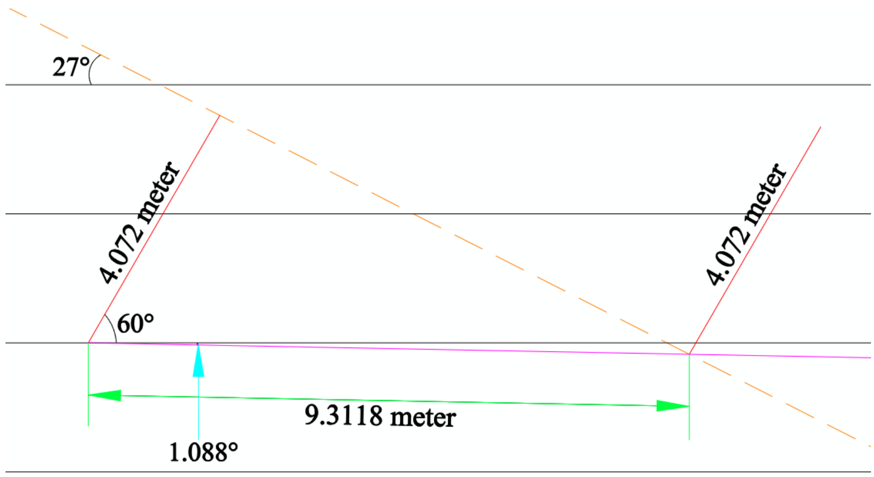


Figure 29. Drawing of calculation of space between trackers

The minimum space between the trackers calculated in ProgeCad drawing as 9.3118 meter as shown in Figure 29 is taken as 9.32 meter in this project. This dimension represents the space between the start point of a tracker and the start point of the 2nd tracker closest at W-E direction.

2.9 Calculating Number of Inverters

Calculation of the number of inverters is related to string size, the output power of the PV module and planned installed power of the solar PV plant. Both types of inverters used have 24 string inputs, but as mentioned before, not all of these inputs always can be used. Each of the strings formed by the serial modules generates power. The overloading ratio is multiplied by the maximum input power of the inverter, and the value is obtained, which shows uploaded power for an inverter. After obtaining uploaded power to an inverter, intended installed DC power of the plant is divided into this value, and the total number of inverters to be used in the project is reached.

Calculation Number of Inverter for 1000V String Inverter Design

The power to be loaded on the 1000V inverter is calculated as 142080Wp in the string size calculation section.

DC installed power of the plant is determined as 6000kWp for this project.

The number of inverters is calculated by the method below:

$$\text{Number of Inverter} = \frac{\text{DC installed power of the plant}}{\text{loaded power of an inverter}}$$

$$\text{Number of Inverter} = 6000\text{kWp}/142.08\text{kWp}$$

$$\text{Number of Inverter} = 42.2297$$

If a solar power plant design with a fully installed power of 6000kWp was planned, 43 inverters would had been used. However, 23% capacity of the 43rd inverter was being used. The full capacity of 43 inverters is used in this project since it is planned to have all inverter performances. Since the economic analysis is carried out as kWp, the installed power does not have to be the same in two projects with different inverters.

The DC installed power of plant is calculated by the method below:

$$\text{DC installed power of the plant} = \text{loaded power of an inverter} \times \text{number of inverters}$$

$$\text{DC installed power of the plant} = 142.08\text{kWp} \times 43$$

$$\text{DC installed power of the plant} = 6109.44\text{kWp}$$

Calculation Number of Inverter for 1500V String Inverter Design

The power to be loaded on the 1500V inverter is calculated as 211640Wp in the string size calculation section.

DC installed power of the solar power plant is determined as 6000kWp for this project as mentioned before.

The number of inverters is calculated by the method below:

$$\text{Number of Inverter} = \frac{\text{DC installed power of the plant}}{\text{loaded power of an inverter}}$$

$$\text{Number of Inverter} = 6000\text{kWp}/211.64\text{kWp}$$

$$\text{Number of Inverter} = 28.35$$

If a solar power plant design with a fully installed power of 6000kWp was planned, 29 inverters would had been used. However, 35% capacity of the 29th inverter was being used. The full capacity of 29 inverters is used in this project since it is planned to have all inverter performances as mentioned before.

The DC installed power of plant is calculated by the method below:

$$\text{DC installed power of the plant} = \text{loaded power of an inverter} \times \text{number of inverters}$$

$$\text{DC installed power of the plant} = 211.64\text{kWp} \times 29$$

$$\text{DC installed power of the plant} = 6137.56\text{kWp}$$

2.10 Determining Location of the String Inverters

The position of the inverters and transformer is designed differently for centralized and distributed systems.

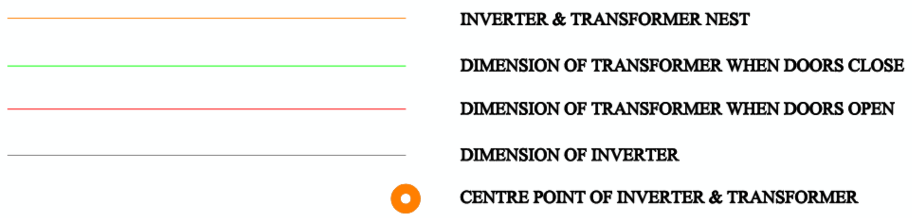
Centralized System Design

The site area is divided into two parts North and South. Both sides have equal rows of trackers.

The centre point of the inverters and transformer nest is located in 305621.1433 E, 6142217.2396 S coordinates (UTM), which is the closest point of the centre of gravity of the trackers in W-E and N-S sequence in the project where 1500V inverters are used.

The centre point of the inverters and transformer nest is located in 305621.1433 E, 6142219.9626 S coordinates (UTM), which is the closest point of the centre of gravity of the trackers in W-E and N-S sequence in the project where 1000V inverters are used.

Table 10. Legend table for Figure 30-31



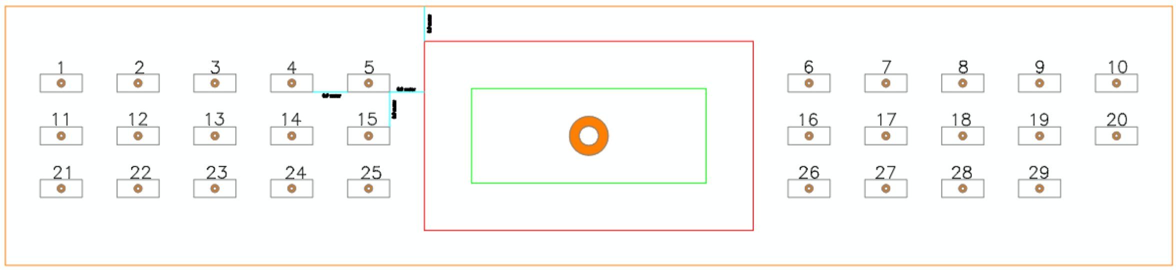


Figure 30. Design of inverter and transformer nest with 1500V string inverter (plan view)

Space around the inverter must be at least 30 cm [78]. However, the space between inverters on W-E and N-S direction, space between inverter and transformer, and the space between transformer and nest is taken 0.9 meter, which is the width that a person can comfortably pass and shown ABB PV-175-TL product manual [66]. It is shown in Figure 31.

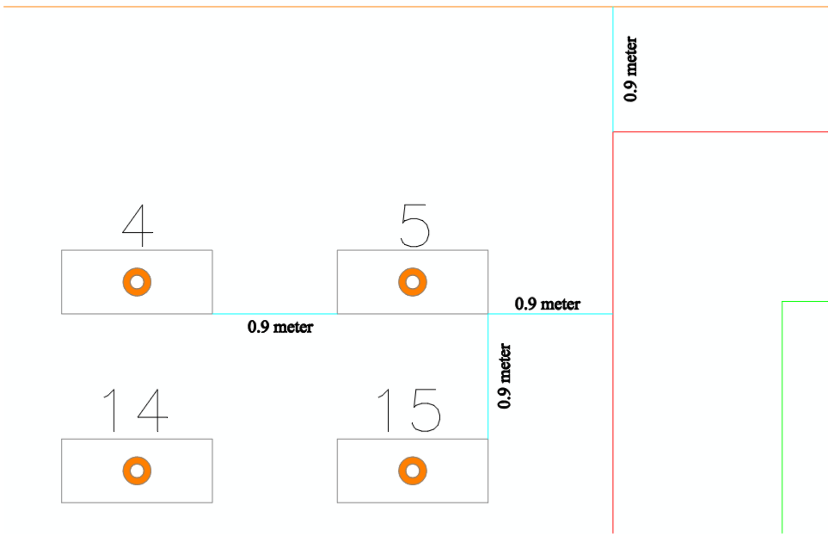


Figure 31. Design of inverter and transformer nest with 1500V string inverter (close view)

Distributed (Decentralized) System Design

The site area is divided into three parts North, Middle and South for both 1000V and 1500V distributed designs. Both north and south sides have equal rows of trackers. However, the middle area is designed to be closest to twice the number of tracker rows in the north and south. In this way, the trackers in the middle which are close to the north part are connected to the inverters that are distributed in the north line, and the trackers which are close to the south part are connected to the inverters that are distributed in the south line. Thus, DC cable usage is reduced.

The inverters are placed on north and south lines with equal distance between each other after calculating how many inverters are distributed to the south and north lines.

The transformer is placed in the mid-point of the east part of the trackers in the centre area. The purpose of placing the transformer in the east part is due to the fact that the distribution line connection point where the power plant is connected is located on the east side.

2.11 Calculating AC–DC Cables Length

ProgeCad (professional 2020) drawing program is used to calculate all AC and DC cable length.

The 64-module tracker has four 16-string to connect with 1000V inverter. The solar PV modules within these four strings are connected in series between them and connected to the input point of the inverter separately. There are two separate cables to be positive (+) and negative (-) at the output of each string. It is numbered with string 1 in red colour, string 2 in green, string 3 in orange and string 4 in blue in Figure 32. The cable output of the string is located at the points symbolised by the red hatch. The string cables from this point reach the inverter by following a 50 cm deep cable path excavated on the way to the inverter.

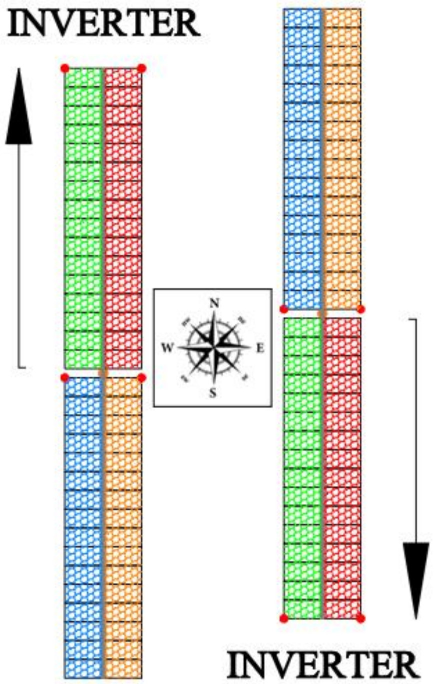


Figure 32. Showing of strings on 64-module trackers for 1000V inverter used project

The 52-module tracker has two 26-string to connect with 1500V inverter. The solar PV modules within these two strings are connected in series between them and connected to the input point of the inverter separately. There are two separate cables to be positive (+) and negative (-) at the output of each string. It is numbered with string 1 in blue colour, string 2 in orange in Figure 33. The cable output of string is located at the points symbolised by the red hatch. The string cables from this point reach the inverter by following a 50 cm deep cable path excavated on the way to the inverter.

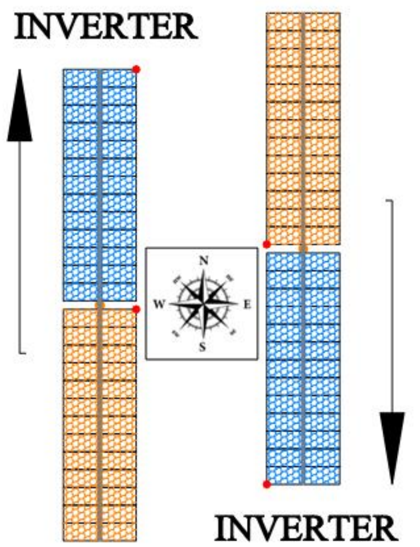


Figure 33. Showing of strings on 52-module trackers for 1500V inverter used project

The connection line between 2nd string of 168th tracker and 23rd inverter is shown with blue colour in Figure 34. Other colouring and shape information are shown in the general legend table.

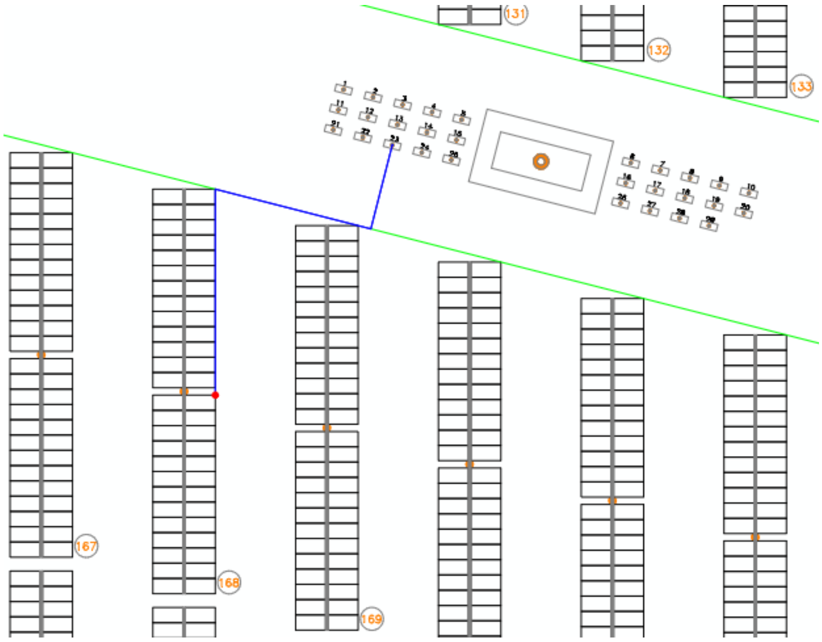


Figure 34. The connection line between 2nd string of 168th tracker and 23rd inverter at 1500V inverter used project

The cable calculation shown in Figure 34 was made for four different cases and three different cables used in each case. The amount of used cables in each project shown in Graph 5. DC cables are used between strings and inverter connections. Low Voltage (LV) AC cables are used between inverters and transformer, and Medium Voltage (MV) AC cables are used between transformer and transmission line connection point. All cable lines are 50 cm deep.

When these conditions are taken into consideration:

For 1000V-centralized inverter system design (6109.44 kWp installed power)

- 297.296 km DC Cables are used
- 1.601 km LV-AC Cables are used
- 0.729 km MV-AC Cables are used

For 1000V-distributed inverter system design (6109.44 kWp installed power)

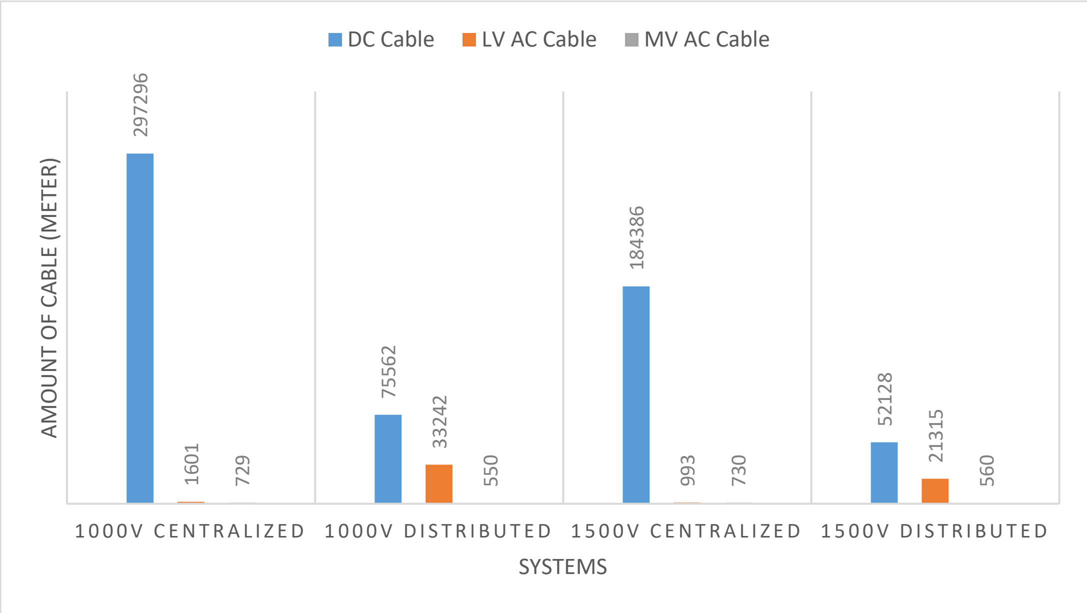
- 75.562 km DC Cables are used
- 33.242 km LV-AC Cables are used
- 0.550 km MV-AC Cables are used

For 1500V-centralized inverter system design (6137.56 kWp installed power)

- 184.386 km DC Cables are used
- 0.993 km LV-AC Cables are used
- 0.730 km MV-AC Cables are used

For 1500V-distributed inverter system design (6137.56 kWp installed power)

- 52.128 km DC Cables are used
- 21.315 km LV-AC Cables are used
- 0.560 km MV-AC Cables are used



Graph 5. Amount of used cable for 1000V-1500V centralized-distributed system designs

2.12 Calculating Cable Capacity, Cable Size and Selection of Cables

All formulas and information used for cable optimization and capacity calculation under this subtitle are based on reference [38].

In this section, firstly, the required current value of the cables is found. Then, according to current, the diameter of the cables is obtained.

The current carrying capacity of a cable buried in the ground is calculated using the formula:

$$Iz = I_r \times k_1 \times k_2 \times k_3$$

(Eq. 5)

where:

- I_r is the current carrying capacity of the single conductor for installation in the ground at 20°C reference temperature
- k_1 is the correction factor if the temperature of the ground is other than 20°C
- k_2 is the correction factor for adjacent cables
- k_3 is the correction factor if the soil thermal resistivity is different from the reference value, 2.5 Km/W

Modified equation is shown below to obtain the current carrying capacity of the single conductor:

$$I_r = \frac{Iz}{k_1 \times k_2 \times k_3}$$

Current Carrying Capacity Calculation of DC Cable for 1000V – 1500V Inverter System Designs

Iz is obtained from the solar PV module datasheet as 9.39 A [48].

The average underground temperature is given 14.4 °C [57]. This value is accepted as 15°C due to the high temperatures with the effect of global warming in this project. Cable insulation is considered as XLPE (Cross-linked Polyethylene). According to these information k_1 factor is given as 1.04 at correction factor k_1 table [58]. The same value of k_1 factor is used for all other DC – AC current carrying capacity calculations.

There are maximum four trackers in the north or south part of the site area on N-S direction and each tracker has four string outputs. Therefore, there are 16 positive and negative strings in a row. It is assumed that all of these cables are located in the same DC line and touching each other. According to these information k_2 factor is given as 0.32 at reduction factor k_2 table [59].

The soil thermal resistivity varies depending on structure, depth, and humidity of soil. Even in the same terrain, different results can be obtained from the ground studies at various points. This value is accepted as 2.5 Km/W, which is the reference of soil thermal resistivity value. According to these information k_3 factor is given as 1.00 at reduction factor k_2 table [60]. The same value of k_3 factor is used for all other DC – AC current carrying capacity calculations.

In the fifth equation **(Eq. 5)**, when we put the values given above:

$$I_r = \frac{9.39\ A}{1.04 \times 0.32 \times 1}$$

$$I_r = 28.2151\ A$$

The current capacity of the DC cable should be equal or greater than 28.22 ampere.

Aluminium $4mm^2$ cross-sectioned cable with XLPE insulation is enough to carry 22.28 amperes according to referenced table [61]. However, $6mm^2$ cable (KBE) is used to reduce losses for DC cabling [62].

Figure 35. KBE solar cable [63]

Low Voltage (AC) Current Carrying Capacity Calculation for 1000V Inverter System Designs

Iz is obtained from the ABB PVS-120-TL string inverter datasheet as 145 A [46].

In the connection path between inverter and transformer, it is assumed that the cables coming from the output of the 4 inverters are in a group of circuit with touching each other to connect with transformer. According to these information k_2 factor is given as 0.60 at reduction factor k_2 table [59].

k_1 and k_3 correction factors are used same as previous calculation used for DC cabling.

In the fifth equation **(Eq. 5)**, when we put the values given above:

$$I_r = \frac{145\ A}{1.04 \times 0.60 \times 1}$$

$$I_r = 232.3718\ A$$

The current capacity of the low voltage AC cable between 1000V inverter and transformer should be equal or greater than 232.38 ampere.

Single-core NTK NA2X2Y 0,6/1 kV Aluminium XLPE insulation $185mm^2$ cable [64] is used for cabling between inverter and transformer according to referenced table [61].

Figure 36. NTK NA2X2Y 0,6/1 kV multi-core cable [64]

Low Voltage (AC) Current Carrying Capacity Calculation for 1500V Inverter System Designs

Iz is obtained from the ABB PVS-175-TL string inverter datasheet as 134 A [45].

In the connection path between inverter and transformer, it is assumed that the cables coming from the output of 3 inverters are in a group with touching each other to connect with the transformer. According to these information k_2 factor is given as 0.65 at reduction factor k_2 table [59].

k_1 and k_3 correction factors are used same as previous calculation used for DC cabling.

In the fifth equation **(Eq. 5)**, when we put the values given above:

$$I_r = \frac{134\ A}{1.04 \times 0.65 \times 1}$$

$$I_r = 198.2249\ A$$

The current capacity of the low voltage AC cable between 1500V inverter and transformer should be equal or greater than 198.23 ampere.

Single-core NTK NA2X2Y 0,6/1 kV Aluminium XLPE insulation $150mm^2$ cable [64] is used for cabling between inverter and transformer according to referenced table [61].

Medium Voltage (AC) Current Carrying Capacity Calculation for 1000V–1500V Inverter System Designs

The solar PV power plant is assumed to connect 15.0kV distribution network.

Iz is calculated using the formula:

$$I_Z = \frac{P}{V_{out} \times \sqrt{3}}$$

(Eq. 6)

where:

- I_Z is the current carrying capacity of a cable buried in the ground (A)
- P is the power of the transformer (kW) [79]
- V_{out} is the output voltage of the transformer (kV) [79]

In the sixth equation **(Eq. 6)**, when we put the values given above:

$$I_Z = \frac{6300}{15 \times \sqrt{3}}$$

$$I_Z = 242.4871\ A$$

Iz is obtained from calculation above for ENERGIA 6.3kW transformer as 242.4871 A [45].

In the connection line between transformer and substation, there is only one circuit coming from the transformer connect with the distribution system. According to these information k_2 factor is taken as 1.00

k_1 and k_3 correction factors are used same as previous calculation used for DC cabling.

In the fifth equation **(Eq. 5)**, when we put the values given above:

$$I_r = \frac{242.4871\,A}{1.04 \times 1 \times 1}$$

$$I_r = 233.1607\,A$$

The current capacity of the medium voltage AC cable between transformer and distribution system should be equal or greater than 233.17 ampere.

Single-Core NTK NA2S2Y 12/20 kV Aluminium XLPE insulation $185mm^2$ cable [65] is used for cabling between inverter and transformer according to referenced table [61].

Figure 38. NTK NA2S2Y 12/20 kV Single-Core cable [65]

2.13 Power Loss Calculation

The calculation of power loss for cables are given by the following equation:

$$P_{LOSS} = \frac{(I^2 \times L \times R)}{1000}$$

(Eq. 7)

where,

- P_{LOSS} power loss (W)
- I current (A)
- L length of the cable (m)
- R resistance of cable (Ω/km)

When we calculate the percent of power loss due to the cables:

$$P_{LOSS\,\%} = \frac{P_{LOSS}}{P_{INSTALLED}} \times 100$$

(Eq. 8)

where,

- P_{LOSS} power loss (W)
- $P_{INSTALLED}$ DC installed power of the plant (W)

Power Loss of 1000V-Centalized Inverter System Design

DC Cable Loss

I is obtained from the solar PV module datasheet as 9.39 A [48]
L is calculated 297296 meters for centralized 1000V inverter project
R is obtained from the KBE cable datasheet for $6mm^2$ as 3.39 Ω/km [63]

In the seventh equation **(Eq. 7)**, when we put the values given above:

$$P_{LOSS} = \frac{(9.39^2 \times 297296 \times 3.39)}{1000}$$

$$P_{LOSS} = 88862.79\ W$$

In the eight equation **(Eq. 8)**, when we put the values given above:

$$P_{LOSS\,\%} = \frac{88862.72}{6109440} \times 100$$

$$P_{LOSS\,\%} = 1.4545\%$$

Low Voltage AC Cable Loss

I is obtained from the ABB PVS-120-TL string inverter datasheet as 145 A [46].
L is calculated 1601 meters for centralized 1000V inverter project
R is obtained from the NTK NA2X2Y 0,6/1 kV cable datasheet for $185mm^2$ as 0.164 Ω/km [64]

In the seventh equation **(Eq. 7)**, when we put the values given above:

$$P_{LOSS} = \frac{(145^2 \times 1601 \times 0.164)}{1000}$$

$$P_{LOSS} = 5520.41\ W$$

In the eight equation **(Eq. 8)**, when we put the values given above:

$$P_{LOSS\,\%} = \frac{5520.41}{6109440} \times 100$$

$$P_{LOSS\,\%} = 0.0904\%$$

Medium Voltage AC Cable Loss

I is obtained from the Iz calculation for ENERGIA 6.3MVA transformer as 242.4871 A [45].
L is calculated 729 meters for centralized 1000V inverter project
R is obtained from the NTK NA2S2Y 12/20 kV cable datasheet for $185mm^2$ as 0.164 Ω/km [65]

In the seventh equation **(Eq. 7)**, when we put the values given above:

$$P_{LOSS} = \frac{(242.4871^2 \times 729 \times 0.164)}{1000}$$

$$P_{LOSS} = 7029.89\ W$$

In the eight equation **(Eq. 8)**, when we put the values given above:

$$P_{LOSS\,\%} = \frac{7029.89}{6109440} \times 100$$

$$P_{LOSS\,\%} = 0.1151\%$$

Power Loss of 1000V-Distributed Inverter System Design

Except length of the cables, all values are the same with centralized 1000V Inverter project.

DC Cable Loss

L is calculated 75562 meters for distributed 1000V inverter project

In the seventh equation **(Eq. 7)**, when we put given values:

$$P_{LOSS} = \frac{(9.39^2 \times 75562 \times 3.39)}{1000}$$

$$P_{LOSS} = 22585.74\ W$$

In the eight equation **(Eq. 8)**, when we put given values:

$$P_{LOSS\,\%} = \frac{22585.74}{6109440} \times 100$$

$$P_{LOSS\,\%} = 0.3697\%$$

Low Voltage AC Cable Loss

L is calculated 33242 meters for distributed 1000V inverter project

In the seventh equation **(Eq. 7)**, when we put given values:

$$P_{LOSS} = \frac{(145^2 \times 33242 \times 0.164)}{1000}$$

$$P_{LOSS} = 114621.74\ W$$

In the eight equation **(Eq. 8)**, when we put given values:

$$P_{LOSS\,\%} = \frac{114621.74}{6109440} \times 100$$

$$P_{LOSS\,\%} = 1.8761\%$$

Medium Voltage AC Cable Loss

L is calculated 550 meters for distributed 1000V inverter project

In the seventh equation **(Eq. 7)**, when we put given values:

$$P_{LOSS} = \frac{(242.4871^2 \times 550 \times 0.164)}{1000}$$

$$P_{LOSS} = 5303.76\, W$$

In the eight equation **(Eq. 8)**, when we put given values:

$$P_{LOSS\,\%} = \frac{5303.76}{6109440} \times 100$$

$$P_{LOSS\,\%} = 0.0868\%$$

Power Loss of 1500V-Centralized Inverter System Design

DC Cable Loss

Except length of the cables and installed power of the plant, all values are the same with centralized 1000V Inverter project for DC cable loss calculation

L is calculated 184386 meters for centralized 1500V inverter project

In the seventh equation **(Eq. 7)**, when we put given values:

$$P_{LOSS} = \frac{(9.39^2 \times 184386 \times 3.39)}{1000}$$

$$P_{LOSS} = 55113.61\, W$$

In the eight equation **(Eq. 8)**, when we put given values:

$$P_{LOSS\,\%} = \frac{55113.61}{6137560} \times 100$$

$$P_{LOSS\,\%} = 0.8980\%$$

Low Voltage AC Cable Loss

I is obtained from the ABB PVS-175-TL string inverter datasheet as 134 A [45].
L is calculated 993 meters for centralized 1500V inverter project
R is obtained from the NTK NA2X2Y 0,6/1 kV cable datasheet for $150mm^2$ as 0.206 Ω/km [64]

In the seventh equation **(Eq. 7)**, when we put the values given above:

$$P_{LOSS} = \frac{(134^2 \times 993 \times 0.206)}{1000}$$

$$P_{LOSS} = 3673.04\, W$$

In the eight equation **(Eq. 8)**, when we put the values given above:

$$P_{LOSS\,\%} = \frac{3673.04}{6137560} \times 100$$

$$P_{LOSS\,\%} = 0.0598\%$$

Medium Voltage AC Cable Loss

Except length of the cables and installed power of the plant, all values are the same with centralized 1000V Inverter project for Medium Voltage AC cable loss calculation

L is calculated 730 meters for centralized 1500V inverter project

In the seventh equation **(Eq. 7)**, when we put given values:

$$P_{LOSS} = \frac{(242.4871^2 \times 730 \times 0.164)}{1000}$$

$$P_{LOSS} = 7039.54\,W$$

In the eight equation **(Eq. 8)**, when we put given values:

$$P_{LOSS\,\%} = \frac{7039.54}{6137560} \times 100$$

$$P_{LOSS\,\%} = 0.1147\%$$

Power Loss of 1500V-Distributed Inverter System Design

Except length of the cables, all values are the same with centralized 1500V Inverter project

DC Cable Loss

L is calculated 52128 meters for distributed 1500V inverter project

In the seventh equation **(Eq. 7)**, when we put given values:

$$P_{LOSS} = \frac{(9.39^2 \times 52128 \times 3.39)}{1000}$$

$$P_{LOSS} = 15581.24\,W$$

In the eight equation **(Eq. 8)**, when we put given values:

$$P_{LOSS\,\%} = \frac{15581.24}{6137560} \times 100$$

$$P_{LOSS\,\%} = 0.2539\%$$

Low Voltage AC Cable Loss

L is calculated 21315 meters for distributed 1500V inverter project

In the seventh equation **(Eq. 7)**, when we put the given values:

$$P_{LOSS} = \frac{(134^2 \times 21315 \times 0.206)}{1000}$$

$$P_{LOSS} = 78842.82\ W$$

In the eight equation **(Eq. 8)**, when we put the given values:

$$P_{LOSS\,\%} = \frac{78842.82}{6137560} \times 100$$

$$P_{LOSS\,\%} = 1.2846\%$$

Medium Voltage AC Cable Loss

L is calculated 560 meters for distributed 1500V inverter project

In the seventh equation **(Eq. 7)**, when we put given values:

$$P_{LOSS} = \frac{(242.4871^2 \times 560 \times 0.164)}{1000}$$

$$P_{LOSS} = 5400.19\ W$$

In the eight equation **(Eq. 8)**, when we put given values:

$$P_{LOSS\,\%} = \frac{5400.19}{6137560} \times 100$$

$$P_{LOSS\,\%} = 0.0880\%$$

Overall 1000V-Centralized Inverter Solar Photovoltaic System Design Drawing

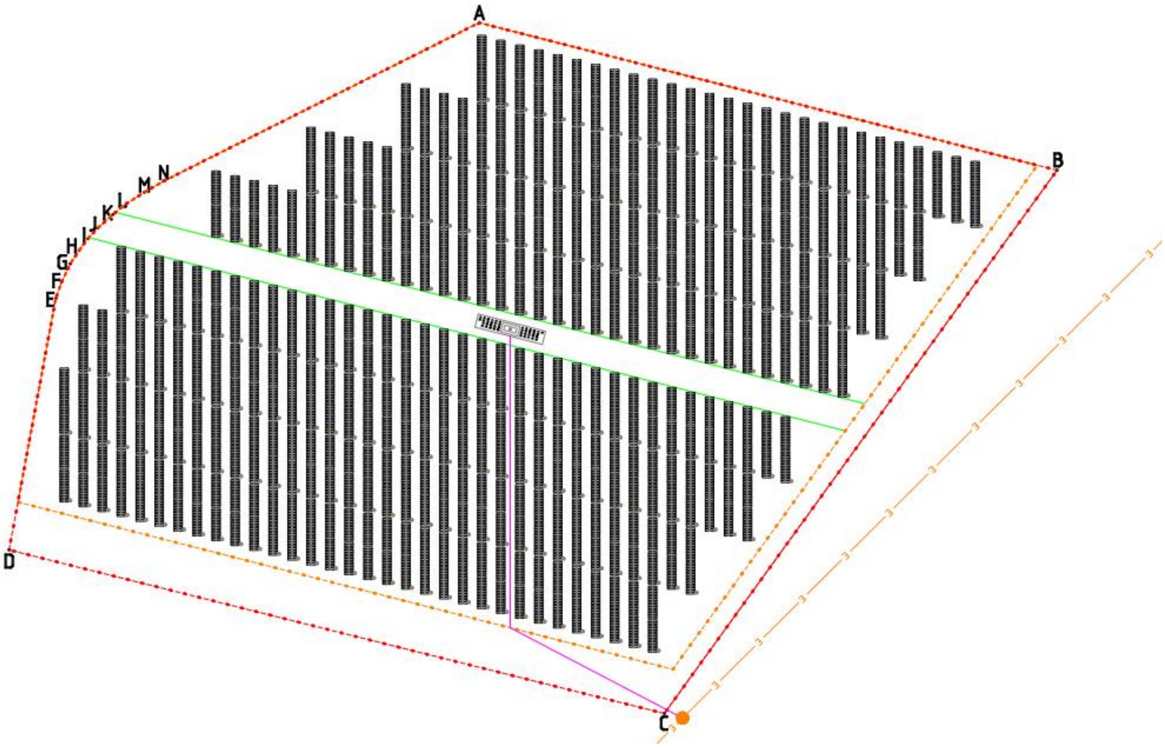


Figure 37. Overall 1000V-Centralized Inverter Solar Photovoltaic System Design Drawing

Overall 1000V-Distributed Inverter Solar Photovoltaic System Design Drawing

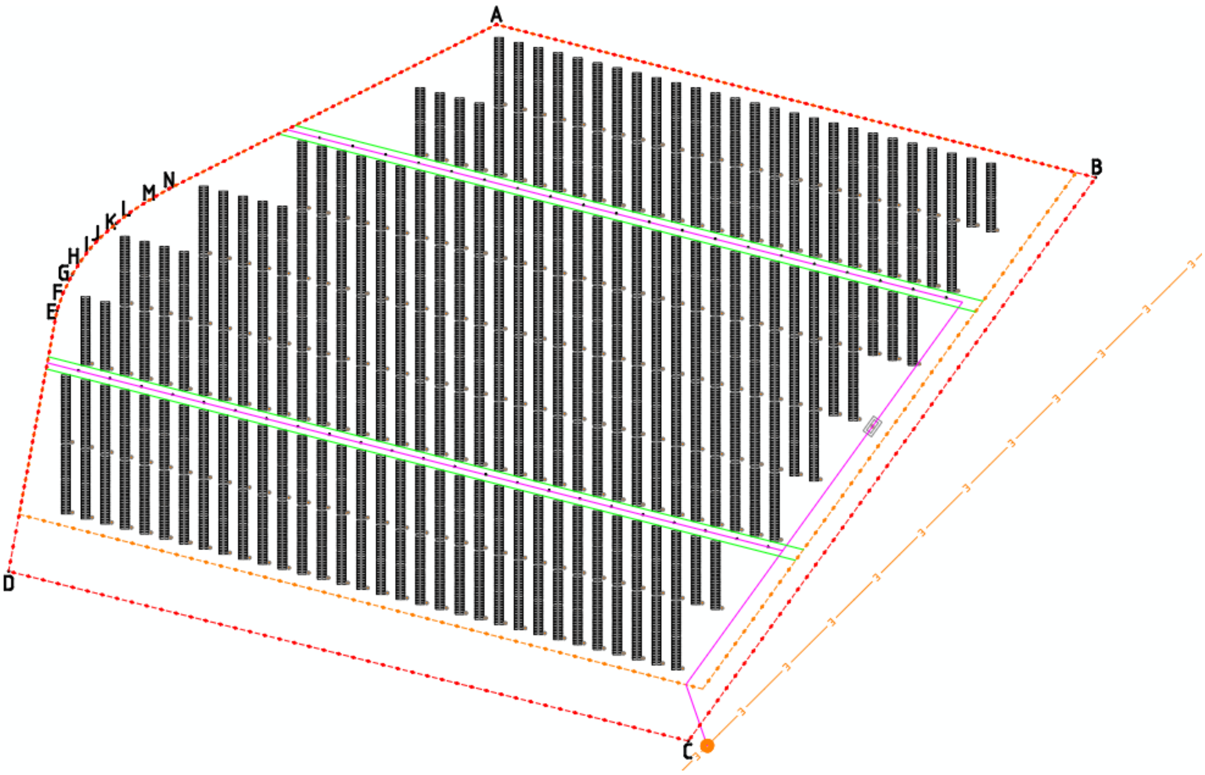


Figure 38. Overall 1000V-Distributed Inverter Solar Photovoltaic System Design Drawing

Overall 1500V-Centralized Inverter Solar Photovoltaic System Design Drawing

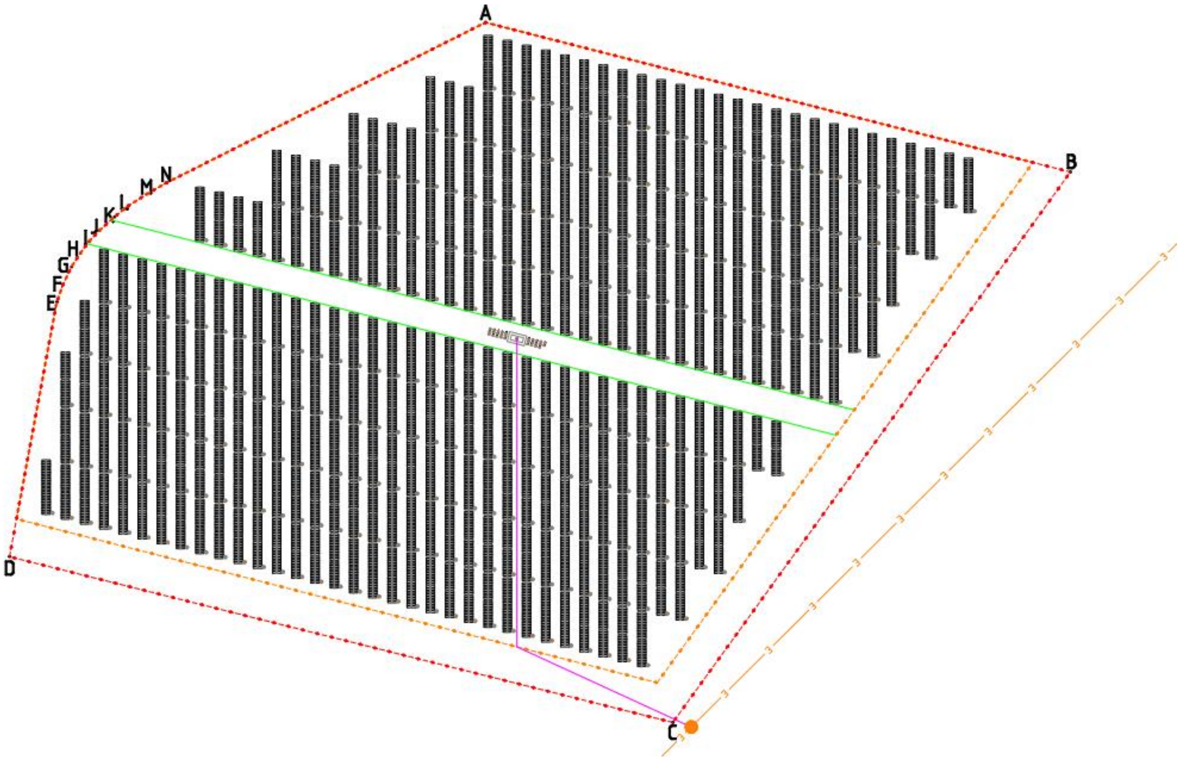


Figure 39. Overall 1500V-Centralized Inverter Solar Photovoltaic System Design Drawing

Overall 1500V-Distributed Inverter Solar Photovoltaic System Design Drawing

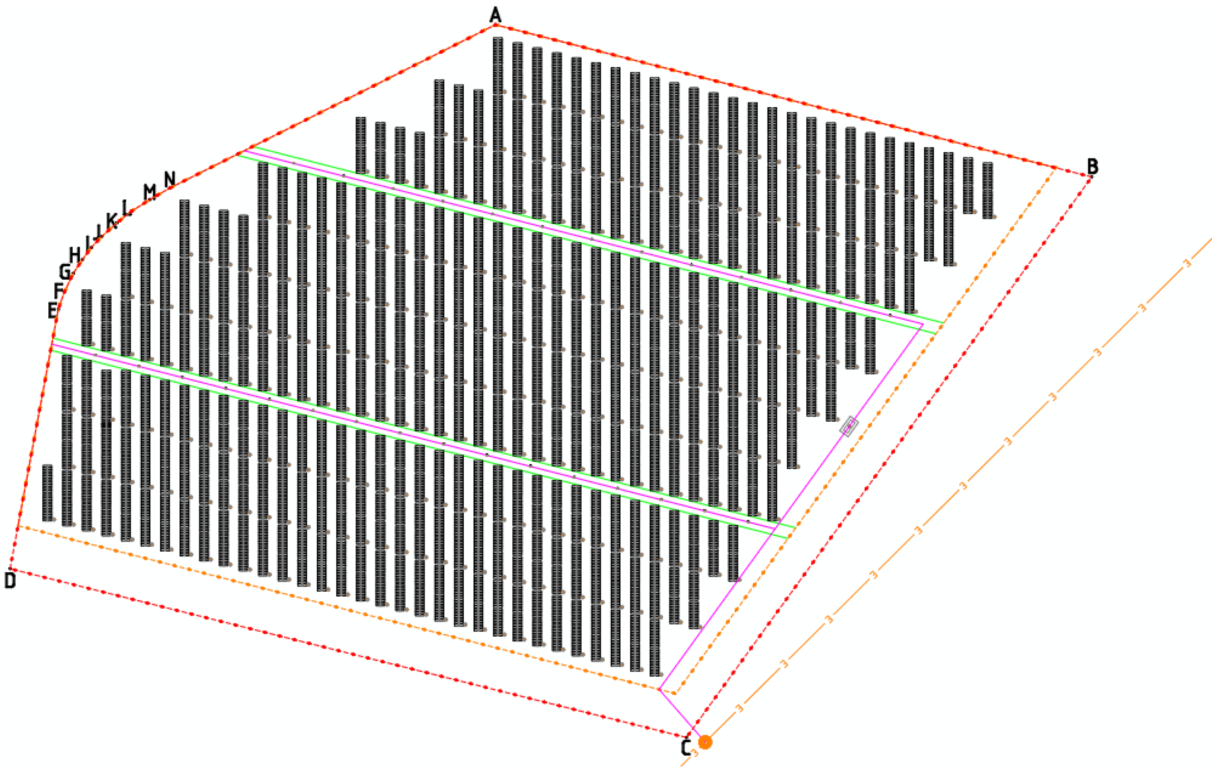


Figure 40. Overall 1500V-Distributed Inverter Solar Photovoltaic System Design Drawing

3. Analysis

3.1 Technical Analysis

Table 11. Power losses according to design status of the projects

Power Losses	1000V Centralized	1000V Distributed	1500V Centralized	1500V Distributed
DC	1.4545%	0.3697%	0.8980%	0.2539%
LV AC	0.0904%	1.8761%	0.0598%	1.2846%
MV AC	0.1151%	0.0868%	0.1147%	0.0880%

As shown in Table 11, the cable losses were obtained as 1.46% for DC and 0.21% for total AC in the project where 1000V string inverters are positioned as a group in the centre of the site area. The cable losses were obtained as 0.37% for DC and 1.96% for total AC in the project where 1000V string inverters are distributed on the line between trackers in the site area. When inverters are distributed, it is observed that the DC losses were decreased by 1.09%, but AC losses were increased by 1.75% according to the used amount of cables. When all the loss rates arising from the cable are examined, it is seen that the 0.66% more efficiency is obtained from centralized inverter design.

The cable losses were obtained as 0.90% for DC and 0.17% for total AC in the project where 1500V string inverters are positioned as a group in the centre of the site area. The cable losses were obtained as 0.25% for DC and 1.37% for total AC in the project where 1500V string inverters are distributed on the line between trackers in the site area. As in designs using 1000V inverters for 1500V, when inverters are distributed, it is observed that the DC losses were decreased by 0.65%, but AC losses were increased by 1.20% according to the used amount of cables. When all the loss rates arising from the cable are examined, it is seen that the 0.55% more efficiency is obtained from centralized inverter design.

In projects designed with 1000V and 1500V inverters, when we examine the centralized and distributed designs technically between them, in the 1000V centralized inverter design, the DC usage is increased by 112909 meters and total AC cable usage is increased by 607 meters when compared with 1500V. In the 1000V distributed inverter design, the DC usage is increased by 23435 meters and total AC cable usage is increased by 11916 meters when compared with 1500V.

As a result, using 1500V inverter in solar PV system designs decreased cable losses by 0.59% in centralized designs and it decreased cable losses by 0.70% in distributed design.

Solargis Report Results

Report for the project which has 6109.44 kWp installed power, located at 34° 50' 39.35" S, 71° 07' 28.36" W coordinates and designed with LONGI LR6-72PH 370 watt crystalline silicon (c-Si) PV module, ABB PVS-120-TL 1000V-centralized string inverter, Arctech Skysmart two portrait single-axis (N-S) 72-module solar tracker, Energia 6.3 kW transformer is given at Table 12.

Table 12. Solargis PV System report for 1000V centralized string inverter design [56]

Site Information	
Coordinates	34° 50' 39.35" S, 71° 07' 28.36" W
Elevation a.s.l.	296 m
PV System Information for 1000V Centralized String Inverter Desing	
Installed Power	6109.44 kWp
Type of Modules	crystalline silicon (c-Si)
Mounting System	1-axis tracking, horizontal NS
Inverter Euro Efficiency	98.6%
DC / AC Losses	1.5% / 0.2%
Transformer Efficiency	98.7%
Annual Average Electricity Production	12.77 GWh
Yealy Sum of Specific Electricity Production	2091 kWh/kWp

According to the information obtained from the Solargis platform report, the annual average electricity production of the design is 12.77 GWh, and the yearly sum of specific electricity production is 2091 kWh/kWp.

Report for the project which has 6109.44 kWp installed power, located at 34° 50' 39.35" S, 71° 07' 28.36" W coordinates and designed with LONGI LR6-72PH 370 watt crystalline silicon (c-Si) PV module, ABB PVS-120-TL 1000V-distributed string inverter, Arctech Skysmart two portrait single-axis (N-S) 72-module solar tracker, Energia 6.3 kW transformer is given at Table 13.

Table 13. Solargis PV System report for 1000V distributed string inverter design [56]

Site Information	
Coordinates	34° 50' 39.35" S, 71° 07' 28.36" W
Elevation a.s.l.	296 m
PV System Information for 1000V Distributed String Inverter Desing	
Installed Power	6109.44 kWp
Type of Modules	crystalline silicon (c-Si)
Mounting System	1-axis tracking, horizontal NS
Inverter Euro Efficiency	98.6%
DC / AC Losses	0.4% / 2.0%
Transformer Efficiency	98.7%
Annual Average Electricity Production	12.68 GWh
Yealy Sum of Specific Electricity Production	2076 kWh/kWp

According to the information obtained from the Solargis platform report, the annual average electricity production of the design is 12.68 GWh, and the yearly sum of specific electricity production is 2076 kWh/kWp.

Report for the project which has 6137.56 kWp installed power, located at 34° 50' 39.35" S, 71° 07' 28.36" W coordinates and designed with LONGI LR6-72PH 370 watt crystalline silicon (c-Si) PV module, ABB PVS-175-TL 1500V-centralized string inverter, Arctech Skysmart two portrait single-axis (N-S) 56-module solar tracker, Energia 6.3 kW transformer is given at Table 14.

Table 14. Solargis PV System report for 1500V centralized string inverter design [56]

Site Information	
Coordinates	34° 50' 39.35" S, 71° 07' 28.36" W
Elevation a.s.l.	296 m
PV System Information for 1500V Centralized String Inverter Desing	
Installed Power	6137.56 kWp
Type of Modules	crystalline silicon (c-Si)
Mounting System	1-axis tracking, horizontal NS
Inverter Euro Efficiency	98.40%
DC / AC Losses	0.9% / 0.2%
Transformer Efficiency	98.7%
Annual Average Electricity Production	12.89 GWh
Yealy Sum of Specific Electricity Production	2099 kWh/kWp

According to the information obtained from the Solargis platform report, the annual average electricity production of the design is 12.89 GWh, and the yearly sum of specific electricity production is 2099 kWh/kWp.

Report for the project which has 6137.56 kWp installed power, located at 34° 50' 39.35" S, 71° 07' 28.36" W coordinates and designed with LONGI LR6-72PH 370 watt crystalline silicon (c-Si) PV module, ABB PVS-175-TL 1500V-distributed string inverter, Arctech Skysmart two portrait single-axis (N-S) 56-module solar tracker, Energia 6.3 kW transformer is given at Table 15.

Table 15. Solargis PV System report for 1500V distributed string inverter design [56]

Site Information	
Coordinates	34° 50' 39.35" S, 71° 07' 28.36" W
Elevation a.s.l.	296 m
PV System Information for 1500V Distributed String Inverter Desing	
Installed Power	6137.56 kWp
Type of Modules	crystalline silicon (c-Si)
Mounting System	1-axis tracking, horizontal NS
Inverter Euro Efficiency	98.40%
DC / AC Losses	0.3% / 1.4%
Transformer Efficiency	98.7%
Annual Average Electricity Production	12.81 GWh
Yealy Sum of Specific Electricity Production	2087 kWh/kWp

According to the information obtained from the Solargis platform report, the annual average electricity production of the design is 12.81 GWh, and the yearly sum of specific electricity production is 2087 kWh/kWp.

Technically, it has been concluded that the yearly sum of the specific electricity productions of the projects designed with centralized-inverters are higher than the projects designed with distributed-inverters. 1500V-centralized design has the highest yearly sum of specific electricity production with 2099 kWh/kWp.

3.2 Economic Analysis

Economic result is obtained in €/kWh. Provided that the equipment used is the same amount and the same price, the economic result is not affected. Therefore, cost of inverters, cables, trackers, and PV modules are included in the economic calculation.

The unit price of the equipment used in the economic analysis are given below. Prices do not include taxes.

String Inverters

ABB PVS-175-TL-SX2:	8669 €/pcs [67]
ABB PVS-120-TL-SX2:	7579 €/pcs [68]

DC Cables

KBE $6mm^2$:	0.5 €/meter

LV AC Cables

NTK NA2X2Y 0,6/1 kV $150mm^2$:	1.3 €/meter
NTK NA2X2Y 0,6/1 kV $185mm^2$:	1.7 €/meter

MV AC Cables

NTK NA2S2Y 12/20 kV $185mm^2$:	6.8 €/meter

- DC cable price is obtained from ATL Ltd Sti.[2]
- AC cable prices are obtained from NTK A/S

Trackers

Arctech Skysmart two portrait single axis: 0.125 $/Wp

- Tracker price is obtained from Arctech Solar Co. Ltd

PV Modules

LONGI LR6-72PH 370 watt: 224 $/pcs [69]

[2] ATL Aydinlatma San. ve Tic Ltd. Sti. (Antalya/Turkey)

EUR/USD parity is calculated according to the average of the daily ratio of the dates between 01.May.2015 to 01.May.2020 as 1.1284 [70]

Table 16. Amount of used equipment and cost for 1000V-Centralized design

Used Main Equipment & Cost for 1000V-Centralized Desing			
Equipment	**Amount**	**price/pcs**	**Cost**
ABB PVS-120-TL-SX2 string inverter (pcs)	43	7,579.00 €	325,897.00 €
KBE 6mm^2 DC cable (m)	297296	0.50 €	148,648.00 €
NTK NA2X2Y 0,6/1 kV 185mm^2 LV AC cable (m)	1601	1.70 €	2,721.70 €
NTK NA2S2Y 12/20 kV 185mm^2 MV AC cable (m)	729	6.80 €	4,957.20 €
LONGI LR6-72PH solar photovoltaic module (pcs)	16512	198.51 €	3,277,797.12 €
Arctech Skysmart 64-module two portrait solar tracker (pcs)	258	2,623.18 €	676,780.44 €

The total cost of based four parts; inverter, cable, PV module and tracker is obtained as 4,436,801.46 € for 12.77 GWh annual average electricity production with 1000V-Centralized design.

Table 17. Amount of used equipment and cost for 1000V-Distributed design

Used Main Equipment & Cost for 1000V-Distributed Desing			
Equipment	**Amount**	**price/pcs**	**Total Cost**
ABB PVS-120-TL-SX2 string inverter (pcs)	43	7,579.00 €	325,897.00 €
KBE 6mm^2 DC cable (m)	75562	0.50 €	37,781.00 €
NTK NA2X2Y 0,6/1 kV 185mm^2 LV AC cable (m)	33242	1.70 €	56,511.40 €
NTK NA2S2Y 12/20 kV 185mm^2 MV AC cable (m)	550	6.80 €	3,740.00 €
LONGI LR6-72PH solar photovoltaic module (pcs)	16512	198.51 €	3,277,797.12 €
Arctech Skysmart 64-module two portrait solar tracker (pcs)	258	2,623.18 €	676,780.44 €

The total cost of based four parts; inverter, cable, PV module and tracker is obtained as 4,378,506.96 € for 12.68 GWh annual average electricity production with 1000V-Distributed design.

Table 18. Amount of used equipment and cost for 1500V-Centralized design

Used Main Equipment & Cost for 1500V-Centralized Desing			
Equipment	**Amount**	**price/pcs**	**Total Cost**
ABB PVS-175-TL-SX2 string inverter (pcs)	29	8,669.00 €	251,401.00 €
KBE 6mm^2 DC cable (m)	184386	0.50 €	92,193.00 €
NTK NA2X2Y 0,6/1 kV 150mm^2 LV AC cable (m)	993	1.30 €	1,290.90 €
NTK NA2S2Y 12/20 kV 185mm^2 MV AC cable (m)	730	6.80 €	4,964.00 €
LONGI LR6-72PH solar photovoltaic module (pcs)	16588	198.51 €	3,292,883.88 €
Arctech Skysmart 52-module two portrait solar tracker (pcs)	319	2,131.34 €	679,897.46 €

The total cost of based four parts; inverter, cable, PV module and tracker is obtained as 4,322,630.24 € for 12.89 GWh annual average electricity production with 1500V-Centralized design.

Table 19. Amount of used equipment and cost for 1500V-Distributed design

Used Main Equipment & Cost for 1500V-Distributed Desing			
Equipment	**Amount**	**price/pcs**	**Total Cost**
ABB PVS-175-TL-SX2 string inverter (pcs)	29	8,669.00 €	251,401.00 €
KBE 6mm^2 DC cable (m)	52128	0.50 €	26,064.00 €
NTK NA2X2Y 0,6/1 kV 150mm^2 LV AC cable (m)	21315	1.30 €	27,709.50 €
NTK NA2S2Y 12/20 kV 185mm^2 MV AC cable (m)	560	6.80 €	3,808.00 €
LONGI LR6-72PH solar photovoltaic module (pcs)	16588	198.51 €	3,292,883.88 €
Arctech Skysmart 52-module two portrait solar tracker (pcs)	319	2,131.34 €	679,897.46 €

The total cost of based four parts; inverter, cable, PV module and tracker is obtained as 4,281,763.84 € for 12.81 GWh annual average electricity production with 1500V-Distributed design.

In the renewable power generation cost 2017 report published by IRENA in 2018, the weight of PV modules, trackers, inverters, and cables in the investment cost is defined as 48.75% in utility-scale solar PV plant cost analysis established in Chile. Grid connection cost in total share is 5.11%, monitoring and control cost in total share is 1.57%, safety and security in total share is 1.59%, electrical installation cost in total share is 4.63%, inspection cost in total share is 0.63%, mechanical installation cost in total share is 12.38%, customer acquisition cost in total share is 1.81%, financing cost in total share is 4.46% , incentive application in total share is 0.89%, margin cost in total share is 9.91%, permitting cost in total share is 2.79% and system design cost in total share is 5.50% [71]. These ratios are taken to calculate total investment cost of the project.

The solar PV plants investment costs for 1 MWp installed power in each project are obtained as below according to ratios on above.

- 1000V Inverter Centralized Design: 1.489.683,38 €/MWp
- 1000V Inverter Distributed Design: 1.470.110,64 €/MWp
- 1500V Inverter Centralized Design: 1.444.700,15 €/MWp
- 1500V Inverter Distributed Design: 1.431.041,87 €/MWp

4. Optimal Solution

4.1 Effect of the Based Equipment on Investment Cost

Different costs were obtained for different annual average electricity production. Expenses other than Inverters, PV modules, trackers and cables are considered as same and are not included in this calculation.

For the quick comparison the below method is followed in order to compare these designs with each other according to effects of based equipment on the production.

$$\frac{Total\ based\ equipment\ cost\ (€)}{Annual\ average\ electricity\ production\ (kWh)}$$

The result is obtained €/kWh which describes cost of used based equipment (PV module, tracker, inverter, cable) to obtain 1-kWh energy output in one year.

For 1000V-Centralized design

Total based equipment cost is obtained as 4,436,801.46 €
The average annual electricity production is obtained: 12,770,000 kWh

$$\frac{4{,}436{,}801.46\ €}{12{,}770{,}000\ \text{kWh}} = 0.3474\ €/\text{kWh}$$

For 1000V-Distributed design

Total based equipment cost is obtained as 4,378,506.96 €
The average annual electricity production is obtained: 12,680,000 kWh

$$\frac{4{,}378{,}506.96\ €}{12{,}680{,}000\ \text{kWh}} = 0.3453\ €/\text{kWh}$$

For 1500V-Centralized design

Total based equipment cost is obtained as 4,436,801.46 €
The average annual electricity production is obtained: 12,890,000 kWh

$$\frac{4{,}436{,}801.46\ €}{12{,}890{,}000\ \text{kWh}} = 0.3353\ €/\text{kWh}$$

For 1500V-Distributed design

Total based equipment cost is obtained as 4,281,763.84 €
The average annual electricity production is obtained: 12,810,000 kWh

$$\frac{4{,}281{,}763.84\ €}{12{,}810{,}000\ \text{kWh}} = 0.3343\ €/\text{kWh}$$

According to €/kWh price, obtained above with the total based equipment costs divided by average annual electricity production, we see that the project designed with a 1500V string inverter, has the lowest €/kWh cost.

When we compare the centralized and distributed systems in general, it is observed that, although the energy losses of the distributed systems are high compared to the centralized systems, the unit cost of the produced electricity decreases compared to the based solar PV systems equipment used.

The input voltage of 1000V inverters is 33% lower than that of 1500V inverters, reducing the maximum number of PV modules that can be connected in series to an inverter by approximately 64%. This causes the amount of DC cable used in the 1000V centralized design to be 62% higher than the amount of DC cable used in the 1500V centralized design.

In the distributed systems, even if the amount of total cable usage is reduced when compared with centralized systems, the cable used in the distributed project designed with a 1000V inverter is 69% higher for the DC and 65% higher for the total AC than the cable used in the project designed with a 1500V inverter.

When we compare all designs with each other, the best results are obtained from the 1500V-distributed system, 2nd 1500V-centralized system, 3rd 1000V-distributed system, and the finally 1000V-centralized system design.

4.2 Net Present Value – Minimum Price

In this method, the cash flows of the project to be invested are valued according to the time value of money. When calculating the time value of money, the rate of return expected by the enterprise is taken into consideration. Investment spending will yield a net result because it requires cash outflows, and earnings will be positive. If the net result is negative, the investment project cannot be made and if it gives a non-negative result, it will result in the feasible decision. Also, the selling price which makes NPV=0 is called minimum selling price. [82]

The net present value is calculated by the formula:

$$NPV = \sum_{t=0}^{T} \left(\frac{CF_t}{(1+r)^t} \right) = \sum_{t=1}^{T} \left(\frac{CF_t}{(1+r)^t} \right) - Investment$$

(Eq. 8) [83]

where,

NPV: Net present value. (Today´s value of the expected cash flows)
T: Lifetime of the project
t: Number of time periods
CF_t: Net cash inflow-outflows during a single period t
r: discount rate

For the NPV calculation obtained data is given below:

- Inflation rate is considered as 2.79% from the average inflation between 2009-2019 in Chile [72].
- Annual land rent price is considered as 2.54 $€/m^2$ from the 5% of the average land price in Santiago, Chile [74]. UF/€ parity is obtained as 36.20 from the average parity between May.15 – May.20 to obtain land rent price in $€/m^2$ [75].
- Maintenance and operation cost are considered 0.028€/kWh [80]

According to the above information, maintenance-operation cost and rent price are considered to increase by 2.79% every year, compared to the previous year.

- Lifetime of the solar PV plant is considered 25 years according to 25-year power warranty annual power attenuation -0.55% of the PV modules [48, 76].

According to the above information, it is considered that the annual electricity production is decreased by 0.55% every year, compared to the previous year.

- Electricity inflation rate is considered as 8.00% from the average market price of electricity inflation in Chile between Jan.18 and Jan.20 [73].

According to the above information, it is considered that the electricity selling price is increased by 8.00% every year, compared to the previous year.

- Annual depreciation is considered as investment costs divided by lifetime of the solar PV power plant and assumed is to be same for each year.
- Discount rate is considered as 6.00% according to profitability and discount rates research for solar PV Plants and it is assumed to be the same for each year [76].
- Sales tax considered as 19% for Chile [81].

Table 20. Cash flow calculation from investor point of view

Cash Flow			
	Symbol	**year (0)**	**year (1)**
Investment	I	I	
Revenue	R		R
M&O Cost	MO		MO
Rent Price	RP		RP
Depretiation	D		D
Tax	T		Tax Rate × (R-MO-RP-D)
CF		-I	R-MO-RP-T

The 8th equation **(Eq. 8)** has been created with the information above. As mentioned earlier, the selling price value that makes NPV=0 is defined as the minimum selling price. The obtained minimum selling prices after the calculation are given below:

- 1000V Inverter Centralized Design: 58.1891 €/MWh
- 1000V Inverter Distributed Design: 58.1102 €/MWh
- 1500V Inverter Centralized Design: 57.0755 €/MWh
- 1500V Inverter Distributed Design: 57.0690 €/MWh

4.3 Sensitivity Analysis

Sensitivity analysis is determined how different values of an independent variables affect a dependent variable under a given set of assumptions [84]. In this section, the effects of discount rate and electricity inflation rate, that is, the change of income, on the minimum selling price are examined. The minimum selling price of electricity is related to different discount rate and electricity inflation rate. The following tables show that when the discount rate increases, the minimum selling price increases. However, when the electricity inflation rate increases, the minimum price is decreased. As electricity inflation rate, discount rate and other variable values increase our income with the condition of being constant, production cost decreases and therefore minimum electricity price decreases for all cases.

Table 21. Minimum selling price sensitivity analysis 1000V-Centralized design

	€/MWh	ELECTRICITY INFLATION RATE				
		7.0%	7.5%	8.0%	8.5%	9.0%
DISCOUNT RATE	4.00%	56.2419	52.9938	49.8928	46.9388	44.1230
	5.00%	60.4763	57.0999	53.8719	50.7868	47.8424
	6.00%	65.0588	61.5513	58.1891	54.9676	51.8883
	7.00%	70.0110	66.3554	62.8490	59.4914	56.2672
	8.00%	75.3365	71.5236	67.8689	64.3592	60.9897

Table 22. Minimum selling price sensitivity analysis 1000V-Distributed design

	€/MWh	ELECTRICITY INFLATION RATE				
		7.0%	7.5%	8.0%	8.5%	9.0%
DISCOUNT RATE	4.00%	56.1972	52.9517	49.8535	46.9018	44.0883
	5.00%	60.4104	57.0382	53.8137	50.7324	47.7911
	6.00%	64.9698	61.4671	58.1102	54.8931	51.8185
	7.00%	69.8956	66.2470	62.7464	59.3951	56.1769
	8.00%	75.1915	71.3873	67.7408	64.2387	60.8756

Table 23. Minimum selling price sensitivity analysis 1500V-Centralized design

<table>
<tr><th rowspan="7">DISCOUNT RATE</th><th rowspan="2">€/MWh</th><th colspan="5">ELECTRICITY INFLATION RATE</th></tr>
<tr><th>7.0%</th><th>7.5%</th><th>8.0%</th><th>8.5%</th><th>9.0%</th></tr>
<tr><td>4.00%</td><td>55.2678</td><td>52.0760</td><td>49.0299</td><td>46.1270</td><td>43.3599</td></tr>
<tr><td>5.00%</td><td>59.3709</td><td>56.0580</td><td>52.8889</td><td>49.8617</td><td>46.9709</td></tr>
<tr><td>6.00%</td><td>63.8111</td><td>60.3709</td><td>57.0755</td><td>53.9156</td><td>50.8972</td></tr>
<tr><td>7.00%</td><td>68.6044</td><td>65.0256</td><td>61.5910</td><td>58.3020</td><td>55.1448</td></tr>
<tr><td>8.00%</td><td>73.7551</td><td>70.0268</td><td>66.4526</td><td>63.0197</td><td>59.7204</td></tr>
</table>

Table 24. Minimum selling price sensitivity analysis 1500V-Distributed design

<table>
<tr><th rowspan="7">DISCOUNT RATE</th><th rowspan="2">€/MWh</th><th colspan="5">ELECTRICITY INFLATION RATE</th></tr>
<tr><th>7.0%</th><th>7.5%</th><th>8.0%</th><th>8.5%</th><th>9.0%</th></tr>
<tr><td>4.00%</td><td>55.2817</td><td>52.0891</td><td>49.0425</td><td>46.1388</td><td>43.3710</td></tr>
<tr><td>5.00%</td><td>59.3744</td><td>56.0617</td><td>52.8924</td><td>49.8653</td><td>46.9743</td></tr>
<tr><td>6.00%</td><td>63.8033</td><td>60.3636</td><td>57.0690</td><td>53.9095</td><td>50.8918</td></tr>
<tr><td>7.00%</td><td>68.5836</td><td>65.0064</td><td>61.5735</td><td>58.2853</td><td>55.1295</td></tr>
<tr><td>8.00%</td><td>73.7194</td><td>69.9937</td><td>66.4220</td><td>62.9914</td><td>59.6935</td></tr>
</table>

Conclusion

By considering remarkable increase of the world population, the needs of people increase rapidly. Especially since the 2000s, the leap in development of the technology has become significant. For this reason, the demand of energy is gradually increasing.

Globalizing of the World´ brings along economic crises. In recent years, the policies that countries have implemented to sustain their independence are primarily on energy independence and sustainability. It is obvious that fossil fuels are consumed and depleted very quickly. This brings renewable energy to the fore.

Especially on the Asian continent, significant investments have been made on solar energy in recent years. This enabled more diverse and cost-effective equipment to enter the market in the solar energy industry. With the increase in diversity, solar power plant designs gain importance.

The grid-connected solar power systems consist of five based equipment. First one is cells that convert solar irradiation into electrical energy. The second is solar tracking systems which modules are connected to increase efficiency. The third one is cables used to transmit the produced electricity from the solar power plant to the end-user. Fourth is inverters which convert DC power generated in the panels into AC power, and the last one is step-up transformers to increase AC voltage to reduce losses in transmission.

During the design stage, there are many points to be considered, such as security, cost, and efficiency. The area where the solar power plant will be installed is one of the most affected factors to the amount generated electricity. The production cost decreases in the regions that receive the sunlight more intensely and at right angles. Therefore, the area where the solar power plant was planned to build is in 34° 50' 39.35" S, 71° 07' 28.36" W coordinates within the agricultural land region of Chile near Santiago city. Also, slope of the terrain is an essential factor for the installation of any types of equipment.

Tracking systems, cables, transformers, and inverters are among the essential equipment in which electricity losses are most common. Increasing efficiency and ensuring the proper functioning of the system can be feasible by combining the most suitable equipment. Because of that reason, the main purpose of this dissertation was to show which steps need to be followed and what to consider in these steps when designing a utility-scale solar power system. Evaluate technical, economic reflections of the design changes were made in inverter and cabling which effects the efficiency of the system directly hence the production and selling cost. In the designs, feasibility and optimization studies were carried out in order to combine mentioned five based equipment under the most favourable conditions.

After specifying the site area, Global mapper program was used to convert KMZ files created in Google Earth to make proper format DWG to use in ProgeCad drawing program. Then, solar modules, which constitutes approximately one-third of the investment cost, were selected. According to the international renewable energy agency research, although the solar module costs decreased by 83% between 2010 and 2017, share of solar modules on on-grid solar photovoltaic systems investment is between 30% and 33%. Therefore, lifetime of the solar modules is affected in system lifetime directly. After the solar module selection inverters were selected with varying values of voltage produced by the same brand have been preferred to avoid brand differences. Also, it is not possible to reach the parameters of standard test conditions in real life and there is undoubtedly an energy loss in the equipment used. For these reasons, the overloading ratio to be loaded into the inverter was calculated. According to the data of the solar modules and inverters used in the project, minimum and maximum string size calculation have been made to find the minimum number of photovoltaic modules connected in series that are required for the inverter to operate during the hottest summer periods, and to find the maximum number of photovoltaic modules connected in series during the coldest period of the inverter to avoid any damages. After these values were calculated, trackers have been designed with the appropriate number of modules. Then, the distance was calculated between the fence and trackers on the interior to provide access to every part of the site area. In order to use the site area in the most efficient way and to avoid the shadow effect, the optimal distance between the trackers has been calculated with optimally incline angle which was obtained from the Solargis platform to the site area where the plant will be installed. Four utility-scale solar power systems were designed with a 6MWp installed power to be 1000V-centralized, 1000V-distributed, 1500V-centralized and 1500V-distributed using ProgeCad drawing program. Cables have been selected to be used in electricity transmission, in accordance with the equipment used in the system. Carrying capacity calculation has been made to find a suitably sized cable for different systems. The amount of usage of DC, LV AC and MV AC cables were calculated by ProjeCad drawing program. In the last part of the design chapter, cable losses were calculated.

After following the steps mentioned above, the cable losses were obtained as 1.46% for DC and 0.21% for total AC in the project where 1000V string inverters are positioned as a group in the centre of the site area. The cable losses were obtained as 0.37% for DC and 1.96% for total AC in the project where 1000V string inverters are distributed on the line between trackers in the site area. When inverters are distributed, it is observed that the DC losses were decreased by 1.09%, but AC losses were increased by 1.75% according to the used amount of cables. By considering the losses in the inverter and substation, the yearly sum of electricity production increased by 0.72% compared to the 1000V-distributed design of the 1000V-centralized design.

The cable losses were obtained as 0.90% for DC and 0.17% for total AC in the project where 1500V string inverters are positioned as a group in the centre of the site area. The cable losses were obtained as 0.25% for DC and 1.37% for total AC in the project where 1500V string inverters are distributed on the line between trackers in the site area. When inverters are distributed, it is observed that the DC losses were decreased by 0.65%, but AC losses were increased by 1.20% according to the used amount of cables. To take account of the losses in the inverter and substation, the yearly sum of electricity production increased by 0.57% compared to the 1500V-distributed design of the 1500V-centralized design.

When distributed systems are compared among themselves, it was observed that 1500V inverter contributes 0.38% to yearly sum of electricity production. This contribution was obtained as 0.53% in the centralized design.

Economic analysis was completed by net present value analysis. While doing this analysis, Inflation rate was considered as 2.79%, annual land rent price was considered as $2.54\ €/m^2$, maintenance and operation cost were considered 0.028€/kWh and maintenance-operation cost, rent price were considered to increase by 2.79% every year, compared to the previous year. Lifetime of the solar PV plants were considered 25 years. it was considered that the annual electricity production was decreased by 0.55% every year, compared to the previous year. Electricity inflation rate was noted as 8.00% and it was considered that the electricity selling price is increased by 8.00% every year, compared to the previous year. The annual depreciation was accepted as investment costs divided by lifetime of the solar PV power plant and assumed to be same for each year. The discount rate was considered as 6.00% and sales tax considered as 19% for Chile. These assumptions were accepted the same for all designs. According to calculation minimum sales prices were obtained as 58.1891 €/MWh for 1000V-Inverter centralized design, 58.1102 €/MWh for 1000V-Inverter distributed design, 57.0755 €/MWh for 1500V-Inverter centralized design and 57.0690 €/MWh for 1500V-Inverter distributed design.

In the obtained result, distributed systems decreased minimum selling price as 0.01% compared to centralized systems. According to the solar system designed with 1000V, the solar system designed with 1500V inverter has been observed to have a minimum selling price of nearly 2% decreased. It was concluded that the most suitable design was the solar PV system designed with distributed a 1500V inverter. Also, sensitivity analyses were made to see effects of discount rate and electricity inflation rate on the minimum selling price for four designs.

This study can be supported by performing maintenance and operation cost analysis particularly. Different results can be obtained in the future, as equipment prices regulations. The structure of the land is one of the most significant factors affecting the design. Consequently, the results can also vary in different lands.

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Appendices

Appendix 1. LV AC cable usage detail of 1000V-Inverter Centralized Solar System

INVERTER NUMBER	AC CABLE BETWEEN INVERTER & SUBSTATION (m)
1	17.5995
2	15.6135
3	13.6275
4	11.6415
5	9.6555
6	7.6695
7	7.6695
8	9.6555
9	11.6415
10	13.6275
11	15.6135
12	17.5995
13	16.2805
14	14.2945
15	12.3085
16	10.3225
17	8.3365
18	6.3505
19	6.3505
20	8.3365
21	10.3225
22	12.3085
23	14.2945
24	14.2945
25	12.3085
26	10.3225
27	8.3365
28	6.3505
29	6.3505
30	8.3365
31	10.3225
32	12.3085
33	14.2945
34	15.6135
35	13.6275
36	11.6415
37	9.6555
38	7.6695
39	7.6695
40	9.6555
41	11.6415
42	13.6275
43	15.6135

Appendix 2. DC cable usage detail of 1000V-Inverter Centralized Solar System

TRACKER NUMBER	STRING NUMBER	DC CABLE BETWEEN STRING & INVERTER (m)	INVERTER NUMBER	STRING NUMBER
87	1	139.8310	1	1
	2	143.9030		2
	3	156.2570		3
	4	160.3290		4
88	1	130.2233		5
	2	134.2953		6
	3	146.6493		7
	4	150.7213		8
89	1	120.6156		9
	2	124.6876		10
	3	137.0416		11
	4	141.1136		12
90	1	111.0079		13
	2	115.0799		14
	3	127.4339		15
	4	131.5059		16
91	1	101.4002		17
	2	105.4722		18
	3	117.8262		19
	4	121.8982		20
92	1	91.7925		21
	2	95.8645		22
	3	108.2185		23
	4	112.2905		24
56	1	127.0505	2	1
	2	131.1225		2
	3	143.4765		3
	4	147.5485		4
93	1	84.1708		5
	2	88.2428		6
	3	100.5968		7
	4	104.6688		8
57	1	117.4428		9
	2	121.5148		10
	3	133.8688		11
	4	137.9408		12
94	1	74.5631		13
	2	78.6351		14
	3	90.9891		15
	4	95.0611		16
58	1	107.8351		17
	2	111.9071		18
	3	124.2611		19
	4	128.3331		20
95	1	64.9554		21
	2	69.0274		22
	3	81.3814		23
	4	85.4534		24
59	1	100.2134	3	1
	2	104.2854		2
	3	116.6394		3
	4	120.7114		4
96	1	57.3337		5
	2	61.4057		6
	3	73.7597		7
	4	77.8317		8
60	1	90.6057		9
	2	94.6777		10
	3	107.0317		11
	4	111.1037		12
97	1	47.7260		13
	2	51.7980		14
	3	64.1520		15
	4	68.2240		16
61	1	80.9980		17
	2	85.0700		18
	3	97.4240		19
	4	101.4960		20
28	1	114.2700		21
	2	118.3420		22
	3	130.6960		23
	4	134.7680		24
98	1	40.1043	4	1
	2	44.1763		2
	3	56.5303		3
	4	60.6023		4
62	1	73.3763		5
	2	77.4483		6
	3	89.8023		7
	4	93.8743		8
29	1	106.6483		9
	2	110.7203		10
	3	123.0743		11
	4	127.1463		12
99	1	30.4966		13
	2	34.5686		14
	3	46.9226		15
	4	50.9946		16
63	1	63.7686		17
	2	67.8406		18
	3	80.1946		19
	4	84.2666		20
30	1	97.0406		21
	2	101.1126		22
	3	113.4666		23
	4	117.5386		24
100	1	22.8749	5	1
	2	26.9469		2
	3	39.3009		3
	4	43.3729		4
64	1	56.1469		5
	2	60.2189		6
	3	72.5729		7
	4	76.6449		8
31	1	89.4189		9
	2	93.4909		10
	3	105.8449		11
	4	109.9169		12
101	1	13.2672		13
	2	17.3392		14
	3	29.6932		15
	4	33.7652		16
65	1	46.5392		17
	2	50.6112		18
	3	62.9652		19
	4	67.0372		20
32	1	79.8112		21
	2	83.8832		22
	3	96.2372		23
	4	100.3092		24
1	1	115.0692	6	1
	2	119.1412		2
	3	131.4952		3
	4	135.5672		4
102	1	7.7272		5
	2	11.7992		6
	3	24.1532		7
	4	28.2252		8
66	1	40.9992		9
	2	45.0712		10
	3	57.4252		11
	4	61.4972		12
33	1	74.2712		13
	2	78.3432		14
	3	90.6972		15
	4	94.7692		16
2	1	107.5432		17
	2	111.6152		18
	3	123.9692		19
	4	128.0412		20
103	1	16.1640		21
	2	12.0920		22
	3	32.5900		23
	4	28.5180		24

67	1	40.6920	7	1
	2	44.7640		2
	3	57.1180		3
	4	61.1900		4
34	1	73.9640		5
	2	78.0360		6
	3	90.3900		7
	4	94.4620		8
3	1	107.2360		9
	2	111.3080		10
	3	123.6620		11
	4	127.7340		12
104	1	14.3896		13
	2	10.3176		14
	3	30.8156		15
	4	26.7436		16
68	1	47.6616		17
	2	43.5896		18
	3	64.0876		19
	4	60.0156		20
35	1	80.9336		21
	2	76.8616		22
	3	97.3596		23
	4	93.2876		24
4	1	112.2196	8	1
	2	108.1476		2
	3	128.6456		3
	4	124.5736		4
105	1	22.0113		5
	2	17.9393		6
	3	38.4373		7
	4	34.3653		8
69	1	55.2833		9
	2	51.2113		10
	3	71.7093		11
	4	67.6373		12
36	1	88.5553		13
	2	84.4833		14
	3	104.9813		15
	4	100.9093		16
5	1	121.8273		17
	2	117.7553		18
	3	138.2533		19
	4	134.1813		20
106	1	31.6190		21
	2	27.5470		22
	3	48.0450		23
	4	43.9730		24
70	1	62.9050	9	1
	2	58.8330		2
	3	79.3310		3
	4	75.2590		4
37	1	96.1770		5
	2	92.1050		6
	3	112.6030		7
	4	108.5310		8
6	1	129.4490		9
	2	125.3770		10
	3	145.8750		11
	4	141.8030		12
107	1	39.2407		13
	2	35.1687		14
	3	55.6667		15
	4	51.5947		16
71	1	72.5127		17
	2	68.4407		18
	3	88.9387		19
	4	84.8667		20
38	1	105.7847		21
	2	101.7127		22
	3	122.2107		23
	4	118.1387		24

7	1	137.0707	10	1
	2	132.9987		2
	3	153.4967		3
	4	149.4247		4
108	1	46.8624		5
	2	42.7904		6
	3	63.2884		7
	4	59.2164		8
72	1	80.1344		9
	2	76.0624		10
	3	96.5604		11
	4	92.4884		12
39	1	113.4064		13
	2	109.3344		14
	3	129.8324		15
	4	125.7604		16
8	1	146.6784		17
	2	142.6064		18
	3	163.1044		19
	4	159.0324		20
109	1	56.4701		21
	2	52.3981		22
	3	72.8961		23
	4	68.8241		24
73	1	87.7561	11	1
	2	83.6841		2
	3	104.1821		3
	4	100.1101		4
40	1	121.0281		5
	2	116.9561		6
	3	137.4541		7
	4	133.3821		8
9	1	154.3001		9
	2	150.2281		10
	3	170.7261		11
	4	166.6541		12
110	1	64.0918		13
	2	60.0198		14
	3	80.5178		15
	4	76.4458		16
74	1	97.3638		17
	2	93.2918		18
	3	113.7898		19
	4	109.7178		20
41	1	130.6358		21
	2	126.5638		22
	3	147.0618		23
	4	142.9898		24
10	1	161.9218	12	1
	2	157.8498		2
	3	178.3478		3
	4	174.2758		4
111	1	71.7135		5
	2	67.6415		6
	3	88.1395		7
	4	84.0675		8
75	1	104.9855		9
	2	100.9135		10
	3	121.4115		11
	4	117.3395		12
42	1	138.2575		13
	2	134.1855		14
	3	154.6835		15
	4	150.6115		16
11	1	171.5295		17
	2	167.4575		18
	3	187.9555		19
	4	183.8835		20
112	1	81.3212		21
	2	77.2492		22
	3	97.7472		23
	4	93.6752		24

76	1	125.8422	19	1
	2	121.7702		2
	3	142.2682		3
	4	138.1962		4
43	1	159.1142		5
	2	155.0422		6
	3	175.5402		7
	4	171.4682		8
12	1	192.3862		9
	2	188.3142		10
	3	208.8122		11
	4	204.7402		12
113	1	102.1779		13
	2	98.1059		14
	3	118.6039		15
	4	114.5319		16
77	1	135.4499		17
	2	131.3779		18
	3	151.8759		19
	4	147.8039		20
44	1	168.7219		21
	2	164.6499		22
	3	185.1479		23
	4	181.0759		24
13	1	200.0079	20	1
	2	195.9359		2
	3	216.4339		3
	4	212.3619		4
114	1	109.7996		5
	2	105.7276		6
	3	126.2256		7
	4	122.1536		8
78	1	143.0716		9
	2	138.9996		10
	3	159.4976		11
	4	155.4256		12
45	1	176.3436		13
	2	172.2716		14
	3	192.7696		15
	4	188.6976		16
14	1	209.6156		17
	2	205.5436		18
	3	226.0416		19
	4	221.9696		20
115	1	119.4073		21
	2	115.3353		22
	3	135.8333		23
	4	131.7613		24
79	1	150.6933	21	1
	2	146.6213		2
	3	167.1193		3
	4	163.0473		4
46	1	183.9653		5
	2	179.8933		6
	3	200.3913		7
	4	196.3193		8
15	1	217.2373		9
	2	213.1653		10
	3	233.6633		11
	4	229.5913		12
116	1	127.0290		13
	2	122.9570		14
	3	143.4550		15
	4	139.3830		16
80	1	160.3010		17
	2	156.2290		18
	3	176.7270		19
	4	172.6550		20
47	1	193.5730		21
	2	189.5010		22
	3	209.9990		23
	4	205.9270		24

16	1	224.8590	22	1
	2	220.7870		2
	3	241.2850		3
	4	237.2130		4
117	1	134.6507		5
	2	130.5787		6
	3	151.0767		7
	4	147.0047		8
81	1	167.9227		9
	2	163.8507		10
	3	184.3487		11
	4	180.2767		12
48	1	201.1947		13
	2	197.1227		14
	3	217.6207		15
	4	213.5487		16
17	1	234.4667		17
	2	230.3947		18
	3	250.8927		19
	4	246.8207		20
118	1	144.2584		21
	2	140.1864		22
	3	160.6844		23
	4	156.6124		24
82	1	175.5444	23	1
	2	171.4724		2
	3	191.9704		3
	4	187.8984		4
49	1	208.8164		5
	2	204.7444		6
	3	225.2424		7
	4	221.1704		8
18	1	242.0884		9
	2	238.0164		10
	3	258.5144		11
	4	254.4424		12
119	1	151.8801		13
	2	147.8081		14
	3	168.3061		15
	4	164.2341		16
83	1	185.1521		17
	2	181.0801		18
	3	201.5781		19
	4	197.5061		20
50	1	218.4241		21
	2	214.3521		22
	3	234.8501		23
	4	230.7781		24
19	1	260.9591	29	1
	2	256.8871		2
	3	277.3851		3
	4	273.3131		4
120	1	170.7508		5
	2	166.6788		6
	3	187.1768		7
	4	183.1048		8
84	1	204.0228		9
	2	199.9508		10
	3	220.4488		11
	4	216.3768		12
51	1	237.2948		13
	2	233.2228		14
	3	253.7208		15
	4	249.6488		16
20	1	270.5668		17
	2	266.4948		18
	3	286.9928		19
	4	282.9208		20
85	1	213.6303		21
	2	209.5583		22
	3	230.0563		23
	4	225.9843		24

52	1	244.9163	30	1
	2	240.8443		2
	3	261.3423		3
	4	257.2703		4
21	1	278.1883		5
	2	274.1163		6
	3	294.6143		7
	4	290.5423		8
86	1	215.8758		9
	2	211.8038		10
	3	232.3018		11
	4	228.2298		12
53	1	249.1478		13
	2	245.0758		14
	3	265.5738		15
	4	261.5018		16
22	1	282.4198		17
	2	278.3478		18
	3	298.8458		19
	4	294.7738		20
54	1	249.7818		21
	2	245.7098		22
	3	266.2078		23
	4	262.1358		24
23	1	281.0678	31	1
	2	276.9958		2
	3	297.4938		3
	4	293.4218		4
55	1	248.4297		5
	2	244.3577		6
	3	264.8557		7
	4	260.7837		8
24	1	281.7017		9
	2	277.6297		10
	3	298.1277		11
	4	294.0557		12
25	1	282.3357		13
	2	278.2637		14
	3	298.7617		15
	4	294.6897		16
26	1	282.9676		17
	2	278.8956		18
	3	299.3936		19
	4	295.3216		20
27	1	283.5994		21
	2	279.5274		22
	3	300.0254		23
	4	295.9534		24
193	1	271.2085	13	1
	2	275.2805		2
	3	287.6345		3
	4	291.7065		4
227	1	304.4805		5
	2	308.5525		6
	3	320.9065		7
	4	324.9785		8
157	1	237.4704		9
	2	241.5424		10
	3	253.8964		11
	4	257.9684		12
194	1	270.7424		13
	2	274.8144		14
	3	287.1684		15
	4	291.2404		16
228	1	304.0144		17
	2	308.0864		18
	3	320.4404		19
	4	324.5124		20
158	1	228.4518		21
	2	232.5238		22
	3	244.8778		23
	4	248.9498		24

195	1	263.7098	14	1
	2	267.7818		2
	3	280.1358		3
	4	284.2078		4
229	1	296.9818		5
	2	301.0538		6
	3	313.4078		7
	4	317.4798		8
121	1	187.5581		9
	2	191.6301		10
	3	203.9841		11
	4	208.0561		12
159	1	220.8301		13
	2	224.9021		14
	3	237.2561		15
	4	241.3281		16
196	1	254.1021		17
	2	258.1741		18
	3	270.5281		19
	4	274.6001		20
230	1	287.3741		21
	2	291.4461		22
	3	303.8001		23
	4	307.8721		24
122	1	179.9364	15	1
	2	184.0084		2
	3	196.3624		3
	4	200.4344		4
160	1	213.2084		5
	2	217.2804		6
	3	229.6344		7
	4	233.7064		8
197	1	246.4804		9
	2	250.5524		10
	3	262.9064		11
	4	266.9784		12
231	1	279.7524		13
	2	283.8244		14
	3	296.1784		15
	4	300.2504		16
123	1	170.3287		17
	2	174.4007		18
	3	186.7547		19
	4	190.8267		20
161	1	203.6007		21
	2	207.6727		22
	3	220.0267		23
	4	224.0987		24
198	1	238.8587	16	1
	2	242.9307		2
	3	255.2847		3
	4	259.3567		4
232	1	272.1307		5
	2	276.2027		6
	3	288.5567		7
	4	292.6287		8
124	1	162.7070		9
	2	166.7790		10
	3	179.1330		11
	4	183.2050		12
162	1	195.9790		13
	2	200.0510		14
	3	212.4050		15
	4	216.4770		16
199	1	229.2510		17
	2	233.3230		18
	3	245.6770		19
	4	249.7490		20
233	1	262.5230		21
	2	266.5950		22
	3	278.9490		23
	4	283.0210		24

125	1	155.0853	17	1
	2	159.1573		2
	3	171.5113		3
	4	175.5833		4
163	1	188.3573		5
	2	192.4293		6
	3	204.7833		7
	4	208.8553		8
200	1	221.6293		9
	2	225.7013		10
	3	238.0553		11
	4	242.1273		12
234	1	254.9013		13
	2	258.9733		14
	3	271.3273		15
	4	275.3993		16
126	1	145.4776		17
	2	149.5496		18
	3	161.9036		19
	4	165.9756		20
164	1	178.7496		21
	2	182.8216		22
	3	195.1756		23
	4	199.2476		24
201	1	214.0076	18	1
	2	218.0796		2
	3	230.4336		3
	4	234.5056		4
235	1	247.2796		5
	2	251.3516		6
	3	263.7056		7
	4	267.7776		8
127	1	137.8559		9
	2	141.9279		10
	3	154.2819		11
	4	158.3539		12
165	1	171.1279		13
	2	175.1999		14
	3	187.5539		15
	4	191.6259		16
202	1	204.3999		17
	2	208.4719		18
	3	220.8259		19
	4	224.8979		20
236	1	237.6719		21
	2	241.7439		22
	3	254.0979		23
	4	258.1699		24
128	1	118.9852	24	1
	2	123.0572		2
	3	135.4112		3
	4	139.4832		4
166	1	152.2572		5
	2	156.3292		6
	3	168.6832		7
	4	172.7552		8
203	1	185.5292		9
	2	189.6012		10
	3	201.9552		11
	4	206.0272		12
237	1	218.8012		13
	2	222.8732		14
	3	235.2272		15
	4	239.2992		16
129	1	109.3775		17
	2	113.4495		18
	3	125.8035		19
	4	129.8755		20
167	1	142.6495		21
	2	146.7215		22
	3	159.0755		23
	4	163.1475		24

204	1	177.9075	25	1
	2	181.9795		2
	3	194.3335		3
	4	198.4055		4
238	1	211.1795		5
	2	215.2515		6
	3	227.6055		7
	4	231.6775		8
130	1	101.7558		9
	2	105.8278		10
	3	118.1818		11
	4	122.2538		12
168	1	135.0278		13
	2	139.0998		14
	3	151.4538		15
	4	155.5258		16
205	1	168.2998		17
	2	172.3718		18
	3	184.7258		19
	4	188.7978		20
239	1	201.5718		21
	2	205.6438		22
	3	217.9978		23
	4	222.0698		24
131	1	94.1341	26	1
	2	98.2061		2
	3	110.5601		3
	4	114.6321		4
169	1	127.4061		5
	2	131.4781		6
	3	143.8321		7
	4	147.9041		8
206	1	160.6781		9
	2	164.7501		10
	3	177.1041		11
	4	181.1761		12
240	1	193.9501		13
	2	198.0221		14
	3	210.3761		15
	4	214.4481		16
132	1	84.5264		17
	2	88.5984		18
	3	100.9524		19
	4	105.0244		20
170	1	117.7984		21
	2	121.8704		22
	3	134.2244		23
	4	138.2964		24
207	1	153.0564	27	1
	2	157.1284		2
	3	169.4824		3
	4	173.5544		4
241	1	186.3284		5
	2	190.4004		6
	3	202.7544		7
	4	206.8264		8
133	1	76.9047		9
	2	80.9767		10
	3	93.3307		11
	4	97.4027		12
171	1	110.1767		13
	2	114.2487		14
	3	126.6027		15
	4	130.6747		16
208	1	143.4487		17
	2	147.5207		18
	3	159.8747		19
	4	163.9467		20
242	1	176.7207		21
	2	180.7927		22
	3	193.1467		23
	4	197.2187		24

134	1	69.2830	28	1
	2	73.3550		2
	3	85.7090		3
	4	89.7810		4
172	1	102.5550		5
	2	106.6270		6
	3	118.9810		7
	4	123.0530		8
209	1	135.8270		9
	2	139.8990		10
	3	152.2530		11
	4	156.3250		12
243	1	169.0990		13
	2	173.1710		14
	3	185.5250		15
	4	189.5970		16
135	1	59.6753		17
	2	63.7473		18
	3	76.1013		19
	4	80.1733		20
173	1	92.9473		21
	2	97.0193		22
	3	109.3733		23
	4	113.4453		24
210	1	116.9563	34	1
	2	121.0283		2
	3	133.3823		3
	4	137.4543		4
244	1	150.2283		5
	2	154.3003		6
	3	166.6543		7
	4	170.7263		8
136	1	40.8046		9
	2	44.8766		10
	3	57.2306		11
	4	61.3026		12
174	1	74.0766		13
	2	78.1486		14
	3	90.5026		15
	4	94.5746		16
211	1	107.3486		17
	2	111.4206		18
	3	123.7746		19
	4	127.8466		20
245	1	140.6206		21
	2	144.6926		22
	3	157.0466		23
	4	161.1186		24
137	1	33.1829	35	1
	2	37.2549		2
	3	49.6089		3
	4	53.6809		4
175	1	66.4549		5
	2	70.5269		6
	3	82.8809		7
	4	86.9529		8
212	1	99.7269		9
	2	103.7989		10
	3	116.1529		11
	4	120.2249		12
246	1	132.9989		13
	2	137.0709		14
	3	149.4249		15
	4	153.4969		16
138	1	23.5752		17
	2	27.6472		18
	3	40.0012		19
	4	44.0732		20
176	1	56.8472		21
	2	60.9192		22
	3	73.2732		23
	4	77.3452		24

213	1	92.1052	36	1
	2	96.1772		2
	3	108.5312		3
	4	112.6032		4
247	1	125.3772		5
	2	129.4492		6
	3	141.8032		7
	4	145.8752		8
139	1	15.9535		9
	2	20.0255		10
	3	32.3795		11
	4	36.4515		12
177	1	49.2255		13
	2	53.2975		14
	3	65.6515		15
	4	69.7235		16
214	1	82.4975		17
	2	86.5695		18
	3	98.9235		19
	4	102.9955		20
248	1	115.7695		21
	2	119.8415		22
	3	132.1955		23
	4	136.2675		24
140	1	8.3318	37	1
	2	12.4038		2
	3	24.7578		3
	4	28.8298		4
178	1	41.6038		5
	2	45.6758		6
	3	58.0298		7
	4	62.1018		8
215	1	74.8758		9
	2	78.9478		10
	3	91.3018		11
	4	95.3738		12
249	1	108.1478		13
	2	112.2198		14
	3	124.5738		15
	4	128.6458		16
141	1	13.4786		17
	2	9.4066		18
	3	29.9046		19
	4	25.8326		20
179	1	46.7506		21
	2	42.6786		22
	3	63.1766		23
	4	59.1046		24
216	1	78.0366	38	1
	2	73.9646		2
	3	94.4626		3
	4	90.3906		4
250	1	111.3086		5
	2	107.2366		6
	3	127.7346		7
	4	123.6626		8
142	1	21.1003		9
	2	17.0283		10
	3	37.5263		11
	4	33.4543		12
180	1	54.3723		13
	2	50.3003		14
	3	70.7983		15
	4	66.7263		16
217	1	87.6443		17
	2	83.5723		18
	3	104.0703		19
	4	99.9983		20
251	1	120.9163		21
	2	116.8443		22
	3	137.3423		23
	4	133.2703		24

143	1	14.6870	32	1
	2	10.6150		2
	3	31.1130		3
	4	27.0410		4
181	1	47.9590		5
	2	43.8870		6
	3	64.3850		7
	4	60.3130		8
218	1	81.2310		9
	2	77.1590		10
	3	97.6570		11
	4	93.5850		12
252	1	114.5030		13
	2	110.4310		14
	3	130.9290		15
	4	126.8570		16
144	1	24.2947		17
	2	20.2227		18
	3	40.7207		19
	4	36.6487		20
182	1	57.5667		21
	2	53.4947		22
	3	73.9927		23
	4	69.9207		24
219	1	88.8527	33	1
	2	84.7807		2
	3	105.2787		3
	4	101.2067		4
253	1	122.1247		5
	2	118.0527		6
	3	138.5507		7
	4	134.4787		8
145	1	31.9164		9
	2	27.8444		10
	3	48.3424		11
	4	44.2704		12
183	1	65.1884		13
	2	61.1164		14
	3	81.6144		15
	4	77.5424		16
220	1	98.4604		17
	2	94.3884		18
	3	114.8864		19
	4	110.8144		20
254	1	131.7324		21
	2	127.6604		22
	3	148.1584		23
	4	144.0864		24
146	1	48.1491	39	1
	2	44.0771		2
	3	64.5751		3
	4	60.5031		4
184	1	81.4211		5
	2	77.3491		6
	3	97.8471		7
	4	93.7751		8
221	1	114.6931		9
	2	110.6211		10
	3	131.1191		11
	4	127.0471		12
255	1	147.9651		13
	2	143.8931		14
	3	164.3911		15
	4	160.3191		16
147	1	57.7568		17
	2	53.6848		18
	3	74.1828		19
	4	70.1108		20
185	1	91.0288		21
	2	86.9568		22
	3	107.4548		23
	4	103.3828		24

222	1	122.3148	40	1
	2	118.2428		2
	3	138.7408		3
	4	134.6688		4
256	1	155.5868		5
	2	151.5148		6
	3	172.0128		7
	4	167.9408		8
148	1	65.3785		9
	2	61.3065		10
	3	81.8045		11
	4	77.7325		12
186	1	98.6505		13
	2	94.5785		14
	3	115.0765		15
	4	111.0045		16
223	1	131.9225		17
	2	127.8505		18
	3	148.3485		19
	4	144.2765		20
257	1	165.1945		21
	2	161.1225		22
	3	181.6205		23
	4	177.5485		24
149	1	73.0002	41	1
	2	68.9282		2
	3	89.4262		3
	4	85.3542		4
187	1	106.2722		5
	2	102.2002		6
	3	122.6982		7
	4	118.6262		8
224	1	139.5442		9
	2	135.4722		10
	3	155.9702		11
	4	151.8982		12
258	1	172.8162		13
	2	168.7442		14
	3	189.2422		15
	4	185.1702		16
150	1	82.6079		17
	2	78.5359		18
	3	99.0339		19
	4	94.9619		20
188	1	115.8799		21
	2	111.8079		22
	3	132.3059		23
	4	128.2339		24
225	1	147.1659	42	1
	2	143.0939		2
	3	163.5919		3
	4	159.5199		4
151	1	90.2296		5
	2	86.1576		6
	3	106.6556		7
	4	102.5836		8
189	1	123.5016		9
	2	119.4296		10
	3	139.9276		11
	4	135.8556		12
226	1	156.7736		13
	2	152.7016		14
	3	173.1996		15
	4	169.1276		16
152	1	99.8373		17
	2	95.7653		18
	3	116.2633		19
	4	112.1913		20
190	1	133.1093		21
	2	129.0373		22
	3	149.5353		23
	4	145.4633		24

153	1	107.4590	43	1
	2	103.3870		2
	3	123.8850		3
	4	119.8130		4
191	1	140.7310		5
	2	136.6590		6
	3	157.1570		7
	4	153.0850		8
154	1	117.0667		9
	2	112.9947		10
	3	133.4927		11
	4	129.4207		12
192	1	150.3387		13
	2	146.2667		14
	3	166.7647		15
	4	162.6927		16
155	1	126.6744		17
	2	122.6024		18
	3	143.1004		19
	4	139.0284		20
156	1	136.2821		21
	2	132.2101		22
	3	152.7081		23
	4	148.6361		24

Appendix 3. LV AC cable usage detail of 1000V-Inverter Distributed Solar System

INVERTER NUMBER	AC CABLE BETWEEN INVERTER & TRANSFORMER (m)
1	404.9596
2	388.8691
3	372.7786
4	356.6881
5	340.5976
6	324.5071
7	308.4166
8	292.3261
9	276.2356
10	260.1451
11	244.0546
12	227.9641
13	211.8736
14	195.7831
15	179.6926
16	163.6021
17	147.5116
18	131.4211
19	115.3306
20	99.2401
21	428.9296
22	413.6337
23	398.3378
24	383.0419
25	367.7460
26	352.4501
27	337.1542
28	321.8583
29	306.5624
30	291.2665
31	275.9706
32	260.6747
33	245.3788
34	230.0829
35	214.7870
36	199.4911
37	184.1952
38	168.8993
39	153.6034
40	138.3075
41	123.0116
42	107.7157
43	92.4198

Appendix 4. DC cable usage detail of 1000V-Inverter Distributed Solar System

TRACKER NUMBER	STRING NUMBER	DC CABLE BETWEEN STRING & INVERTER (m)	INVERTER NUMBER	STRING NUMBER
87	1	65.8176	1	1
	2	69.8896		2
	3	82.2436		3
	4	86.3156		4
88	1	62.4600		5
	2	66.5320		6
	3	78.8860		7
	4	82.9580		8
89	1	59.0951		9
	2	63.1671		10
	3	75.5211		11
	4	79.5931		12
90	1	55.7369		13
	2	59.8089		14
	3	72.1629		15
	4	76.2349		16
91	1	52.3831		17
	2	56.4551		18
	3	68.8091		19
	4	72.8811		20
55	1	9.5034		21
	2	13.5754		22
	3	25.9294		23
	4	30.0014		24
92	1	58.8659	2	1
	2	62.9379		2
	3	75.2919		3
	4	79.3639		4
56	1	15.9863		5
	2	20.0583		6
	3	32.4123		7
	4	36.4843		8
93	1	49.2583		9
	2	53.3303		10
	3	65.6843		11
	4	69.7563		12
57	1	6.3786		13
	2	10.4506		14
	3	22.8046		15
	4	26.8766		16
94	1	39.6506		17
	2	43.7226		18
	3	56.0766		19
	4	60.1486		20
58	1	10.1248		21
	2	6.0528		22
	3	26.5508		23
	4	22.4788		24
95	1	46.1334	3	1
	2	50.2054		2
	3	62.5594		3
	4	66.6314		4
59	1	3.2537		5
	2	7.3257		6
	3	19.6797		7
	4	23.7517		8
96	1	36.5257		9
	2	40.5977		10
	3	52.9517		11
	4	57.0237		12
60	1	13.2497		13
	2	9.1777		14
	3	29.6757		15
	4	25.6037		16
97	1	46.5217		17
	2	42.4497		18
	3	62.9477		19
	4	58.8757		20
27	1	21.8172		21
	2	17.7452		22
	3	38.2432		23
	4	34.1712		24
61	1	9.4438	4	1
	2	5.3718		2
	3	25.8698		3
	4	21.7978		4
98	1	42.7158		5
	2	38.6438		6
	3	59.1418		7
	4	55.0698		8
28	1	15.3344		9
	2	11.2624		10
	3	31.7604		11
	4	27.6884		12
62	1	16.3746		13
	2	12.3026		14
	3	32.8006		15
	4	28.7286		16
99	1	49.6466		17
	2	45.5746		18
	3	66.0726		19
	4	62.0006		20
29	1	24.9420		21
	2	20.8700		22
	3	41.3680		23
	4	37.2960		24
63	1	9.8918	5	1
	2	5.8198		2
	3	26.3178		3
	4	22.2458		4
100	1	43.1638		5
	2	39.0918		6
	3	59.5898		7
	4	55.5178		8
30	1	18.4592		9
	2	14.3872		10
	3	34.8852		11
	4	30.8132		12
64	1	19.4994		13
	2	15.4274		14
	3	35.9254		15
	4	31.8534		16
101	1	52.7714		17
	2	48.6994		18
	3	69.1974		19
	4	65.1254		20
31	1	28.0669		21
	2	23.9949		22
	3	44.4929		23
	4	40.4209		24
1	1	45.2484	6	1
	2	41.1764		2
	3	61.6744		3
	4	57.6024		4
65	1	13.0166		5
	2	8.9446		6
	3	29.4426		7
	4	25.3706		8
102	1	46.2886		9
	2	42.2166		10
	3	62.7146		11
	4	58.6426		12
32	1	21.5841		13
	2	17.5121		14
	3	38.0101		15
	4	33.9381		16
2	1	54.8561		17
	2	50.7841		18
	3	71.2821		19
	4	67.2101		20
66	1	22.6243		21
	2	18.5523		22
	3	39.0503		23
	4	34.9783		24

103	1	42.9489	7	1
	2	38.8769		2
	3	59.3749		3
	4	55.3029		4
33	1	15.1013		5
	2	11.0293		6
	3	31.5273		7
	4	27.4553		8
3	1	48.3733		9
	2	44.3013		10
	3	64.7993		11
	4	60.7273		12
67	1	16.1415		13
	2	12.0695		14
	3	32.5675		15
	4	28.4955		16
104	1	49.4135		17
	2	45.3415		18
	3	65.8395		19
	4	61.7675		20
34	1	24.7090		21
	2	20.6370		22
	3	41.1350		23
	4	37.0630		24
4	1	41.8905	8	1
	2	37.8185		2
	3	58.3165		3
	4	54.2445		4
68	1	9.6587		5
	2	5.5867		6
	3	26.0847		7
	4	22.0127		8
105	1	42.9307		9
	2	38.8587		10
	3	59.3567		11
	4	55.2847		12
35	1	18.2262		13
	2	14.1542		14
	3	34.6522		15
	4	30.5802		16
5	1	51.4982		17
	2	47.4262		18
	3	67.9242		19
	4	63.8522		20
69	1	19.2664		21
	2	15.1944		22
	3	35.6924		23
	4	31.6204		24
106	1	36.9918	9	1
	2	41.0638		2
	3	53.4178		3
	4	57.4898		4
36	1	11.7434		5
	2	7.6714		6
	3	28.1694		7
	4	24.0974		8
6	1	45.0154		9
	2	40.9434		10
	3	61.4414		11
	4	57.3694		12
70	1	12.7836		13
	2	8.7116		14
	3	29.2096		15
	4	25.1376		16
107	1	46.0556		17
	2	41.9836		18
	3	62.4816		19
	4	58.4096		20
37	1	21.3510		21
	2	17.2790		22
	3	37.7770		23
	4	33.7050		24

7	1	8.8697	10	1
	2	4.7977		2
	3	25.2957		3
	4	21.2237		4
71	1	9.9099		5
	2	5.8379		6
	3	26.3359		7
	4	22.2639		8
108	1	43.1819		9
	2	39.1099		10
	3	59.6079		11
	4	55.5359		12
38	1	14.8682		13
	2	10.7962		14
	3	31.2942		15
	4	27.2222		16
8	1	48.1402		17
	2	44.0682		18
	3	64.5662		19
	4	60.4942		20
72	1	15.9084		21
	2	11.8364		22
	3	32.3344		23
	4	28.2624		24
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	3	24.8114		7
	4	20.7394		8
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	3	58.0834		11
	4	54.0114		12
73	1	9.4256		13
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	3	25.8516		15
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	2	38.6256		18
	3	59.1236		19
	4	55.0516		20
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	3	34.4191		23
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	3	54.6911		3
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74	1	3.9529		5
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	3	20.3789		7
	4	24.4509		8
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	3	27.9363		15
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	2	40.7103		18
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	3	28.9765		23
	4	24.9045		24

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	4	64.2057		4
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	3	25.5288		7
	4	21.4568		8
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	2	38.3028		10
	3	58.8008		11
	4	54.7288		12
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	2	9.2302		14
	3	21.5842		15
	4	25.6562		16
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43	1	14.6352		21
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	3	31.0612		23
	4	26.9892		24
13	1	41.6230	14	1
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	3	23.7368		7
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	2	37.3524		18
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	4	53.7784		20
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	3	25.6186		23
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115	1	47.0656	15	1
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	3	21.6522		7
	4	25.7242		8
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	3	20.6120		15
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116	1	37.4580		17
	2	41.5300		18
	3	53.8840		19
	4	57.9560		20
46	1	11.2772		21
	2	7.2052		22
	3	27.7032		23
	4	23.6312		24

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	4	64.4388		12
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	4	21.6898		16
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	2	38.5358		18
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	3	21.3512		23
	4	25.4232		24
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	3	66.8496		3
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	3	23.9699		15
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	3	57.2419		19
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	2	3.8473		22
	3	24.3453		23
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19	1	48.3389	18	1
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	3	21.8852		15
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	2	42.8032		18
	3	55.1572		19
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	3	20.8450		23
	4	24.9170		24

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	3	21.1181		23
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	3	57.3842		15
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194	1	9.3702		13
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	3	25.7962		15
	4	21.7242		16
228	1	42.6422		17
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	4	54.9962		20
158	1	17.9377		21
	2	13.8657		22
	3	34.3637		23
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195	1	3.2139	22	1
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	3	19.6399		3
	4	23.7119		4
229	1	36.4859		5
	2	40.5579		6
	3	52.9119		7
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159	1	12.2495		9
	2	8.1775		10
	3	28.6755		11
	4	24.6035		12
121	1	45.5215		13
	2	41.4495		14
	3	61.9475		15
	4	57.8755		16
196	1	13.2897		17
	2	9.2177		18
	3	29.7157		19
	4	25.6437		20
230	1	46.5617		21
	2	42.4897		22
	3	62.9877		23
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160	1	7.5692	23	1
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	3	23.9952		3
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122	1	40.8412		5
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	2	12.0970		18
	3	32.5950		19
	4	28.5230		20
123	1	49.4410		21
	2	45.3690		22
	3	65.8670		23
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198	1	4.9826	24	1
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	3	21.4086		3
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232	1	38.2546		5
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	3	54.6806		7
	4	58.7526		8
162	1	10.4808		9
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	3	26.9068		11
	4	22.8348		12
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	2	39.6808		14
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	4	56.1068		16
199	1	11.5210		17
	2	7.4490		18
	3	27.9470		19
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233	1	44.7930		21
	2	40.7210		22
	3	61.2190		23
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163	1	9.3379	25	1
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	3	25.7639		3
	4	21.6919		4
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	3	59.0359		7
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	3	21.3494		11
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	3	54.6214		15
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164	1	14.4003		17
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	3	30.8263		19
	4	26.7543		20
126	1	47.6723		21
	2	43.6003		22
	3	64.0983		23
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	3	23.1773		3
	4	27.2493		4
235	1	40.0233		5
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	3	56.4493		7
	4	60.5213		8
165	1	8.7121		9
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	4	21.0661		12
127	1	41.9841		13
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	3	58.4101		15
	4	54.3381		16
202	1	9.7523		17
	2	5.6803		18
	3	26.1783		19
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236	1	43.0243		21
	2	38.9523		22
	3	59.4503		23
	4	55.3783		24
166	1	4.1949	27	1
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	3	20.6209		3
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128	1	37.4669		5
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203	1	3.1547		9
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237	1	36.4267		13
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167	1	12.6316		17
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	2	41.8316		22
	3	62.3296		23
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204	1	8.5201	28	1
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238	1	41.7921		5
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	3	58.2181		7
	4	62.2901		8
168	1	7.1872		9
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	4	52.8132		16
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239	1	41.4994		21
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170	1	10.8629		17
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	3	60.5609		23
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207	1	10.2888	30	1
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	3	26.7148		3
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241	1	43.5608		5
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	4	21.3099		12
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208	1	5.3054		17
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	3	21.7314		19
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242	1	38.5774		21
	2	42.6494		22
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172	1	7.4096	31	1
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	3	23.8356		3
	4	27.9076		4
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	3	57.1076		7
	4	61.1796		8
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173	1	9.0941		17
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211	1	3.5370		17
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245	1	36.8090		21
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	3	53.2350		23
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175	1	9.1780	33	1
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246	1	41.4097		13
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176	1	7.3257		17
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138	1	40.5977		21
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247	1	47.0980		5
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177	1	5.2585		9
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214	1	4.2183		17
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248	1	37.4903		21
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	3	53.9163		23
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178	1	10.9467	35	1
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249	1	43.1785		13
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179	1	8.5736		17
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216	1	15.5947	36	1
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217	1	5.9870		17
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	3	55.6850		23
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181	1	12.7154	37	1
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182	1	4.9592		17
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144	1	38.2312		21
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219	1	17.3634	38	1
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253	1	50.6354		5
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183	1	9.3059		9
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145	1	42.5779		13
	2	46.6499		14
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	4	63.0759		16
220	1	7.7558		17
	2	11.8278		18
	3	24.1818		19
	4	28.2538		20
254	1	41.0278		21
	2	45.0998		22
	3	57.4538		23
	4	61.5258		24
184	1	14.4842	39	1
	2	18.5562		2
	3	30.9102		3
	4	34.9822		4
146	1	47.7562		5
	2	51.8282		6
	3	64.1822		7
	4	68.2542		8
221	1	13.4440		9
	2	17.5160		10
	3	29.8700		11
	4	33.9420		12
255	1	46.7160		13
	2	50.7880		14
	3	63.1420		15
	4	67.2140		16
185	1	4.8765		17
	2	8.9485		18
	3	21.3025		19
	4	25.3745		20
147	1	38.1485		21
	2	42.2205		22
	3	54.5745		23
	4	58.6465		24

222	1	19.1322	40	1
	2	23.2042		2
	3	35.5582		3
	4	39.6302		4
256	1	52.4042		5
	2	56.4762		6
	3	68.8302		7
	4	72.9022		8
186	1	10.5647		9
	2	14.6367		10
	3	26.9907		11
	4	31.0627		12
148	1	43.8367		13
	2	47.9087		14
	3	60.2627		15
	4	64.3347		16
223	1	9.5245		17
	2	13.5965		18
	3	25.9505		19
	4	30.0225		20
257	1	42.7965		21
	2	46.8685		22
	3	59.2225		23
	4	63.2945		24
187	1	16.2529	41	1
	2	20.3249		2
	3	32.6789		3
	4	36.7509		4
149	1	49.5249		5
	2	53.5969		6
	3	65.9509		7
	4	70.0229		8
224	1	15.2127		9
	2	19.2847		10
	3	31.6387		11
	4	35.7107		12
258	1	48.4847		13
	2	52.5567		14
	3	64.9107		15
	4	68.9827		16
188	1	6.6452		17
	2	10.7172		18
	3	23.0712		19
	4	27.1432		20
150	1	39.9172		21
	2	43.9892		22
	3	56.3432		23
	4	60.4152		24
225	1	20.9009	42	1
	2	24.9729		2
	3	37.3269		3
	4	41.3989		4
189	1	12.3334		5
	2	16.4054		6
	3	28.7594		7
	4	32.8314		8
151	1	45.6054		9
	2	49.6774		10
	3	62.0314		11
	4	66.1034		12
226	1	11.2932		13
	2	15.3652		14
	3	27.7192		15
	4	31.7912		16
190	1	5.3412		17
	2	9.4132		18
	3	21.7672		19
	4	25.8392		20
152	1	38.6132		21
	2	42.6852		22
	3	55.0392		23
	4	59.1112		24

191	1	8.4140	43	1
	2	12.4860		2
	3	24.8400		3
	4	28.9120		4
153	1	41.6860		5
	2	45.7580		6
	3	58.1120		7
	4	62.1840		8
192	1	8.0897		9
	2	4.0177		10
	3	24.5157		11
	4	20.4437		12
154	1	41.3617		13
	2	37.2897		14
	3	57.7877		15
	4	53.7157		16
155	1	50.9694		17
	2	46.8974		18
	3	67.3954		19
	4	63.3234		20
156	1	55.9591		21
	2	51.8871		22
	3	72.3851		23
	4	68.3131		24

Appendix 5. LV AC cable usage detail of 1500V-Inverter Centralized Solar System

INVERTER NUMBER	AC CABLE BETWEEN INVERTER & TRANSFORMER (m)
1	14.9930
2	13.0070
3	11.0210
4	9.0350
5	7.0490
6	7.0490
7	9.0350
8	11.0210
9	13.0070
10	14.9930
11	13.6350
12	11.6490
13	9.6630
14	7.6770
15	5.6910
16	5.6910
17	7.6770
18	9.6630
19	11.6490
20	13.6350
21	14.9930
22	13.0070
23	11.0210
24	9.0350
25	7.0490
26	7.0490
27	9.0350
28	11.0210
29	13.0070

Appendix 6. DC cable usage detail of 1500V-Inverter Centralized Solar System

TRACKER NUMBER	STRING NUMBER	DC CABLE BETWEEN STRING & INVERTER (m)	INVERTER NUMBER	STRING NUMBER
115	1	151.2673	1	1
	2	164.7023		2
116	1	141.6596		3
	2	155.0946		4
117	1	132.0519		5
	2	145.4869		6
118	1	122.4442		7
	2	135.8792		8
119	1	112.8365		9
	2	126.2715		10
83	1	140.1267		11
	2	153.5617		12
120	1	103.2288		13
	2	116.6638		14
84	1	130.5190		15
	2	143.9540		16
121	1	93.6211		17
	2	107.0561		18
85	1	120.9113		19
	2	134.3463		20
122	1	84.0134		21
	2	97.4484		22
86	1	113.2896	2	1
	2	126.7246		2
123	1	76.3917		3
	2	89.8267		4
87	1	103.6819		5
	2	117.1169		6
54	1	130.9721		7
	2	144.4071		8
124	1	66.7840		9
	2	80.2190		10
88	1	94.0742		11
	2	107.5092		12
55	1	121.3644		13
	2	134.7994		14
125	1	57.1763		15
	2	70.6113		16
89	1	84.4665		17
	2	97.9015		18
56	1	111.7567		19
	2	125.1917		20
126	1	47.5686		21
	2	61.0036		22
90	1	76.8448	3	1
	2	90.2798		2
57	1	104.1350		3
	2	117.5700		4
127	1	39.9469		5
	2	53.3819		6
91	1	67.2371		7
	2	80.6721		8
58	1	94.5273		9
	2	107.9623		10
27	1	121.8175		11
	2	135.2525		12
128	1	30.3392		13
	2	43.7742		14
92	1	57.6294		15
	2	71.0644		16
59	1	84.9196		17
	2	98.3546		18
28	1	112.2098		19
	2	125.6448		20
129	1	20.7315		21
	2	34.1665		22
93	1	50.0077	4	1
	2	63.4427		2
60	1	77.2979		3
	2	90.7329		4
29	1	104.5881		5
	2	118.0231		6
130	1	13.1098		7
	2	26.5448		8
94	1	40.4000		9
	2	53.8350		10
61	1	67.6902		11
	2	81.1252		12
30	1	94.9804		13
	2	108.4154		14
1	1	122.2706		15
	2	135.7056		16
131	1	6.6647		17
	2	20.0997		18
95	1	33.9549		19
	2	47.3899		20
62	1	61.2451		21
	2	74.6801		22
31	1	90.5213	5	1
	2	103.9563		2
2	1	117.8115		3
	2	131.2465		4
132	1	12.2510		5
	2	25.6860		6
96	1	39.5412		7
	2	52.9762		8
63	1	66.8314		9
	2	80.2664		10
32	1	94.1216		11
	2	107.5566		12
3	1	121.4118		13
	2	134.8468		14
133	1	21.8587		15
	2	35.2937		16
97	1	49.1489		17
	2	62.5839		18
64	1	76.4391		19
	2	89.8741		20
33	1	103.7293		21
	2	117.1643		22
4	1	119.6373	6	1
	2	133.0723		2
134	1	20.0844		3
	2	33.5194		4
98	1	47.3746		5
	2	60.8096		6
65	1	74.6648		7
	2	88.0998		8
34	1	101.9550		9
	2	115.3900		10
5	1	129.2452		11
	2	142.6802		12
135	1	29.6921		13
	2	43.1271		14
99	1	56.9823		15
	2	70.4173		16
66	1	84.2725		17
	2	97.7075		18
35	1	111.5627		19
	2	124.9977		20
6	1	138.8529		21
	2	152.2879		22

136	1	37.3138	7	1
	2	50.7488		2
100	1	64.6040		3
	2	78.0390		4
67	1	91.8942		5
	2	105.3292		6
36	1	119.1844		7
	2	132.6194		8
7	1	146.4746		9
	2	159.9096		10
137	1	46.9215		11
	2	60.3565		12
101	1	74.2117		13
	2	87.6467		14
68	1	101.5019		15
	2	114.9369		16
37	1	128.7921		17
	2	142.2271		18
8	1	156.0823		19
	2	169.5173		20
138	1	56.5292		21
	2	69.9642		22
102	1	81.8334	8	1
	2	95.2684		2
69	1	109.1236		3
	2	122.5586		4
38	1	136.4138		5
	2	149.8488		6
9	1	163.7040		7
	2	177.1390		8
139	1	64.1509		9
	2	77.5859		10
103	1	91.4411		11
	2	104.8761		12
70	1	118.7313		13
	2	132.1663		14
39	1	146.0215		15
	2	159.4565		16
10	1	173.3117		17
	2	186.7467		18
140	1	73.7586		19
	2	87.1936		20
104	1	101.0488		21
	2	114.4838		22
71	1	126.3530	9	1
	2	139.7880		2
40	1	153.6432		3
	2	167.0782		4
11	1	180.9334		5
	2	194.3684		6
141	1	81.3803		7
	2	94.8153		8
105	1	108.6705		9
	2	122.1055		10
72	1	135.9607		11
	2	149.3957		12
41	1	163.2509		13
	2	176.6859		14
12	1	190.5411		15
	2	203.9761		16
142	1	90.9880		17
	2	104.4230		18
106	1	118.2782		19
	2	131.7132		20
73	1	145.5684		21
	2	159.0034		22

42	1	170.8726	10	1
	2	184.3076		2
13	1	198.1628		3
	2	211.5978		4
143	1	98.6097		5
	2	112.0447		6
107	1	125.8999		7
	2	139.3349		8
74	1	153.1901		9
	2	166.6251		10
43	1	180.4803		11
	2	193.9153		12
14	1	207.7705		13
	2	221.2055		14
144	1	108.2174		15
	2	121.6524		16
108	1	135.5076		17
	2	148.9426		18
75	1	162.7978		19
	2	176.2328		20
44	1	190.0880		21
	2	203.5230		22
15	1	226.6802	16	1
	2	240.1152		2
145	1	127.1271		3
	2	140.5621		4
109	1	154.4173		5
	2	167.8523		6
76	1	181.7075		7
	2	195.1425		8
45	1	208.9977		9
	2	222.4327		10
16	1	236.2879		11
	2	249.7229		12
146	1	136.7348		13
	2	150.1698		14
110	1	164.0250		15
	2	177.4600		16
77	1	191.3152		17
	2	204.7502		18
46	1	218.6054		19
	2	232.0404		20
17	1	245.8956		21
	2	259.3306		22
147	1	144.3565	17	1
	2	157.7915		2
111	1	171.6467		3
	2	185.0817		4
78	1	198.9369		5
	2	212.3719		6
47	1	226.2271		7
	2	239.6621		8
18	1	253.5173		9
	2	266.9523		10
148	1	153.9642		11
	2	167.3992		12
112	1	181.2544		13
	2	194.6894		14
79	1	208.5446		15
	2	221.9796		16
48	1	235.8348		17
	2	249.2698		18
19	1	263.1250		19
	2	276.5600		20
113	1	190.8618		21
	2	204.2968		22

80	1	216.1660	18	1
	2	229.6010		2
49	1	243.4562		3
	2	256.8912		4
20	1	270.7464		5
	2	284.1814		6
114	1	191.9693		7
	2	205.4043		8
81	1	219.2595		9
	2	232.6945		10
50	1	246.5497		11
	2	259.9847		12
21	1	273.8399		13
	2	287.2749		14
82	1	219.8934		15
	2	233.3284		16
51	1	247.1836		17
	2	260.6186		18
22	1	274.4738		19
	2	287.9088		20
52	1	247.8175		21
	2	261.2525		22
23	1	273.1217	19	1
	2	286.5567		2
53	1	246.4655		3
	2	259.9005		4
24	1	273.7557		5
	2	287.1907		6
25	1	274.3896		7
	2	287.8246		8
26	1	275.0235		9
	2	288.4585		10
184	1	125.7879		11
	2	139.2229		12
183	1	116.1802		13
	2	129.6152		14
182	1	106.5725		15
	2	120.0075		16
219	1	133.8627		17
	2	147.2977		18
181	1	96.9648		19
	2	110.3998		20
218	1	124.2550		21
	2	137.6900		22
254	1	149.5592	20	1
	2	162.9942		2
180	1	85.3711		3
	2	98.8061		4
217	1	112.6613		5
	2	126.0963		6
253	1	139.9515		7
	2	153.3865		8
179	1	75.7634		9
	2	89.1984		10
216	1	103.0536		11
	2	116.4886		12
252	1	130.3438		13
	2	143.7788		14
287	1	157.6340		15
	2	171.0690		16
178	1	66.1557		17
	2	79.5907		18
215	1	93.4459		19
	2	106.8809		20
251	1	120.7361		21
	2	134.1711		22

286	1	146.6683	29	1
	2	160.1033		2
177	1	55.1900		3
	2	68.6250		4
214	1	82.4802		5
	2	95.9152		6
250	1	109.7704		7
	2	123.2054		8
285	1	137.0606		9
	2	150.4956		10
319	1	164.3508		11
	2	177.7858		12
176	1	45.5823		13
	2	59.0173		14
213	1	72.8725		15
	2	86.3075		16
249	1	100.1627		17
	2	113.5977		18
284	1	127.4529		19
	2	140.8879		20
318	1	154.7431		21
	2	168.1781		22
175	1	37.9606	28	1
	2	51.3956		2
212	1	65.2508		3
	2	78.6858		4
248	1	92.5410		5
	2	105.9760		6
283	1	119.8312		7
	2	133.2662		8
317	1	147.1214		9
	2	160.5564		10
174	1	28.3529		11
	2	41.7879		12
211	1	55.6431		13
	2	69.0781		14
247	1	82.9333		15
	2	96.3683		16
282	1	110.2235		17
	2	123.6585		18
316	1	137.5137		19
	2	150.9487		20
173	1	18.7452		21
	2	32.1802		22
210	1	48.0214	27	1
	2	61.4564		2
246	1	75.3116		3
	2	88.7466		4
281	1	102.6018		5
	2	116.0368		6
315	1	129.8920		7
	2	143.3270		8
172	1	11.1235		9
	2	24.5585		10
209	1	38.4137		11
	2	51.8487		12
245	1	65.7039		13
	2	79.1389		14
280	1	92.9941		15
	2	106.4291		16
314	1	120.2843		17
	2	133.7193		18
171	1	6.6645		19
	2	20.0995		20
208	1	33.9547		21
	2	47.3897		22

244	1	62.4668		1
	2	75.9018		2
279	1	89.7570		3
	2	103.1920		4
313	1	117.0472		5
	2	130.4822		6
170	1	12.2512		7
	2	25.6862		8
207	1	39.5414		9
	2	52.9764		10
243	1	66.8316	26	11
	2	80.2666		12
278	1	94.1218		13
	2	107.5568		14
312	1	121.4120		15
	2	134.8470		16
169	1	21.8589		17
	2	35.2939		18
206	1	49.1491		19
	2	62.5841		20
242	1	76.4393		21
	2	89.8743		22
277	1	92.3473		1
	2	105.7823		2
311	1	119.6375		3
	2	133.0725		4
168	1	20.0846		5
	2	33.5196		6
205	1	47.3748		7
	2	60.8098		8
241	1	74.6650		9
	2	88.1000		10
276	1	101.9552	25	11
	2	115.3902		12
310	1	129.2454		13
	2	142.6804		14
167	1	29.6923		15
	2	43.1273		16
204	1	56.9825		17
	2	70.4175		18
240	1	84.2727		19
	2	97.7077		20
275	1	111.5629		21
	2	124.9979		22
309	1	136.8671		1
	2	150.3021		2
166	1	37.3140		3
	2	50.7490		4
203	1	64.6042		5
	2	78.0392		6
239	1	91.8944		7
	2	105.3294		8
274	1	119.1846		9
	2	132.6196		10
308	1	146.4748	24	11
	2	159.9098		12
165	1	46.9217		13
	2	60.3567		14
202	1	74.2119		15
	2	87.6469		16
238	1	101.5021		17
	2	114.9371		18
273	1	128.7923		19
	2	142.2273		20
307	1	156.0825		21
	2	169.5175		22

164	1	54.5434		1
	2	67.9784		2
201	1	81.8336		3
	2	95.2686		4
237	1	109.1238		5
	2	122.5588		6
272	1	136.4140		7
	2	149.8490		8
306	1	163.7042		9
	2	177.1392		10
163	1	64.1511	23	11
	2	77.5861		12
200	1	91.4413		13
	2	104.8763		14
236	1	118.7315		15
	2	132.1665		16
271	1	146.0217		17
	2	159.4567		18
305	1	173.3119		19
	2	186.7469		20
162	1	73.7588		21
	2	87.1938		22
199	1	99.0630		1
	2	112.4980		2
235	1	126.3532		3
	2	139.7882		4
270	1	153.6434		5
	2	167.0784		6
304	1	180.9336		7
	2	194.3686		8
161	1	81.3805		9
	2	94.8155		10
198	1	108.6707	22	11
	2	122.1057		12
234	1	135.9609		13
	2	149.3959		14
269	1	163.2511		15
	2	176.6861		16
303	1	190.5413		17
	2	203.9763		18
160	1	90.9882		19
	2	104.4232		20
197	1	118.2784		21
	2	131.7134		22
233	1	143.5826		1
	2	157.0176		2
268	1	170.8728		3
	2	184.3078		4
302	1	198.1630		5
	2	211.5980		6
159	1	98.6099		7
	2	112.0449		8
196	1	125.9001		9
	2	139.3351		10
232	1	153.1903	21	11
	2	166.6253		12
267	1	180.4805		13
	2	193.9155		14
301	1	207.7707		15
	2	221.2057		16
158	1	108.2176		17
	2	121.6526		18
195	1	135.5078		19
	2	148.9428		20
231	1	162.7980		21
	2	176.2330		22

266	1	199.3902	15	1
	2	212.8252		2
300	1	226.6804		3
	2	240.1154		4
157	1	127.1273		5
	2	140.5623		6
194	1	154.4175		7
	2	167.8525		8
230	1	181.7077		9
	2	195.1427		10
265	1	208.9979		11
	2	222.4329		12
299	1	236.2881		13
	2	249.7231		14
156	1	136.7350		15
	2	150.1700		16
193	1	164.0252		17
	2	177.4602		18
229	1	191.3154		19
	2	204.7504		20
264	1	218.6056		21
	2	232.0406		22
298	1	243.9098	14	1
	2	257.3448		2
155	1	144.3567		3
	2	157.7917		4
192	1	171.6469		5
	2	185.0819		6
228	1	198.9371		7
	2	212.3721		8
263	1	226.2273		9
	2	239.6623		10
297	1	253.5175		11
	2	266.9525		12
154	1	153.9644		13
	2	167.3994		14
191	1	181.2546		15
	2	194.6896		16
227	1	208.5448		17
	2	221.9798		18
262	1	235.8350		19
	2	249.2700		20
296	1	263.1252		21
	2	276.5602		22
153	1	161.5861	13	1
	2	175.0211		2
190	1	188.8763		3
	2	202.3113		4
226	1	216.1665		5
	2	229.6015		6
261	1	243.4567		7
	2	256.8917		8
295	1	270.7469		9
	2	284.1819		10
152	1	171.1938		11
	2	184.6288		12
189	1	198.4840		13
	2	211.9190		14
225	1	225.7742		15
	2	239.2092		16
260	1	253.0644		17
	2	266.4994		18
294	1	280.3546		19
	2	293.7896		20
151	1	180.8015		21
	2	194.2365		22

188	1	206.1057	12	1
	2	219.5407		2
224	1	233.3959		3
	2	246.8309		4
259	1	260.6861		5
	2	274.1211		6
293	1	287.9763		7
	2	301.4113		8
150	1	188.4232		9
	2	201.8582		10
187	1	215.7134		11
	2	229.1484		12
223	1	243.0036		13
	2	256.4386		14
258	1	270.2938		15
	2	283.7288		16
292	1	297.5840		17
	2	311.0190		18
149	1	198.0309		19
	2	211.4659		20
186	1	225.3211		21
	2	238.7561		22
222	1	250.6253	11	1
	2	264.0603		2
257	1	277.9155		3
	2	291.3505		4
291	1	305.2057		5
	2	318.6407		6
185	1	232.9425		7
	2	246.3775		8
221	1	260.2327		9
	2	273.6677		10
256	1	287.5229		11
	2	300.9579		12
290	1	314.8131		13
	2	328.2481		14
220	1	261.3979		15
	2	274.8329		16
255	1	288.6881		17
	2	302.1231		18
289	1	315.9783		19
	2	329.4133		20
288	1	315.1376		21
	2	328.5726		22

Appendix 7. LV AC cable usage detail of 1500V-Inverter Distributed Solar System

INVERTER NUMBER	AC CABLE BETWEEN INVERTER & TRANSFORMER(m)
1	387.5430
2	363.1709
3	338.7988
4	314.4267
5	290.0546
6	265.6825
7	241.3104
8	216.9383
9	192.5662
10	168.1941
11	143.8220
12	119.4499
13	95.0778
14	406.3175
15	384.9658
16	363.6141
17	342.2624
18	320.9107
19	299.5590
20	278.2073
21	256.8556
22	235.5039
23	214.1522
24	192.8005
25	171.4488
26	150.0971
27	128.7454
28	107.3937
29	86.0420

Appendix 8. DC cable usage detail of 1500V-Inverter Distributed Solar System

TRACKER NUMBER	STRING NUMBER	DC CABLE BETWEEN STRING & INVERTER (m)	INVERTER NUMBER	STRING NUMBER
115	1	64.1862	1	1
	2	77.6212		2
116	1	60.8213		3
	2	74.2563		4
117	1	57.4564		5
	2	70.8914		6
118	1	53.0071		7
	2	66.4421		8
83	1	16.1093		9
	2	29.5443		10
119	1	43.3995		11
	2	56.8345		12
84	1	6.5016		13
	2	19.9366		14
120	1	33.7918		15
	2	47.2268		16
85	1	8.1081		17
	2	21.5431		18
121	1	35.3983		19
	2	48.8333		20
86	1	15.5788		21
	2	29.0138		22
122	1	38.9484	2	1
	2	52.3834		2
87	1	3.9770		3
	2	17.4120		4
123	1	31.2672		5
	2	44.7022		6
54	1	9.3819		7
	2	22.8169		8
88	1	10.4221		9
	2	23.8571		10
124	1	37.7123		11
	2	51.1473		12
55	1	18.9896		13
	2	32.4246		14
89	1	20.0298		15
	2	33.4648		16
125	1	47.3200		17
	2	60.7550		18
56	1	28.5973		19
	2	42.0323		20
90	1	29.6375		21
	2	43.0725		22
126	1	32.5556	3	1
	2	45.9906		2
57	1	13.8329		3
	2	27.2679		4
91	1	14.8731		5
	2	28.3081		6
127	1	42.1633		7
	2	55.5983		8
58	1	23.4406		9
	2	36.8756		10
27	1	50.7308		11
	2	64.1658		12
92	1	24.4808		13
	2	37.9158		14
128	1	51.7710		15
	2	65.2060		16
59	1	33.0483		17
	2	46.4833		18
28	1	60.3385		19
	2	73.7735		20
93	1	34.0885		21
	2	47.5235		22
129	1	37.0066	4	1
	2	50.4416		2
60	1	18.2839		3
	2	31.7189		4
29	1	45.5741		5
	2	59.0091		6
94	1	19.3241		7
	2	32.7591		8
130	1	46.6143		9
	2	60.0493		10
61	1	27.8916		11
	2	41.3266		12
30	1	55.1818		13
	2	68.6168		14
1	1	82.4720		15
	2	95.9070		16
95	1	28.9318		17
	2	42.3668		18
131	1	56.2220		19
	2	69.6570		20
62	1	37.4993		21
	2	50.9343		22
31	1	40.4174	5	1
	2	53.8524		2
2	1	67.7076		3
	2	81.1426		4
96	1	14.1674		5
	2	27.6024		6
132	1	41.4576		7
	2	54.8926		8
63	1	22.7349		9
	2	36.1699		10
32	1	50.0251		11
	2	63.4601		12
3	1	77.3153		13
	2	90.7503		14
97	1	23.7751		15
	2	37.2101		16
133	1	51.0653		17
	2	64.5003		18
64	1	32.3426		19
	2	45.7776		20
33	1	59.6328		21
	2	73.0678		22
4	1	62.5508	6	1
	2	75.9858		2
98	1	9.0107		3
	2	22.4457		4
134	1	36.3009		5
	2	49.7359		6
65	1	17.5782		7
	2	31.0132		8
34	1	44.8684		9
	2	58.3034		10
5	1	72.1586		11
	2	85.5936		12
99	1	18.6184		13
	2	32.0534		14
135	1	45.9086		15
	2	59.3436		16
66	1	27.1858		17
	2	40.6208		18
35	1	54.4760		19
	2	67.9110		20
6	1	81.7662		21
	2	95.2012		22

100	1	4.2541	7	1
	2	17.6891		2
136	1	31.5443		3
	2	44.9793		4
67	1	12.4213		5
	2	25.8563		6
36	1	39.7115		7
	2	53.1465		8
7	1	67.0017		9
	2	80.4367		10
101	1	13.4615		11
	2	26.8965		12
137	1	40.7517		13
	2	54.1867		14
68	1	22.0290		15
	2	35.4640		16
37	1	49.3192		17
	2	62.7542		18
8	1	76.6094		19
	2	90.0444		20
102	1	23.0692		21
	2	36.5042		22
138	1	31.4579	8	1
	2	44.8929		2
69	1	7.2647		3
	2	20.6997		4
38	1	34.5549		5
	2	47.9899		6
9	1	61.8451		7
	2	75.2801		8
103	1	8.3049		9
	2	21.7399		10
139	1	35.5951		11
	2	49.0301		12
70	1	16.8724		13
	2	30.3074		14
39	1	44.1626		15
	2	57.5976		16
10	1	71.4528		17
	2	84.8878		18
104	1	17.9126		19
	2	31.3476		20
140	1	45.2028		21
	2	58.6378		22
71	1	3.9196	9	1
	2	17.3546		2
40	1	31.2098		3
	2	44.6448		4
11	1	58.5000		5
	2	71.9350		6
105	1	4.9598		7
	2	18.3948		8
141	1	32.2500		9
	2	45.6850		10
72	1	11.7157		11
	2	25.1507		12
41	1	39.0059		13
	2	52.4409		14
12	1	66.2961		15
	2	79.7311		16
106	1	12.7559		17
	2	26.1909		18
142	1	40.0461		19
	2	53.4811		20
73	1	21.3234		21
	2	34.7584		22

42	1	33.2039	10	1
	2	46.6389		2
13	1	60.4941		3
	2	73.9291		4
107	1	4.8735		5
	2	18.3085		6
143	1	32.1637		7
	2	45.5987		8
74	1	6.5589		9
	2	19.9939		10
43	1	33.8491		11
	2	47.2841		12
14	1	61.1393		13
	2	74.5743		14
108	1	7.5992		15
	2	21.0342		16
75	1	16.1666		17
	2	29.6016		18
44	1	43.4568		19
	2	56.8918		20
15	1	70.7470		21
	2	84.1820		22
109	1	10.0302	11	1
	2	23.4652		2
76	1	4.6253		3
	2	18.0603		4
45	1	31.9155		5
	2	45.3505		6
16	1	59.2057		7
	2	72.6407		8
110	1	5.6050		9
	2	19.0400		10
77	1	11.0099		11
	2	24.4449		12
46	1	38.3001		13
	2	51.7351		14
17	1	65.5903		15
	2	79.0253		16
111	1	12.0501		17
	2	25.4851		18
78	1	20.6176		19
	2	34.0526		20
47	1	47.9078		21
	2	61.3428		22
18	1	61.1998	12	1
	2	74.6348		2
112	1	5.5793		3
	2	19.0143		4
79	1	5.8532		5
	2	19.2882		6
48	1	33.1434		7
	2	46.5784		8
19	1	60.4336		9
	2	73.8686		10
113	1	6.8934		11
	2	20.3284		12
80	1	15.4609		13
	2	28.8959		14
49	1	42.7511		15
	2	56.1861		16
20	1	70.0413		17
	2	83.4763		18
114	1	16.5011		19
	2	29.9361		20
81	1	25.0686		21
	2	38.5036		22

50	1	32.6212	13	1
	2	46.0562		2
21	1	59.9114		3
	2	73.3464		4
82	1	10.3041		5
	2	23.7391		6
51	1	37.5943		7
	2	51.0293		8
22	1	64.8845		9
	2	78.3195		10
52	1	47.2020		11
	2	60.6370		12
23	1	74.4922		13
	2	87.9272		14
53	1	54.8171		15
	2	68.2521		16
24	1	82.1073		17
	2	95.5423		18
25	1	82.7412		19
	2	96.1762		20
26	1	83.3751		21
	2	96.8101		22
288	1	78.9430	14	1
	2	92.3780		2
220	1	14.7754		3
	2	28.2104		4
255	1	42.0656		5
	2	55.5006		6
289	1	69.3558		7
	2	82.7908		8
184	1	6.2061		9
	2	19.6411		10
221	1	5.1660		11
	2	18.6010		12
256	1	32.4562		13
	2	45.8912		14
290	1	59.7464		15
	2	73.1814		16
185	1	6.2663		17
	2	19.7013		18
222	1	7.3064		19
	2	20.7414		20
257	1	34.5966		21
	2	48.0316		22
291	1	71.4903	15	1
	2	84.9253		2
186	1	8.3424		3
	2	21.7774		4
149	1	35.6326		5
	2	49.0676		6
223	1	7.3023		7
	2	20.7373		8
258	1	34.5925		9
	2	48.0275		10
292	1	61.8827		11
	2	75.3177		12
187	1	4.1300		13
	2	17.5650		14
150	1	31.4202		15
	2	44.8552		16
224	1	5.1701		17
	2	18.6051		18
259	1	32.4603		19
	2	45.8953		20
293	1	59.7505		21
	2	73.1855		22

188	1	10.4773	16	1
	2	23.9123		2
151	1	37.7675		3
	2	51.2025		4
225	1	9.4363		5
	2	22.8713		6
260	1	36.7265		7
	2	50.1615		8
294	1	64.0167		9
	2	77.4517		10
189	1	4.0322		11
	2	17.4672		12
152	1	31.3224		13
	2	44.7574		14
226	1	5.0716		15
	2	18.5066		16
261	1	32.3618		17
	2	45.7968		18
295	1	59.6520		19
	2	73.0870		20
190	1	11.6030		21
	2	25.0380		22
153	1	39.9052	17	1
	2	53.3402		2
227	1	11.5749		3
	2	25.0099		4
262	1	38.8651		5
	2	52.3001		6
296	1	66.1553		7
	2	79.5903		8
191	1	5.0997		9
	2	18.5347		10
154	1	32.3899		11
	2	45.8249		12
228	1	4.0596		13
	2	17.4946		14
263	1	31.3498		15
	2	44.7848		16
297	1	58.6400		17
	2	72.0750		18
192	1	9.4667		19
	2	22.9017		20
155	1	36.7569		21
	2	50.1919		22
229	1	13.7090	18	1
	2	27.1440		2
264	1	40.9992		3
	2	54.4342		4
298	1	68.2894		5
	2	81.7244		6
193	1	5.1436		7
	2	18.5786		8
156	1	32.4338		9
	2	45.8688		10
230	1	4.1036		11
	2	17.5386		12
265	1	31.3938		13
	2	44.8288		14
299	1	58.6840		15
	2	72.1190		16
194	1	7.3304		17
	2	20.7654		18
157	1	34.6206		19
	2	48.0556		20
231	1	8.3698		21
	2	21.8048		22

266	1	43.1354	19	1
	2	56.5704		2
300	1	70.4256		3
	2	83.8606		4
195	1	7.2800		5
	2	20.7150		6
158	1	34.5702		7
	2	48.0052		8
232	1	6.2399		9
	2	19.6749		10
267	1	33.5301		11
	2	46.9651		12
301	1	60.8203		13
	2	74.2553		14
196	1	5.1924		15
	2	18.6274		16
159	1	32.4826		17
	2	45.9176		18
233	1	6.2325		19
	2	19.6675		20
268	1	33.5227		21
	2	46.9577		22
302	1	72.5619	20	1
	2	85.9969		2
197	1	9.4149		3
	2	22.8499		4
160	1	36.7051		5
	2	50.1401		6
234	1	8.3739		7
	2	21.8089		8
269	1	35.6641		9
	2	49.0991		10
303	1	62.9543		11
	2	76.3893		12
198	1	3.0577		13
	2	16.4927		14
161	1	30.3479		15
	2	43.7829		16
235	1	4.0972		17
	2	17.5322		18
270	1	31.3874		19
	2	44.8224		20
304	1	58.6776		21
	2	72.1126		22
199	1	11.5513	21	1
	2	24.9863		2
162	1	38.8415		3
	2	52.2765		4
236	1	10.5103		5
	2	23.9453		6
271	1	37.8005		7
	2	51.2355		8
305	1	65.0907		9
	2	78.5257		10
200	1	5.1071		11
	2	18.5421		12
163	1	32.3973		13
	2	45.8323		14
237	1	5.1220		15
	2	18.5570		16
272	1	32.4122		17
	2	45.8472		18
306	1	59.7024		19
	2	73.1374		20
201	1	10.5291		21
	2	23.9641		22

164	1	40.9791	22	1
	2	54.4141		2
238	1	12.6489		3
	2	26.0839		4
273	1	39.9391		5
	2	53.3741		6
307	1	67.2293		7
	2	80.6643		8
202	1	4.0799		9
	2	17.5149		10
165	1	31.3701		11
	2	44.8051		12
239	1	3.0389		13
	2	16.4739		14
274	1	30.3291		15
	2	43.7641		16
308	1	57.6193		17
	2	71.0543		18
203	1	8.3928		19
	2	21.8278		20
166	1	35.6830		21
	2	49.1180		22
240	1	14.7852	23	1
	2	28.2202		2
275	1	42.0754		3
	2	55.5104		4
309	1	69.3656		5
	2	82.8006		6
204	1	6.2176		7
	2	19.6526		8
167	1	33.5078		9
	2	46.9428		10
241	1	5.1775		11
	2	18.6125		12
276	1	32.4677		13
	2	45.9027		14
310	1	59.7579		15
	2	73.1929		16
205	1	6.2565		17
	2	19.6915		18
168	1	33.5467		19
	2	46.9817		20
242	1	7.2959		21
	2	20.7309		22
277	1	44.2094	24	1
	2	57.6444		2
311	1	71.4996		3
	2	84.9346		4
206	1	8.3525		5
	2	21.7875		6
169	1	35.6427		7
	2	49.0777		8
243	1	7.3115		9
	2	20.7465		10
278	1	34.6017		11
	2	48.0367		12
312	1	61.8919		13
	2	75.3269		14
207	1	4.1184		15
	2	17.5534		16
170	1	31.4086		17
	2	44.8436		18
244	1	5.1585		19
	2	18.5935		20
279	1	32.4487		21
	2	45.8837		22

313	1	73.6398	25	1
	2	87.0748		2
208	1	10.4902		3
	2	23.9252		4
171	1	37.7804		5
	2	51.2154		6
245	1	9.4501		7
	2	22.8851		8
280	1	36.7403		9
	2	50.1753		10
314	1	64.0305		11
	2	77.4655		12
209	1	4.0448		13
	2	17.4798		14
172	1	31.3350		15
	2	44.7700		16
246	1	5.0848		17
	2	18.5198		18
281	1	32.3750		19
	2	45.8100		20
315	1	59.6652		21
	2	73.1002		22
210	1	12.6266	26	1
	2	26.0616		2
173	1	39.9168		3
	2	53.3518		4
247	1	11.5865		5
	2	25.0215		6
282	1	38.8767		7
	2	52.3117		8
316	1	66.1669		9
	2	79.6019		10
211	1	5.0882		11
	2	18.5232		12
174	1	32.3784		13
	2	45.8134		14
248	1	4.0481		15
	2	17.4831		16
283	1	31.3383		17
	2	44.7733		18
317	1	58.6285		19
	2	72.0635		20
212	1	9.4552		21
	2	22.8902		22
175	1	42.0530	27	1
	2	55.4880		2
249	1	13.7228		3
	2	27.1578		4
284	1	41.0130		5
	2	54.4480		6
318	1	68.3032		7
	2	81.7382		8
213	1	5.1552		9
	2	18.5902		10
176	1	32.4454		11
	2	45.8804		12
250	1	4.1151		13
	2	17.5501		14
285	1	31.4053		15
	2	44.8403		16
319	1	58.6955		17
	2	72.1305		18
214	1	7.3188		19
	2	20.7538		20
177	1	34.6090		21
	2	48.0440		22

251	1	15.8568	28	1
	2	29.2918		2
286	1	43.1470		3
	2	56.5820		4
215	1	7.2902		5
	2	20.7252		6
178	1	34.5804		7
	2	48.0154		8
252	1	6.2492		9
	2	19.6842		10
287	1	33.5394		11
	2	46.9744		12
216	1	5.1825		13
	2	18.6175		14
179	1	32.4727		15
	2	45.9077		16
253	1	6.2219		17
	2	19.6569		18
217	1	14.7902		19
	2	28.2252		20
180	1	42.0804		21
	2	55.5154		22
254	1	8.3878	29	1
	2	21.8228		2
218	1	3.0462		3
	2	16.4812		4
181	1	30.3364		5
	2	43.7714		6
144	1	57.6266		7
	2	71.0616		8
219	1	12.6539		9
	2	26.0889		10
182	1	39.9441		11
	2	53.3791		12
145	1	67.2343		13
	2	80.6693		14
183	1	49.5517		15
	2	62.9867		16
146	1	76.8419		17
	2	90.2769		18
147	1	79.4404		19
	2	92.8754		20
148	1	80.0744		21
	2	93.5094		22