## 1. Objectives:

- Design Solar System of Mall of Sargodha, Sargodha on Helioscope

## 2. Theoretical Background:

Solar energy, radiation from the Sun capable of producing heat, causing chemical reactions, or generating electricity. The total amount of solar energy incident on Earth is vastly more than the world's current and anticipated energy requirements. If suitably harnessed, this highly diffused source has the potential to satisfy all future energy needs. In the 21st century solar energy is expected to become increasingly attractive as a renewable energy source because of its inexhaustible supply and its non-polluting character, in stark contrast to the finite fossil fuels coal, petroleum, and natural gas.

### 2.1. Solar panels:

A solar panel (also known as "PV panels") is a device that converts light from the sun, which is composed of particles of energy called "photons", into electricity that can be used to power electrical loads.

Solar panels can be used for a wide variety of applications including remote power systems for cabins, telecommunications equipment, remote sensing, and of course to produce electricity by residential and commercial solar electric systems.

#### 2.1.1. How do solar panels work:

Solar panels collect clean renewable energy in the form of sunlight and convert that light into electricity which can then be used to provide power for electrical loads. Solar panels are comprised of several individual solar cells which are themselves composed of layers of silicon, phosphorous (which provides the negative charge), and boron (which provides the positive charge). Solar panels absorb the photons and in doing so initiate an electric current. The resulting energy generated from photons striking the surface of the solar panel allows electrons to be knocked out of their atomic orbits and released into the electric field generated by the solar cells which then pull these free electrons into a directional current. This entire process is known as the Photovoltaic Effect.

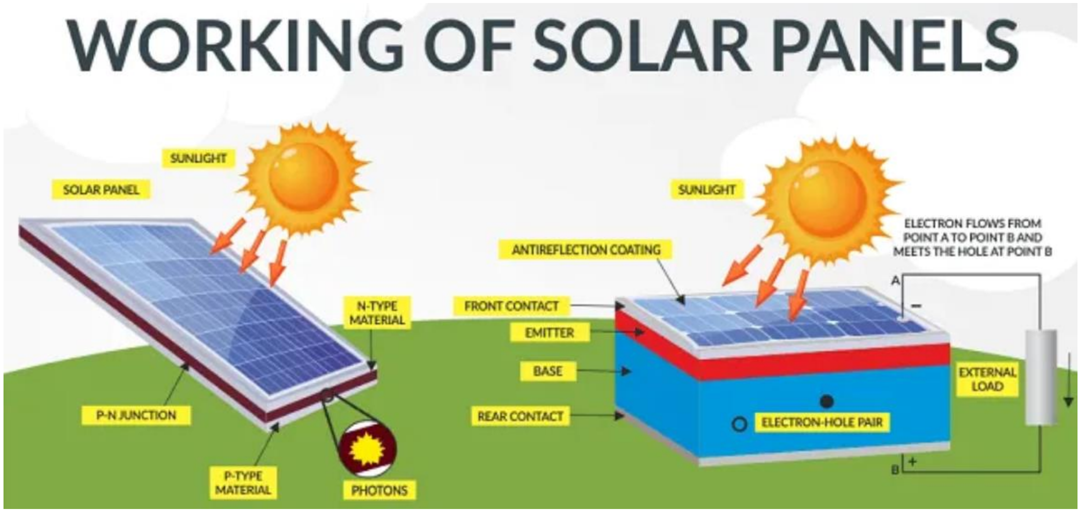



Fig 1: Working of solar panels

## 2.2. Types of solar panels:

There are 4 different types of solar panels named as:

1. Monocrystalline
2. Polycrystalline
3. PERCT
4. Thin-film panels.

### 2.2.1. Monocrystalline solar panels

Also known as single-crystal panels, these are made from a single pure silicon crystal that is cut into several wafers. Since they are made from pure silicon, they can be readily identified by their dark black colour. The use of pure silicon also makes monocrystalline panels the most space efficient and longest lasting among all three solar panel types.

However, this comes at a cost — a lot of silicon is wasted to produce one monocrystalline cell, sometimes reaching over 50%. This results in a hefty price tag.

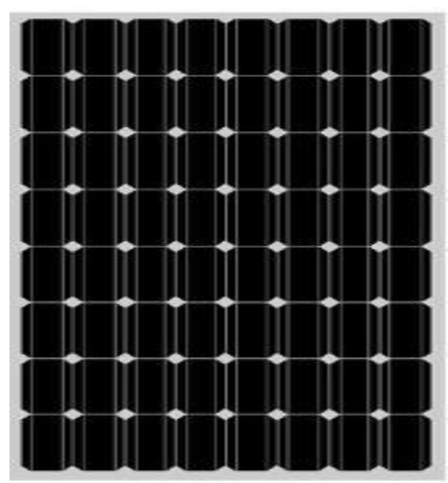


Fig 2: Monocrystalline solar panels

### 2.2.2. Polycrystalline solar panels:

As the name implies, these come from different silicon crystals instead of one. The silicon fragments are melted and poured into a square Mold. This makes polycrystalline cells much more affordable since there is hardly any wastage and gives them that characteristic square shape. However, this also makes them less efficient in terms of energy conversion and space since their silicon purity and construction are lower than monocrystalline panels. They also have lower heat.

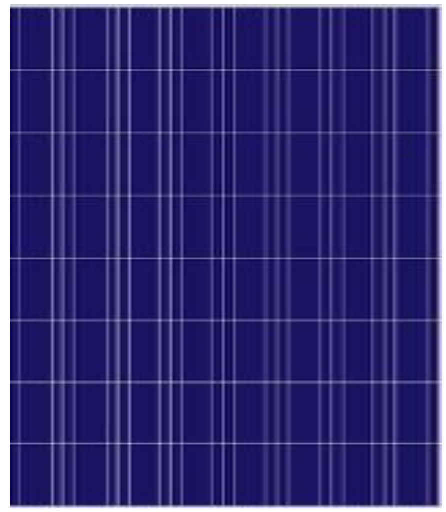


Fig 3: Polycrystalline solar panels

tolerance, which means they are less efficient in high

### 2.2.3. Passivated Emitter and Rear Cell (PERC) panels:

PERC solar panels are an improvement of the traditional monocrystalline cell. This relatively new technology adds a passivation layer in the rear surface of the cell that enhances efficiency in several ways:

It reflects light back into the cell, increasing the amount of solar radiation that gets absorbed.

It reduces the natural tendency of electrons to recombine and inhibit the flow of electrons in the system.

It allows greater wavelengths of light to be reflected. Light waves over 1,180nm can't be absorbed by silicon wafers and simply pass through, so they end up heating the cell's metal back sheet and reduce its efficiency. The passivation layer reflects these higher wavelengths and stops them from heating up the back sheet.

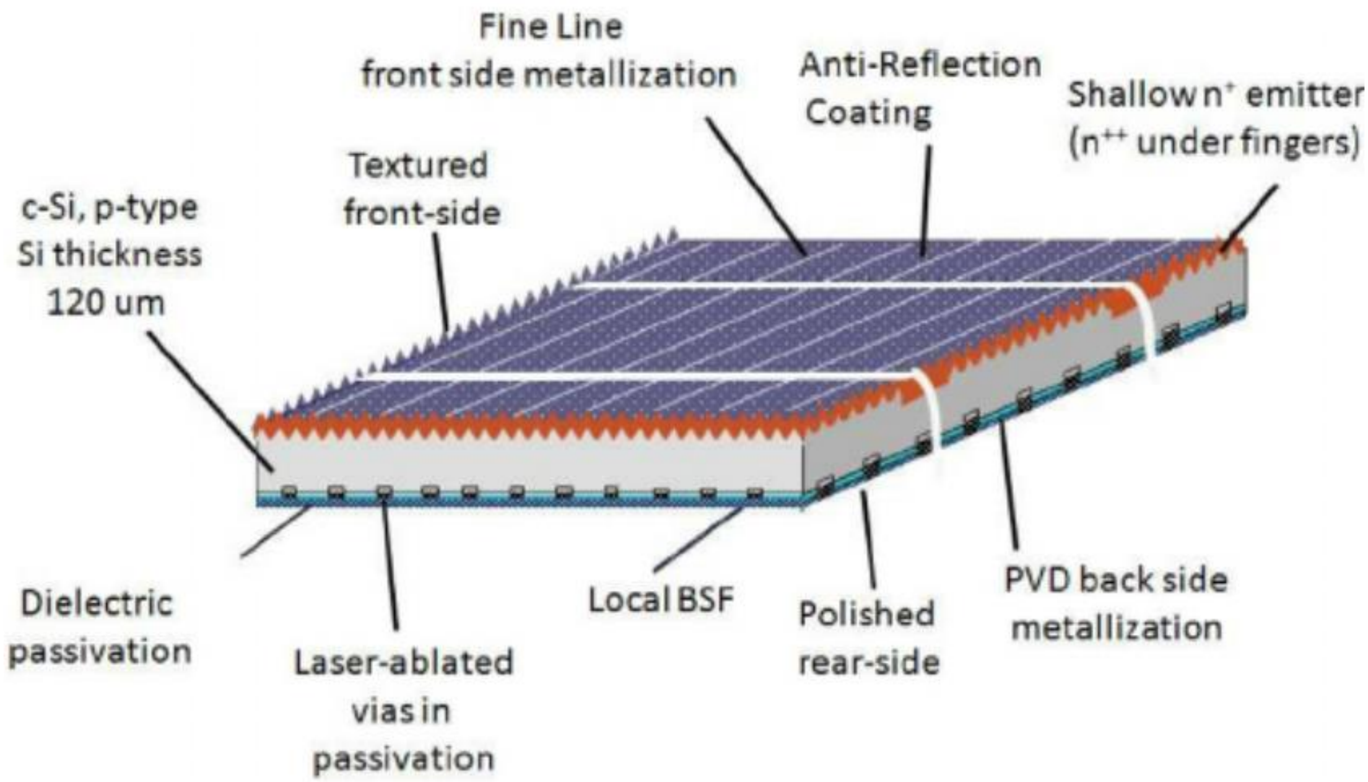



Fig 4: Passivated Emitter and Rear Cell (PERC) panels

### 2.2.4. Thin-film solar panels:

Thin-film panels are characterized by very fine layers that are thin enough to be flexible. Each panel does not require a frame backing, making them lighter and easier to install. Unlike crystalline silicon panels that come in standardized sizes of 60, 72, and 96-cell counts, thin-film panels can come in different sizes to suit specific needs. However, they are less efficient than typical silicon solar panels.

Fig 5: Thin film solar panels

## 2.3. Solar Inverter:

A solar inverter is one of the most crucial parts of a solar power system. A solar inverter converts the energy output from solar panels into a usable electricity form, to be utilised in your home or workplace.

### 2.3.1. How does a solar inverter work:

A solar inverter works by taking in the variable direct current, or 'DC' output, from your solar panels and transforming it into alternating 120V/240V current, or 'AC' output. The appliances in your home run on AC, not DC, which is why the solar inverter must change the DC output that is collected by your solar panels.

Once this energy is produced, it is either stored in a battery for later use or sent directly to an inverter (this depends on the type of system you have). When the energy gets sent to the inverter, it is in DC format but your home requires AC. The inverter grabs the energy and runs it through a transformer, which then spits out an AC output. The inverter, in essence, 'tricks' the transformer into thinking that the DC is actually AC, by forcing it to act in a way like AC – the inverter runs the DC through two or more transistors that turn on and off super fast and feed two varying sides of the transformer.


Fig 6: Conversion of DC to AC using inverters

### 2.3.2. Types of solar inverters

Now you know what a solar inverter is and how it works, it's time to look at the different types of inverters. There are 5 different kinds of solar inverters, all with varying benefits.

#### 2.3.2.1. Battery Inverters

A battery inverter is the best option if you are needing to retrospectively fit a battery into your solar system or are wanting to keep your battery separate from your solar panels and run through a different inverter. A battery inverter converts your battery power into 230V AC and feeds it into your switchboard (instead of grid power) wherever possible.

#### 2.3.2.2. Central Inverters

A central inverter is *huge* and is used for systems requiring hundreds of kilowatts (or even sometimes megawatts) of volume. They aren't for residential use and resemble a large metal cabinet, with each 'cabinet' being able to handle around 500kW of power. They are generally used commercially for large-scale installations, or for utility-scale solar farms.

#### 2.3.2.3. Hybrid Inverters

Hybrid inverters, otherwise known as 'multi-mode inverters', are uncommon in Australia and allow you to connect batteries to your solar system. It engages with the connected batteries through 'DC coupling' (when both the solar and batteries use one inverter and the DC from the solar panels charges the batteries via a DC charger) and its electronics organise the charging and discharging of the battery.

#### 2.3.2.4. String inverters

Finally, there are string inverters. String inverters are the most common inverter option for residential use, and there is usually 1 string inverter per solar installation. They are known as 'string inverters' since a string of solar panels is connected to them.

## 2.4. Helioscope:

Helioscope is the solar industry's leading software platform for designing high-performance solar arrays. Folsom Labs develops Helioscope, an advanced solar PV design & sales tool. It is an online software that gives specific power output from specific area/Location. Helioscope simplifies the process of engineering and selling solar projects by integrating easy layout tools with bankable performance modelling. Helioscope offers CAD Caliber layouts, remote shade analysis, and bankable energy yield calculations. It allows anyone to generate solar layouts and performance estimates. The 4 different modules of helioscope are as follows:

### 2.4.1. Mechanical

This module includes settings related to selection of area for solar panels, their placement, spacing between two adjacent rows, height of panels or solar panels tilt and setbacks, etc.

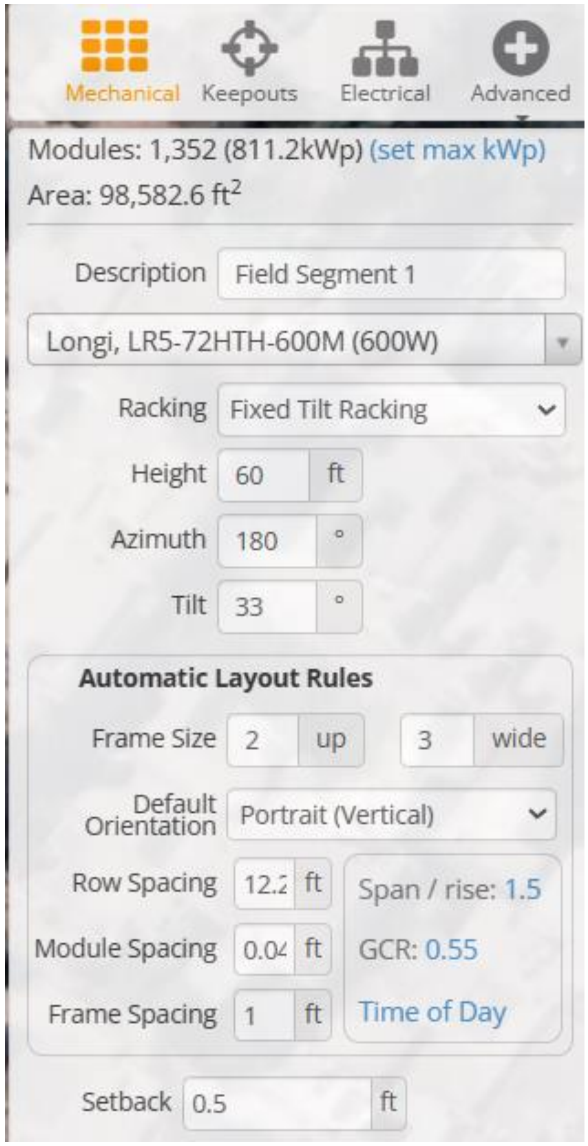



Fig: Mechanical

### 2.4.2. Keep-Outs

If there are any hurdles, trees, or shelter on the site where solar PV is to be installed, it allows to select all those obstacles remove solar panels from installation on that spot.

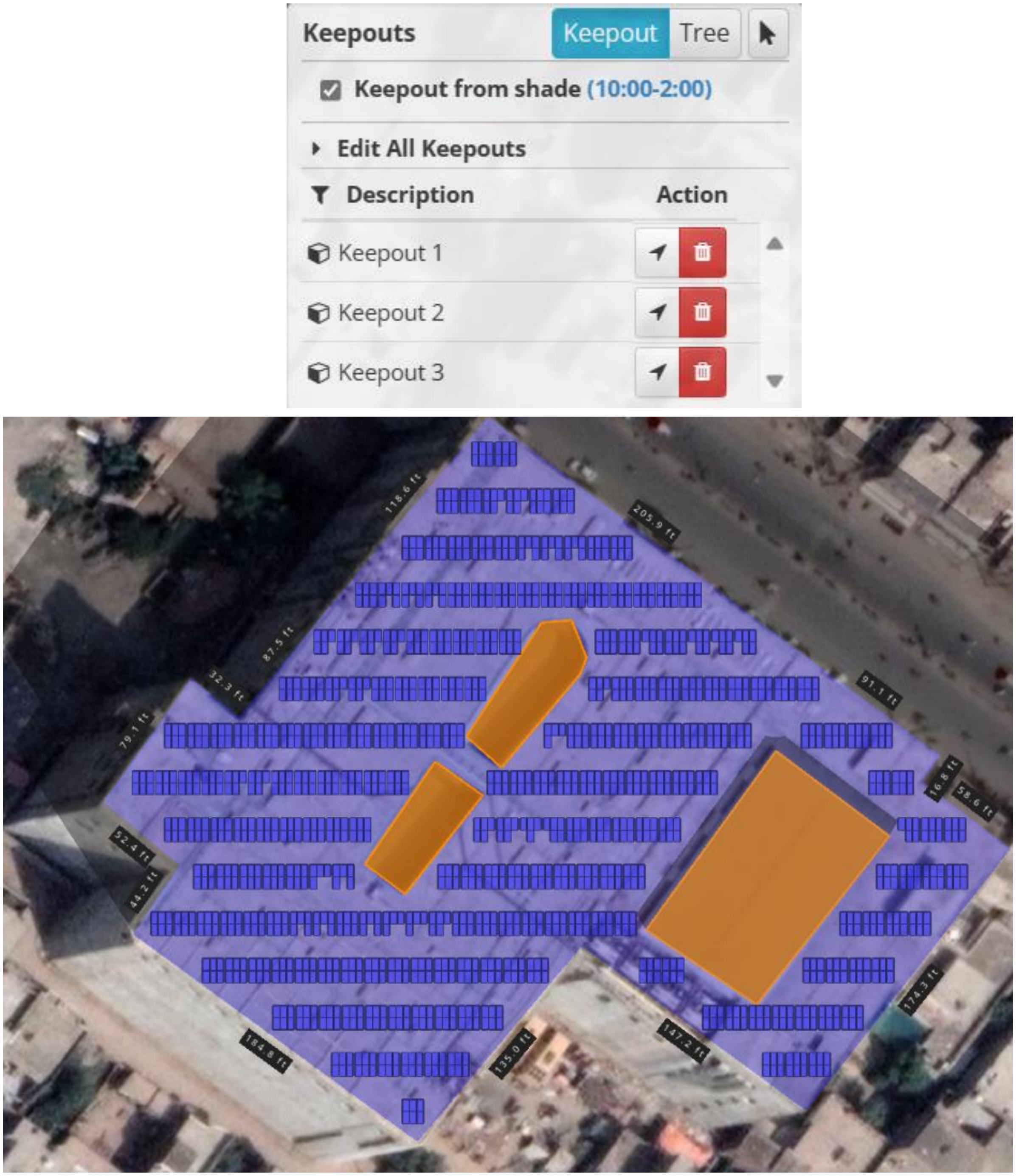
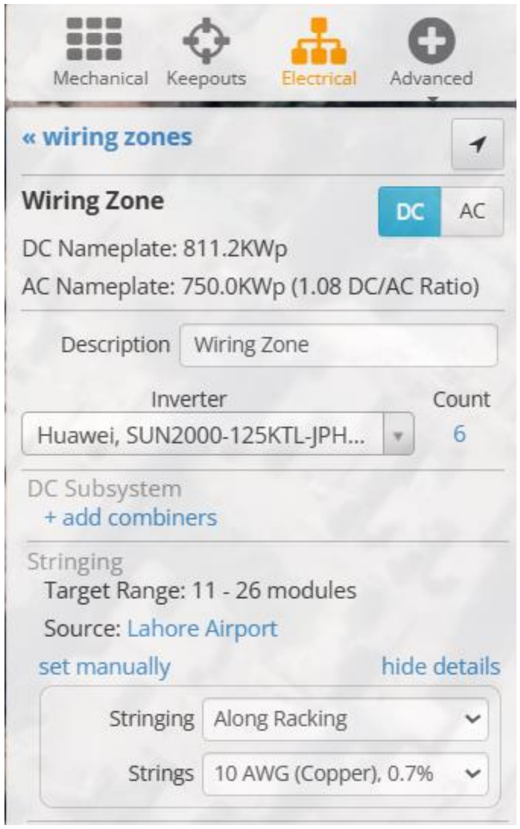



Fig: Keepouts

### 2.4.3. Electrical

It includes selection of electrical components inverter sizing and selection of cables etc.



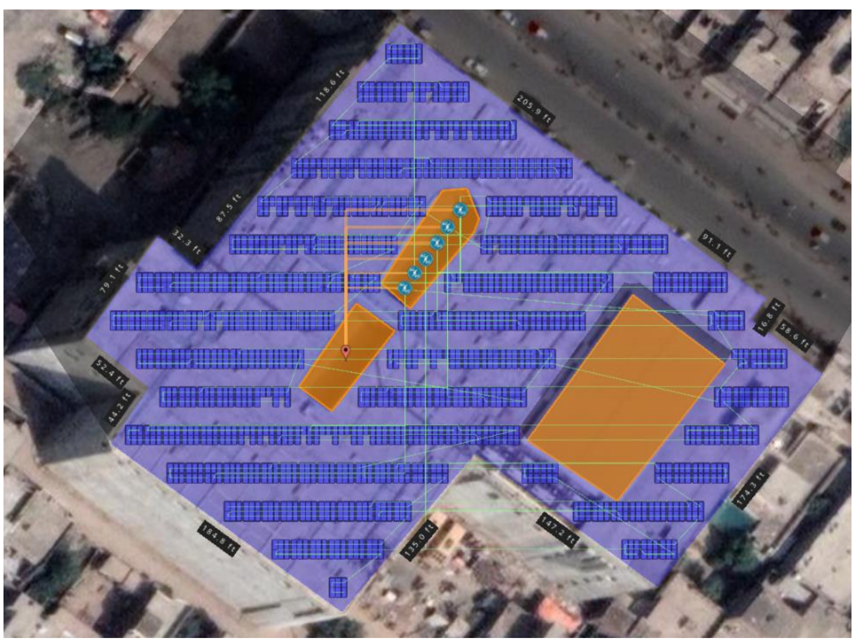



Fig: Electrical

### 2.4.4. Advanced

This tab includes shading and overlays analysis.

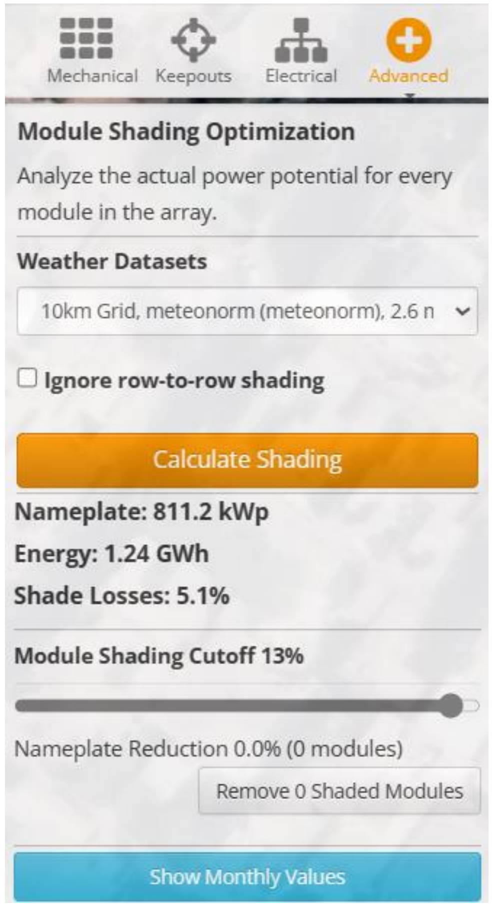



Fig: Advanced

## 2.5. Important terms use in Helioscope:

### 2.5.1. Azimuthal Angle:

Azimuth is the angle that the solar panels are facing and is measured in a clockwise direction from north. Because the sun moves in the sky throughout the day, it's important to position each panel so it produces the most electricity when you need it. If you are not at home in the middle of the day, it would be advantageous to produce less overall electricity by facing the panels west or east. This can allow you to spread the generation between the morning and the afternoon, to match when you use electricity. Increasing the amount of solar energy that you consume yourself, is the key to getting the best savings from your solar system.

### 2.5.2. Tilt Angle:

The tilt angle of the system is the angle it sits on the roof or racking it's attached too. PV modules should ideally be tilted at an angle that's equal to the site's latitude. However, the panels will often be attached to a roof and will follow that angle instead. This may not always be ideal, but it will be the most practical and affordable, and in most cases will still produce good results.
If a roof is flat, a tilt frame might also be used to get the angle closer to the latitude.

Having some tilt to the panels also means that they'll be cleaned when it rains.

### 2.5.3. Stringing:

To have a functional solar PV system, you need to wire the panels together to create an electrical circuit through which current will flow, and you also need to wire the panels to the inverter that will convert the DC power produced by the panels to AC power that can be used in your home and sent to the grid. In the solar industry. This is typically referred to as "stringing" and each series of panels connected is referred to as a string.

### 2.5.4. Intra-row spacing:

It is recommended that a distance between panel rows of at least 1.5 times panel height. This would be enough [to leave] sufficient space for vegetation to develop naturally in between panel arrays.

### 2.5.5. Shading:

Shading analysis is a very crucial step in finalizing panel locations in distributed Photo Voltaic (PV) solar installation. The extent of the rooftop area required by a solar PV plant is a factor of panel efficiency and extent of shading. Any kind of shading is detrimental to the performance of the entire solar PV plant. Solar panels are mostly arranged in strings to meet voltage requirements. A shade in one panel not only reduces the efficiency of that panel but cuts short supply from entire string.

### 2.5.5.1. How do shadows effect PV and VI curves?

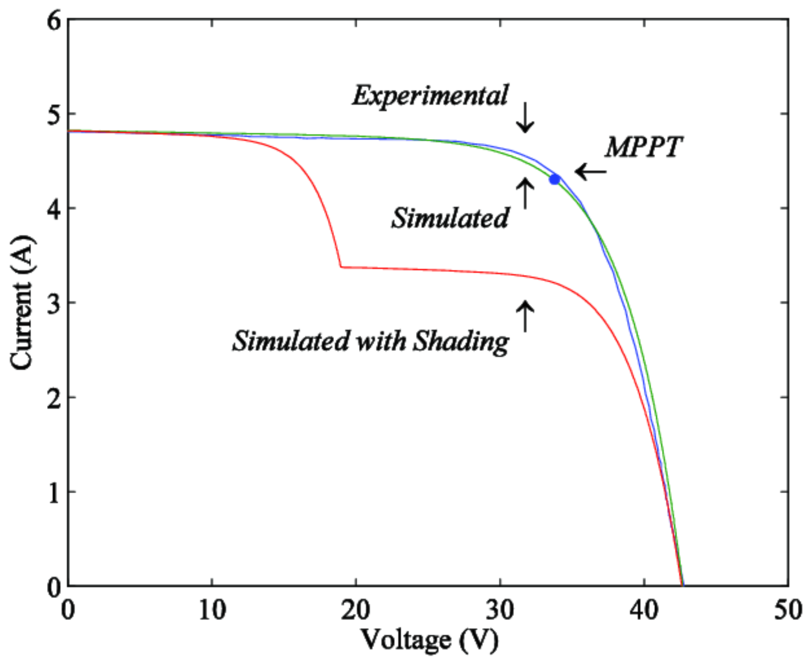



Fig: Effect of shading

### 2.5.5.2. How change in temperature and irradiance effects the power of PV system?

Isc increases slightly with temperature, this is so small that it is normally ignored. However, a more significant effect is the temperature dependence of voltage which decreases with increasing temperature. Typically, the voltage will decrease by 2.3mV per °C per cell.

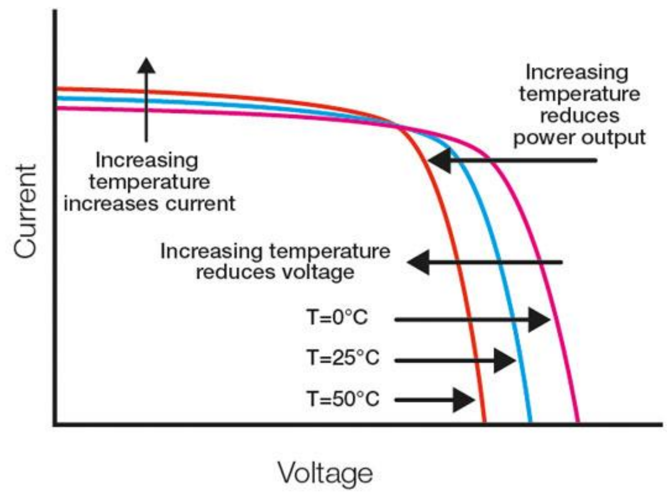



Fig: Effect of temperature on VI curve

Solar irradiance is a measure of the sun's energy, under standard conditions the amount of energy reaching the Earth's surface on a clear day is taken to be 1kW/m2. The amount of irradiance reduces with the slightest amount of haze and becomes quite small on overcast days. Isc is directly proportional to the irradiance: so that if irradiance halves so does Isc. The voltage variation is very small and usually ignored.

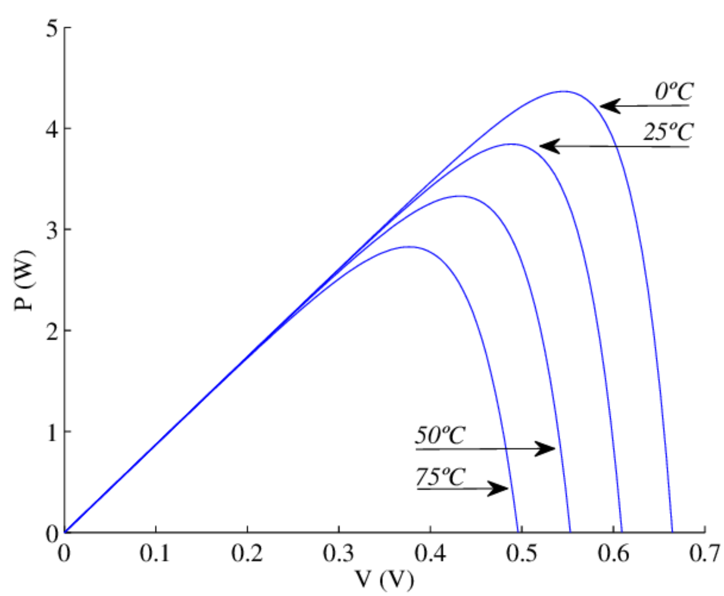



Fig: Effect of temperature on PV curve

## 3.Components used:

Components

| Component | Name | Count |
|---|---|---|
| Inverters | SUN2000-125KTL-JPH0 (Huawei) | 6 (750.0 kW) |
| AC Home Runs | 1/0 AWG (Aluminum) | 6 (2,957.4 ft) |
| Strings | 10 AWG (Copper) | 54 (18,608.9 ft) |
| Module | Longi, LR5-72HTH-600M (600W) | 1,352 (811.2 kW) |

## 4.Procedure:

### Step 1:

First, we have selected the area where we can install solar panels and that is suitable to install solar plates with good efficiency. That’s why we are selecting the Mall of Sargodha, Sargodha where no shadow of building exists and on the whole roof, the sunlight directly falls. Total area is 98,582.6 $ft^2$.

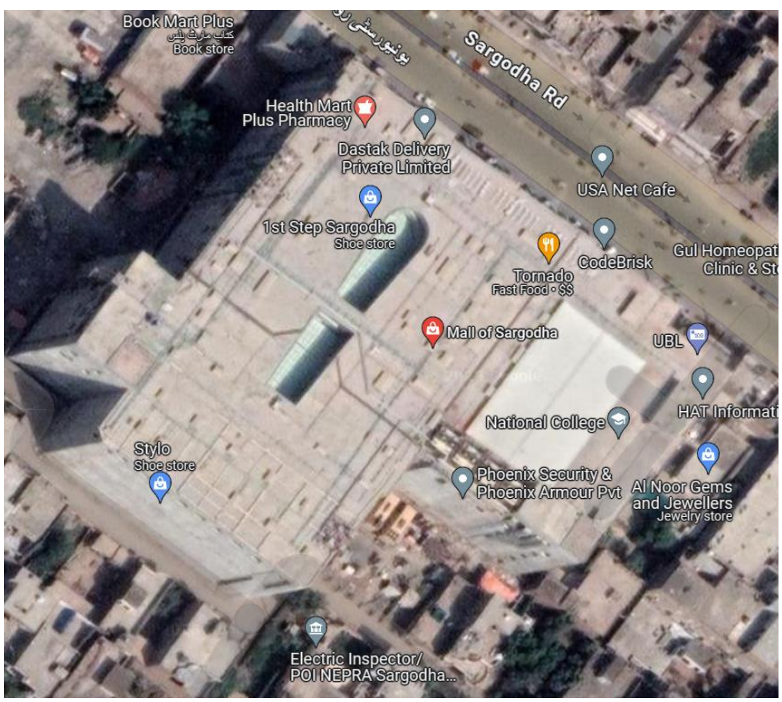



Fig 7: Location to Install solar panels (Mall of Sargodha, Sargodha)

## STEP 2:

Then, we started designing solar panels. Set the tilt angle, azimuthal angle, intra row spacing and then calculate the total number of solar panels we required so that maximum electricity will be produced. We have selected Longi, LR5-72HTH-600M (600W) module of solar panel and after setting all the specification, total 1,352 panels are used that will generate total power of 811.2 kW.

The specifications we selected are:

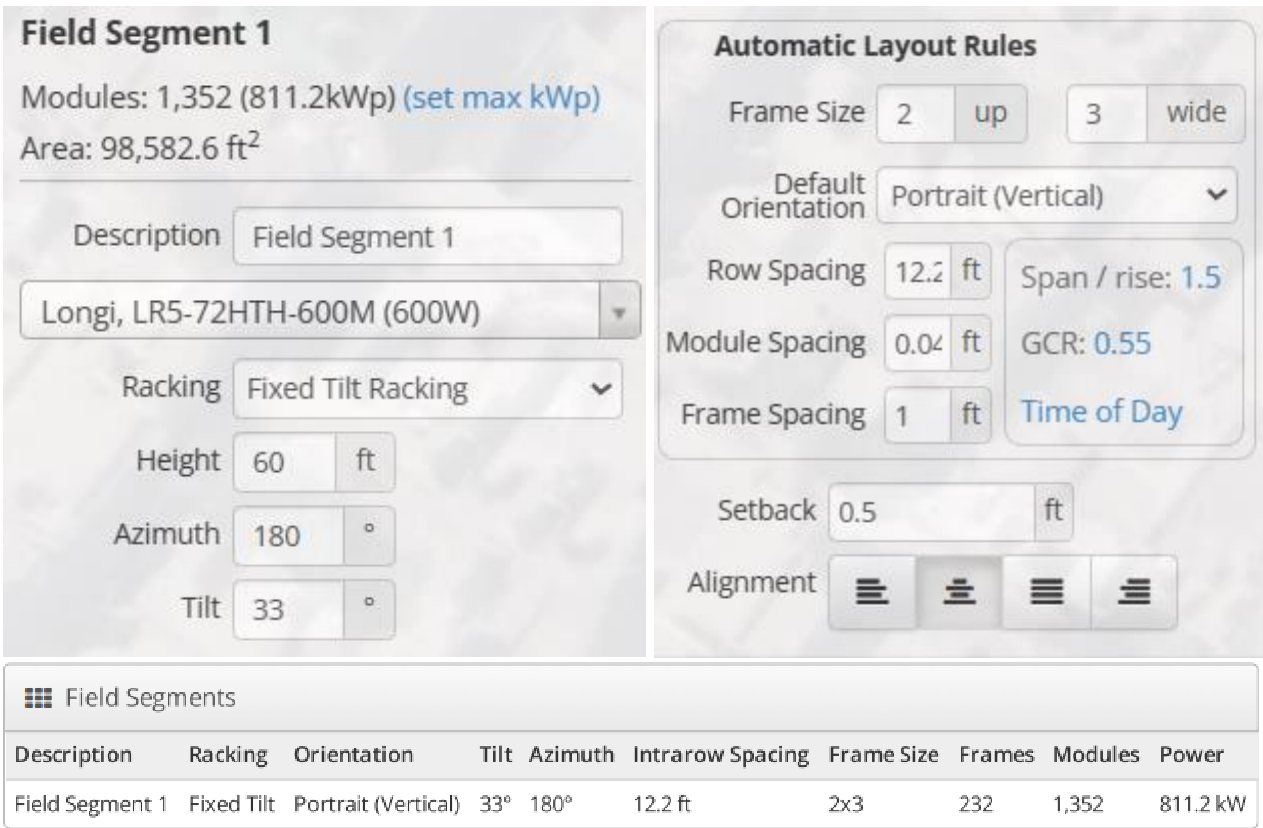



Fig 8: Field segment

## STEP 3:

Then we have selected the inverter type and wiring for solar panels. We have added 6 inverters of SUN2000-125KTL-JPH0 (Huawei). We have used 10 AWG (Copper) strings of 18,608.9 ft.

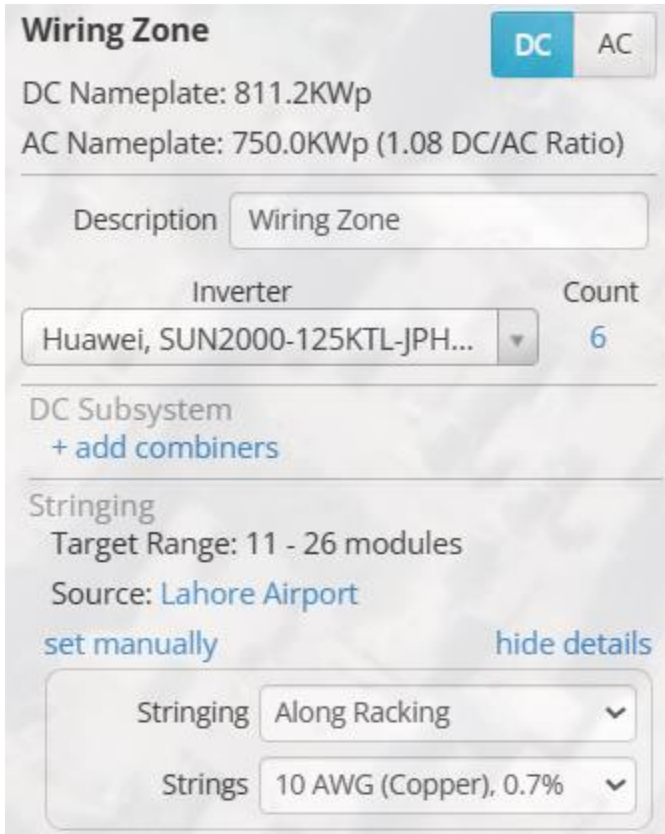



Fig 9: Selection of wiring zone


Wiring Zones

| Description | Combiner Poles | String Size | Stringing Strategy |
|---|---|---|---|
| Wiring Zone | - | 11-26 | Along Racking |

Fig 10: Wiring zone description.

## Design with wiring and inverters:

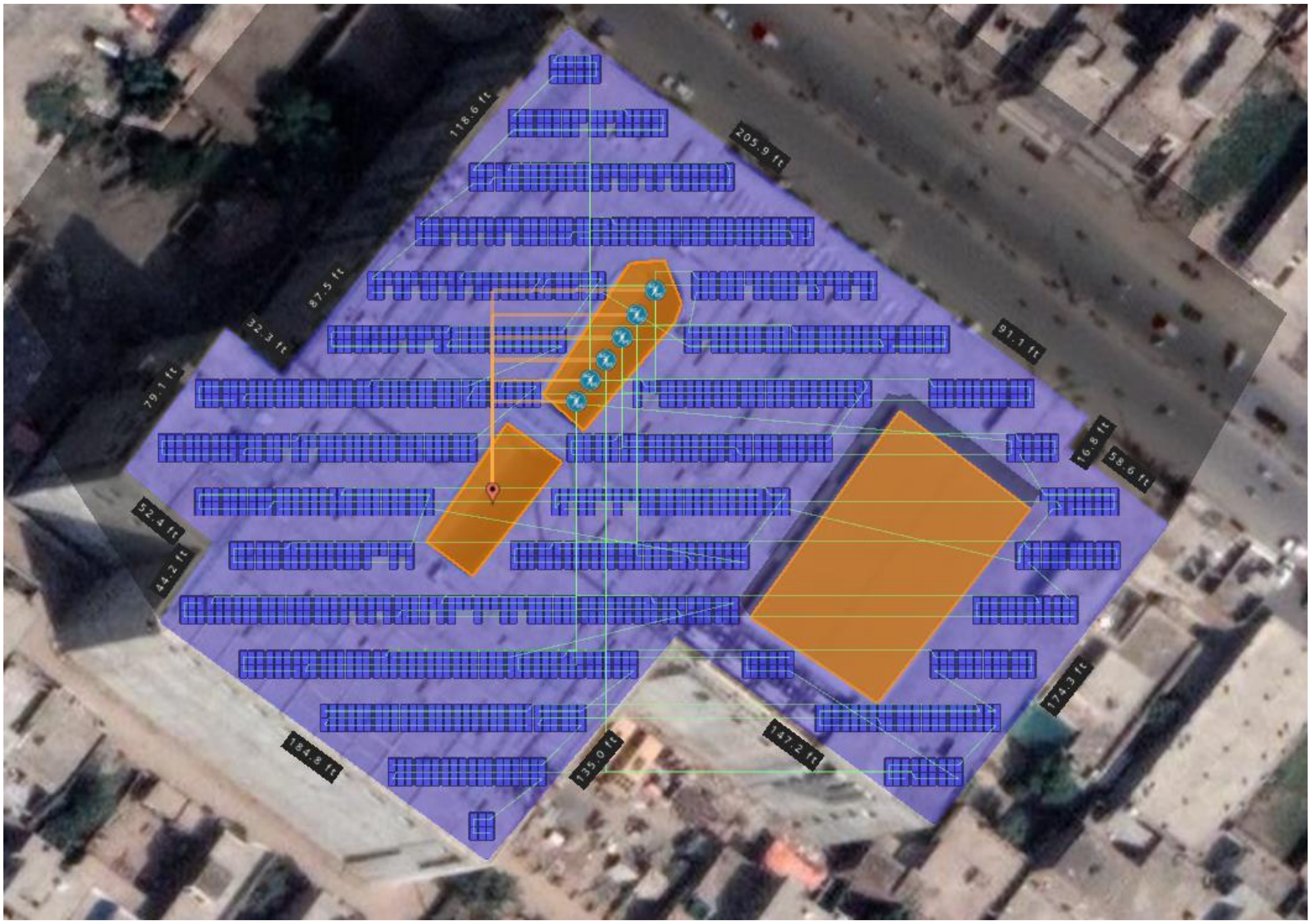



Fig 11: Design with wires and inverters

## STEP 4:

Then, we perform the shading analysis by using advanced options and the report generated shows up. Shading losses are less than 5%, that's why it is acceptable.

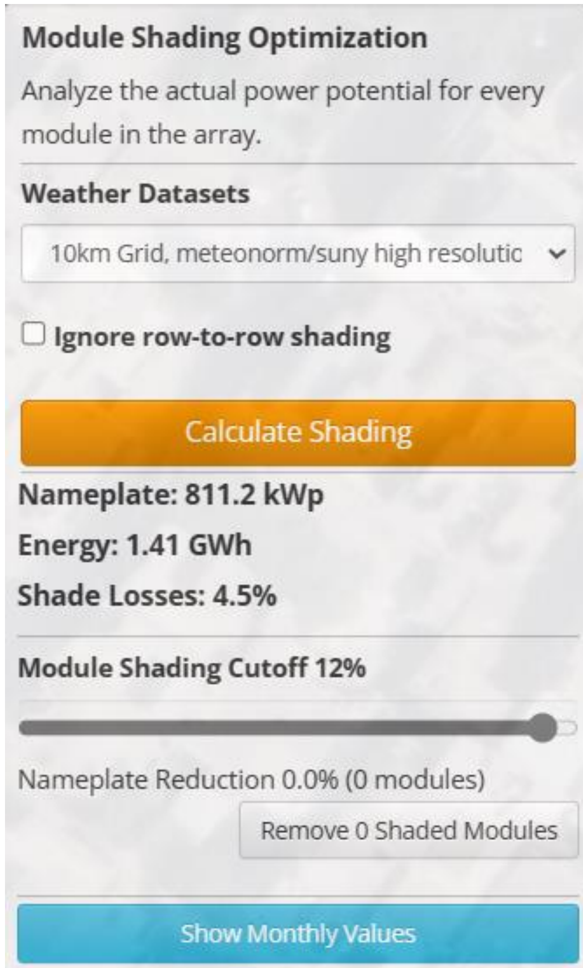



Fig 12: Module shading optimization.

Shading by Field Segment

| Description | Tilt | Azimuth | Modules | Nameplate | Shaded Irradiance |
|---|---|---|---|---|---|
| Field Segment 1 | 33.0° | 180.0° | 1,352 | 811.2 kWp | 1,735.4kWh/m² |
| **Totals, weighted by kWp** | | | **1,352** | **811.2 kWp** | **1,735.4kWh/m²** |

| Description | AC Energy | TOF² | Solar Access | Avg TSRF ² |
|---|---|---|---|---|
| Field Segment 1 | 1.16 GWh¹ | 100.0% | 93.5% | 93.5% |
| **Totals, weighted by kWp** | **1.16 GWh** | **100.0%** | **93.5%** | **93.5%** |

Fig 13: Shading by Field segment.

After applying shading analysis:

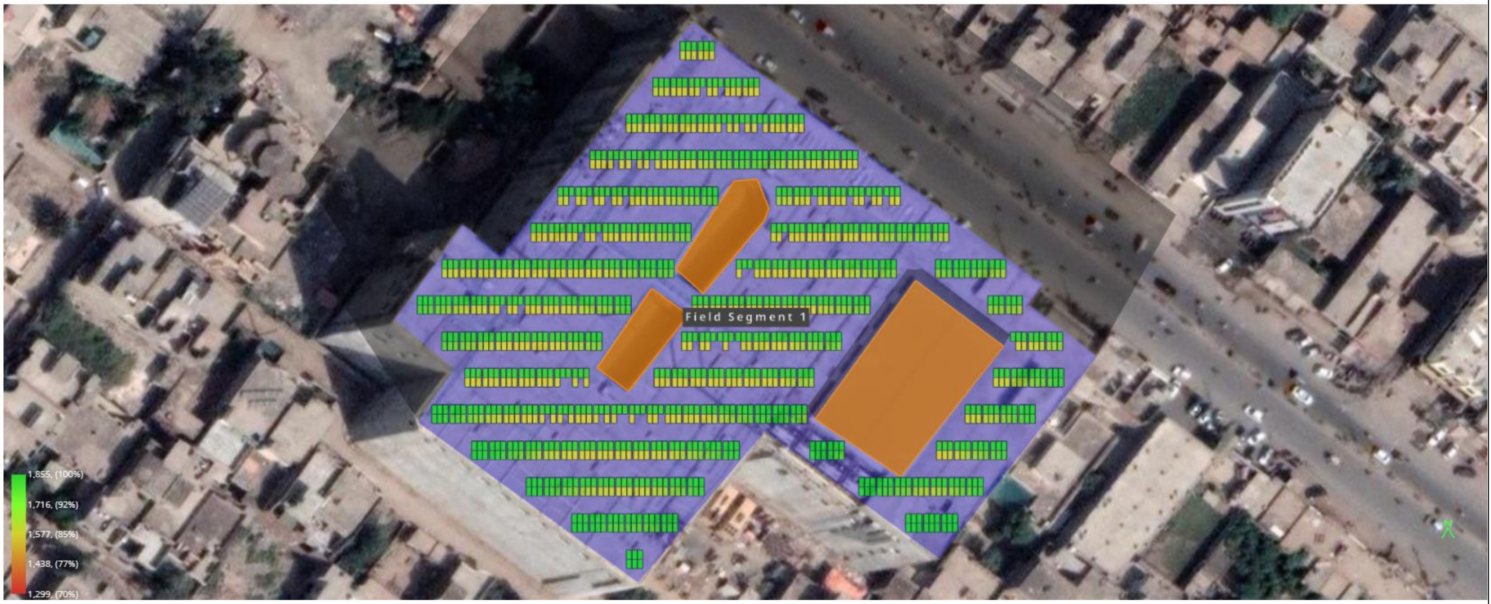



Fig 14: Shading Heatmap

## 4.1. Sources of system loss:

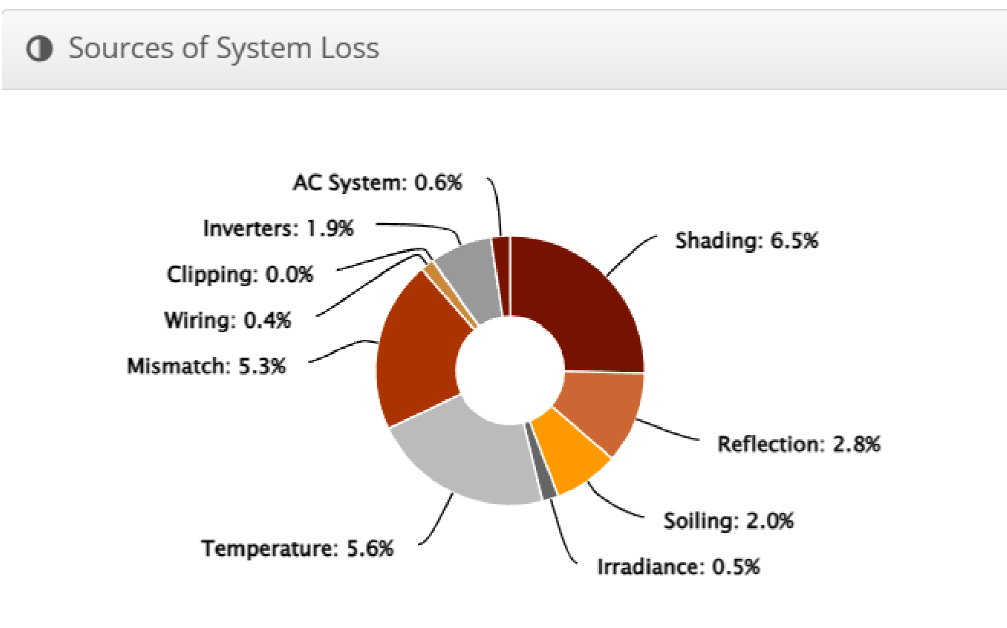



Fig 15: Sources of System Loss

## 4.2. Southwestern Angle of proposed design:

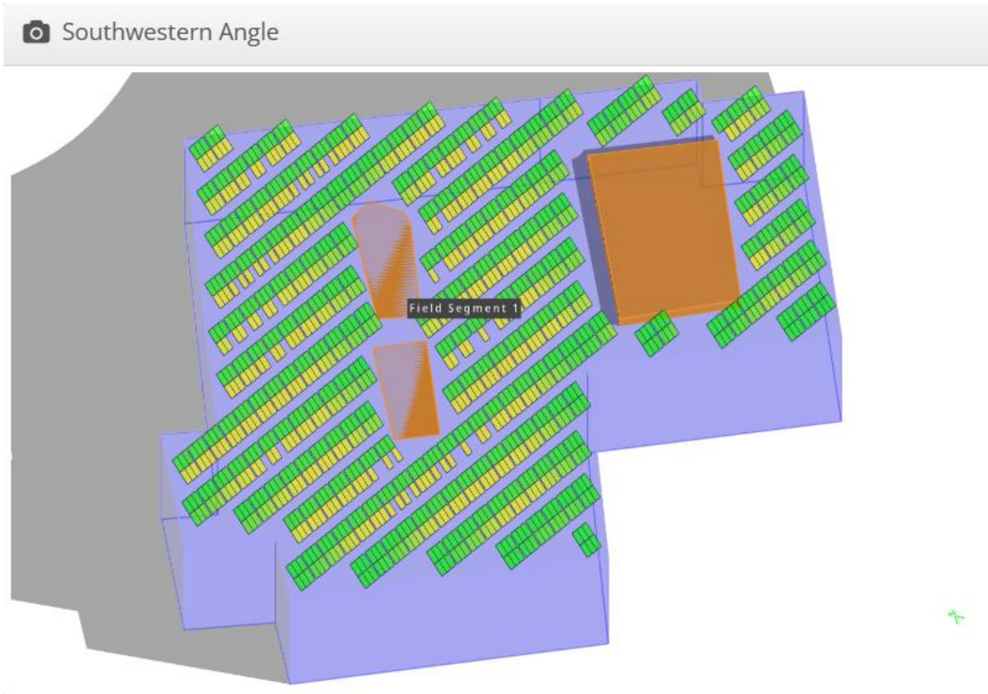



Fig 16: Southwestern Angle

## 4.3. Southeastern Angle of Proposed Design:


Fig 17: Southeastern Angle

## 4.4. Solar access by month:

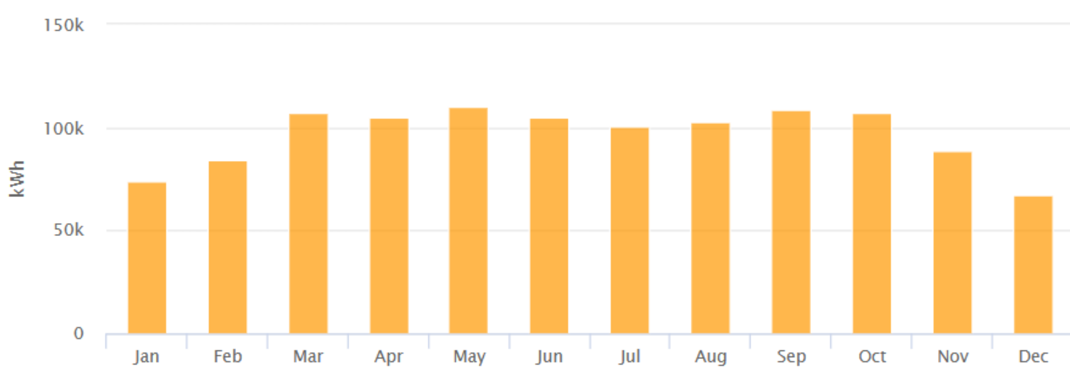
Solar Access by Month

| Description | jan | feb | mar | apr | may | jun |
|---|---|---|---|---|---|---|
| Field Segment 1 | 88% | 95% | 96% | 95% | 95% | 95% |
| **Solar Access, weighted by kWp** | **88.4%** | **95.3%** | **95.9%** | **95.4%** | **95.0%** | **95.0%** |
| **AC Power (kWh)** | **73,586.3** | **83,988.2** | **107,501.7** | **104,834.7** | **109,831.5** | **104,884.9** |
| **Description** | **jul** | **aug** | **sep** | **oct** | **nov** | **dec** |
| Field Segment 1 | 95% | 95% | 96% | 96% | 91% | 82% |
| **Solar Access, weighted by kWp** | **94.8%** | **95.0%** | **95.7%** | **95.8%** | **91.2%** | **81.6%** |
| **AC Power (kWh)** | **100,549.5** | **103,037.4** | **108,339.8** | **107,452.0** | **88,369.9** | **67,260.8** |

Fig 18: Solar access by month

## 4.5. Monthly Report:

Monthly Production

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| Month | GHI (kWh/m$^2$) | POA (kWh/m$^2$) | Shaded (kWh/m$^2$) | Nameplate (kWh) | Grid (kWh) |
|---|---|---|---|---|---|
| January | 84.8 | 125.6 | 111.1 | 86,304.8 | 73,586.3 |
| February | 97.3 | 127.1 | 121.2 | 94,090.5 | 83,988.2 |
| March | 141.1 | 163.6 | 156.9 | 121,494.2 | 107,501.7 |
| April | 158.2 | 163.2 | 155.7 | 120,099.5 | 104,834.7 |
| May | 184.1 | 174.4 | 165.7 | 127,493.5 | 109,831.5 |
| June | 183.4 | 166.4 | 158.0 | 121,369.6 | 104,884.9 |
| July | 171.5 | 159.1 | 150.8 | 115,801.3 | 100,549.5 |
| August | 163.8 | 162.3 | 154.2 | 118,870.1 | 103,037.4 |
| September | 151.8 | 168.5 | 161.2 | 124,615.1 | 108,339.8 |
| October | 132.2 | 165.7 | 158.7 | 123,137.2 | 107,452.0 |
| November | 99.8 | 145.9 | 133.0 | 103,416.4 | 88,369.9 |
| December | 85.3 | 133.3 | 108.8 | 84,490.3 | 67,260.8 |

Fig 19: Monthly Production

The maximum production is in the month of May and minimum production will be in January and December.

## 4.6. Annual Production Report:

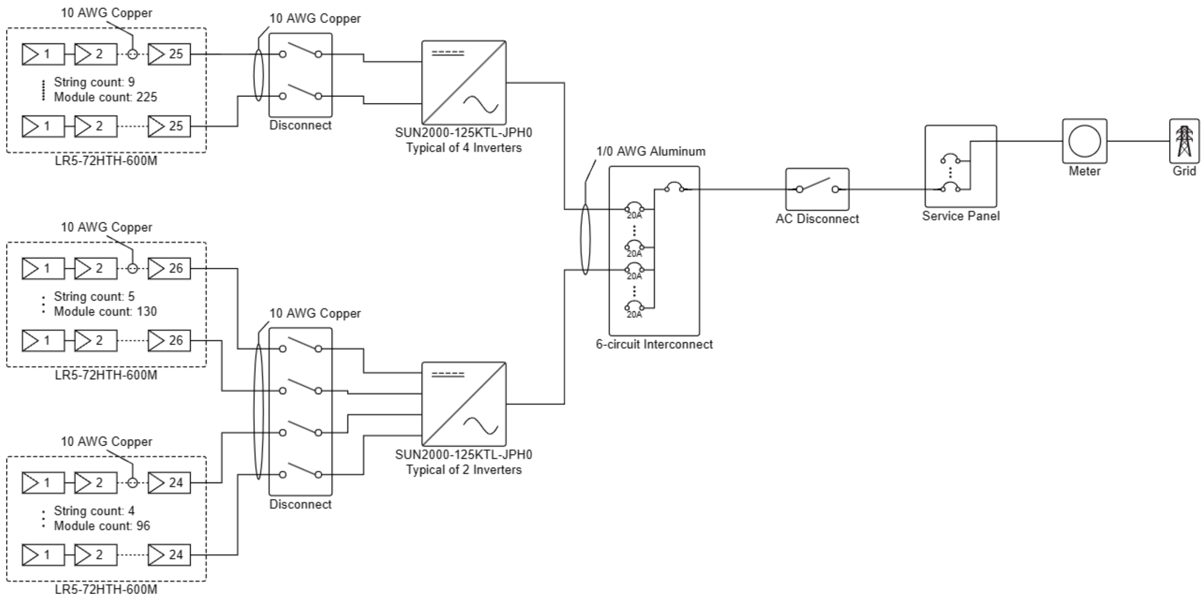
Annual Production

| | Description | Output | % Delta |
|---|---|---|---|
| Irradiance (kWh/m$^2$) | Annual Global Horizontal Irradiance | 1,653.2 | |
| | POA Irradiance | 1,855.1 | 12.2% |
| | Shaded Irradiance | 1,735.4 | -6.5% |
| | Irradiance after Reflection | 1,686.7 | -2.8% |
| | Irradiance after Soiling | 1,652.9 | -2.0% |
| | **Total Collector Irradiance** | **1,652.7** | **0.0%** |
| Energy (kWh) | Nameplate | 1,341,182.3 | |
| | Output at Irradiance Levels | 1,334,625.5 | -0.5% |
| | Output at Cell Temperature Derate | 1,260,420.3 | -5.6% |
| | Output After Mismatch | 1,194,142.7 | -5.3% |
| | Optimal DC Output | 1,189,081.5 | -0.4% |
| | Constrained DC Output | 1,188,973.8 | 0.0% |
| | Inverter Output | 1,166,383.4 | -1.9% |
| | **Energy to Grid** | **1,159,636.6** | **-0.6%** |
| **Temperature Metrics** | | | |
| | Avg. Operating Ambient Temp | | 26.6 °C |
| | Avg. Operating Cell Temp | | 36.3 °C |
| **Simulation Metrics** | | | |
| | | Operating Hours | 4555 |
| | | Solved Hours | 4555 |

Fig 20: Annual Production

## 4.7. Single line diagram:

The single line diagram is shown in this figure. As shown in the diagram, firstly 225 modules are connected to 9 strings to 4 inverters. Then 130 modules are connected to 5 strings and 96 modules are connected to 4 strings, and then they both are connected in parallel to 2 inverters. As there are 6 inverters, so there are 6 circuit interconnects.




| Module Specifications | |
|---|---|
| 1352x Longi LR5-72HTH-600M | |
| STC Rating | 600 W |
| Vmp | 44.66 V |
| Imp | 13.44 A |
| Voc | 52.81 V |
| Isc | 14.46 A |

| Inverter Specifications | |
|---|---|
| 6x Huawei SUN2000-125KTL-JPH0 | |
| Max AC Power Rating | 125 kW |
| Max Input Voltage | 1,500 V |
| Min AC Power Rating | 0 W |
| Min Input Voltage | 500 V |

| Wire Schedule | | |
|---|---|---|
| Tier | Wire | Length |
| AC Branch | 6x 1/0 AWG | 2957ft |
| String | 54x 10 AWG | 18609ft |

Fig: Single Line Diagram

## 4.8. Inverters installation:

We will also install inverters in a space given on the roof of Mall of Sargodha and they will be covered by a shed. Modules are connected in series by string and parallel combination of string will be given to the input of inverters.

## 5. Conclusion:

In this complex engineering problem, we have installed solar modules on roof of Mall of Sargodha, Sargodha. We have set tilt, azimuthal angle, performed shading analysis and set other parameters and tried to make the proposed system as efficient as possible.