ENRICH ENERGY PVT. LTD.

Summer Internship Report

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This report seeks to summarize the learnings from my **Summer Internship at EEPL, Pune** pursued at the end of my first year at IITB.

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Additionally, I would like to thank the entire team at EEPL, Pune for creating a welcoming and conducive learning environment. This internship has been an invaluable experience, and the skills and knowledge I have gained will greatly benefit my future endeavors.

About EEPL

Enrich Energy Pvt. Ltd. was founded in September 2011, with the desire to develop a clean energy source for sustainable living.

Their desire resonates with solar energy, its potential, and emerging technology. Enrich has done several solar projects all across the country and has come a long way since pioneering solar energy in India and is now moving forward into developing leadership positions in other emerging technologies as well, which is in line with its founding philosophy.

1 Basics of working of Solar PVs

The working principle of Solar Photovoltaics (PVs) is the conversion of solar energy to electricity using solar PV modules. This section of the report is about the pathway of energy from the Sun to solar PV modules, from modules to the grid, and finally to our houses.

1.1 Energy from Sun to Earth

- The nuclear fusion of protons of hydrogen atoms which violently collide to create a helium nucleus in the Sun, creates huge amounts of solar energy. This reaction is termed a *proton-proton chain reaction* and is responsible for solar energy generation. Photons released during the fusion processes then hit the earth's surface by traveling through a vacuum.
- Solar radiation mainly comprises visible light (50%), IR rays (45%), and smaller proportions of UV rays. It takes about 8.33 minutes for the radiation to reach the Earth traveling a distance of about 93 million miles by the speed of light through the vacuum of space.
- About 51% of solar energy is absorbed by the earth, the rest being scattered in the atmosphere, absorbed by the clouds, etc.
- Some part of the solar energy also arrives as the solar wind comprising gamma and X-rays and takes about 4 days to travel from the Sun to the Earth.

1.2 Production of Electricity from Solar Energy

Solar technologies convert sunlight into electrical energy through photovoltaic (PV) panels. The hierarchy of construction of solar panels can be explained as follows. Solar cells are made up of semiconductor materials like Silicon (Si). Several solar cells put together make up a solar module. An interconnected array of solar modules forms solar panels. Solar panels are installed in a metal panel frame with a glass casing. Solar panels have silver lines to conduct electricity once electrons have been knocked off by sunlight. MMS (Module Mounting Structure) holds the solar panels at the right tilt angle to expose them to maximum sunlight. In general, the efficiency of panels is lesser than cells because edges and sides are cut while making panels.

Further details about the design and construction of solar cells are described in Section 2 of this report.

1.3 Modular Electricity to Homes

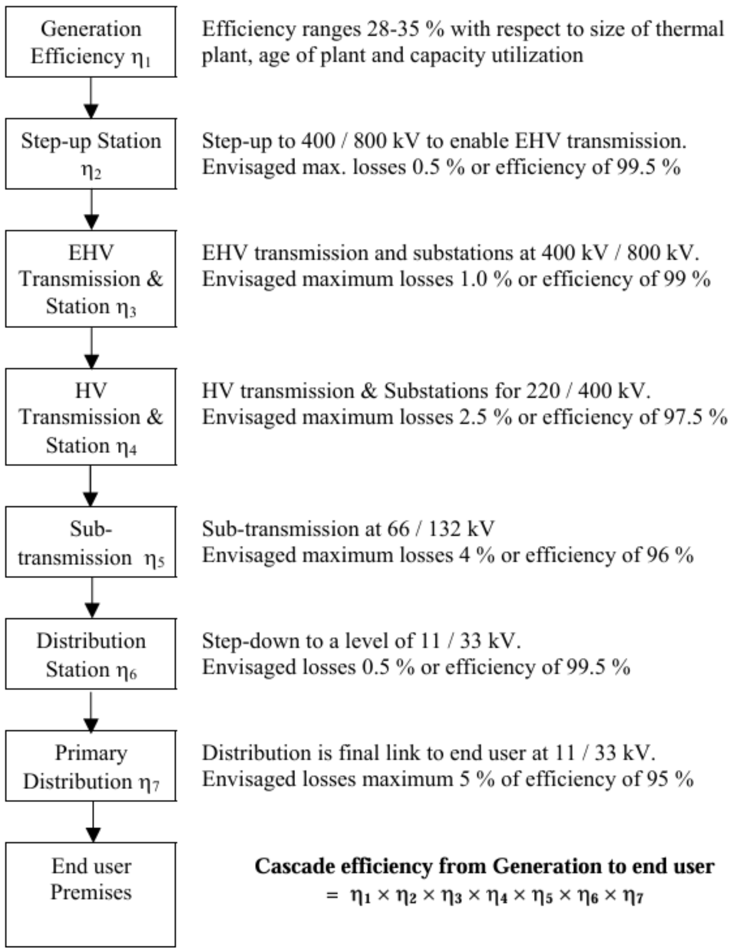
After passing through the PV cell, the current flows through metal contacts- the grid-like lines on a solar cell - before it travels to an inverter. Inverters are used to convert the direct current (DC) electricity generated by solar photovoltaic modules into alternating current (AC) electricity. This is important because local transmission and most of the appliances in our houses use AC. The bulk movement of this electrical energy from the power plant to the power substation is called *electricity power transmission*. After passing through inverters, the electricity is transmitted through the grid to homes or for other industrial applications.

Note that power is generated at a lower voltage but is transmitted at a higher voltage. Generation at lower voltages is a result of insulation and equipment limitations. However, power transmission happens at a higher voltage to reduce the I^2R losses associated with the wires. This also allows the use of smaller and more economical wires to carry lower currents and hence to reduce power losses.

Voltage drops in lines depend on the resistance and reactance of the line, its length, and the current drawn. For the same amount of power handled, *the lower the voltage, the higher the current drawn and the higher the voltage drop*. The current drawn is inversely proportional to the voltage level for the same quantity of power handled. The power loss in line is proportional to resistance and square of current, $P_{Loss} = I^2R$. Higher voltage transmission and distribution would thus help to minimize line voltage drop in the ratio of voltages, and the line power loss in the ratio of square of voltages. For example, if the distribution of power is raised from 11 kV to 33 kV, the voltage drop would be lower by a factor 1/3 and the line loss would be lower by a factor $(1/3)^2$ or 1/9. Lower voltage transmission and distribution also call for bigger-sized conductors due to high current handling capacity.

Transmission and Distribution of Electricity

The flowchart below shows the various links and the efficiencies involved in T&D (Transmission and Distribution) system.



Here, η_1 to η_7 are the efficiencies involved in each step of the T&D network. The cascade efficiency in the T&D system from the output of the power plant to the end use is 0.995 x 0.99 x 0.975 x 0.96 x 0.995 x 0.95, which is about 0.87. The overall (cascade) efficiency is thus 87%.

1. The T&D network includes sub-stations, power lines, and distribution transformers.
2. Power plants usually generate **50 Hz AC electricity** with voltages between **11kV and 33kV**.
3. At the power plant site, this 3-phase voltage is stepped up to a higher voltage for transmission on cables strung on towers. The purpose of high voltage transmission, as mentioned above,

is the reduction of power losses. This is done for **HV (High Voltage) and EHV (Extra-high Voltage) transmissions** of the AC power over long distances from the power plants. Voltages here are of the order of **220 kV to 440 kV** and transmission happens over **thousands of kilometers**.

4. The **sub-transmission network** is the next step of the transmission. Here, the voltage levels are **132 kV, 110 kV, 66 kV, or 33 kV**.

5. The last link of this process is **Distribution** of the electricity to the consumer. Consumers are either connected to the grid directly or through transformers depending upon the drawn level of service. Distribution takes place at **11 kV, 6.6 kV, or 3.3 kV**. **Step-down transformers** in substations reduce the voltage for distribution to industrial users. The voltage is further reduced for commercial facilities.

There is no difference between transmission and distribution lines except for the *voltage level and power handling capability.* Transmission lines can transmit large quantities of electrical energy over larger distances. They operate at high voltages. On the other hand, distribution lines carry limited power over shorter distances.

Recently, the HVDC (High Voltage DC) transmission systems have also been designed. The need for HVDC transmission arises, primarily in the following 3 scenarios:

1. Transmitting large amounts of power over large distances.
2. Transmitting power underwater
3. Asynchronous connections

3 types of links are used in HVDC transmission.

1. **Monopolar**: A single conductor (usually negative) is used. Ground (for usual transmission on land) or Sea water (for submarine cables) are used as return path for the current.
2. **Bipolar**: Two conductors of opposite polarity but the same magnitude are used. If one fails, the other conductor along with the ground can be used to supply power.
3. **Homopolar**: Two conductors of the same polarity (usually negative) are used to transmit the DC power. If one fails, the other conductor along with the ground can still supply more than half of the rated power.

Some advantages of HVDC transmission over HVAC transmission are as follows:

- Less corona loss compared to AC transmission. The corona effect is a partial electrical discharge that occurs when the voltage around a conductor exceeds a certain value, but the conditions don't allow an electric arc to form. The ionization of the surrounding air causes a luminous glow and hissing noise. Also, the use of negative conductors in HVDC reduces radio interference.
- Allows power transfer between regions of different frequencies, which is otherwise impossible using AC.
- Long-distance transmission is possible since DC transmission is independent of capacitive and inductive reactances.
- Both types of HVDC lines - monopolar and bipolar, need a lesser number of conductors compared to the usual AC transmission which needs 3 wires.
- Smaller towers are needed to transmit HVDC power since the number of conductors is less.
- There is no skin effect in HVDC transmission since in case of DC currents, the penetration depth is much higher and covers almost the entire conductor surface.

Why 3-phase systems?

Three-phase or 3ϕ systems are a common type of AC network used in electricity generation, transmission, and distribution. *House current is generally single-phase AC power, but the rest of the power system from generation to secondary distribution employs 3-phase AC.* A 3-phase system means that transmission lines have three separate conductors, each carrying one-third of the power. It is a type of polyphase system that uses three wires (or four, if an optional neutral return wire is also used) and is the most common method used by electrical grids worldwide to transfer power. The waveforms of the voltage in each phase are separated by 120^o.

Normally, any electric circuit requires both an outbound and return wire to make a complete circuit. Balanced 3-phase circuits provide their return, and thus only three, rather than six, wires are required to transmit the same amount of power as three comparable single-phase systems. This can be mathematically explained as follows.

Consider the currents - I_1, I_2, I_3 in the 3 phases of the AC system. Let

$$I_1 = Isin(\omega t)$$
$$I_2 = Isin(\omega t + 120^o)$$
$$I_3 = Isin(\omega t + 240^o)$$

Hence, $I_1 + I_2 + I_3 = Isin(\omega t) + Isin(\omega t + 120^o) + Isin(\omega t + 240^o) = 0$. This zero-sum relationship of the 3-phase system means that one of the three conductors by default provides a return path for the rest of the two conductors combined, thus eliminating the need for 3 separate conductors. Hence, as long as the electrical loads on each phase are kept roughly balanced, only three wires are required to transmit power.

So, a three-wire three-phase circuit is more economical than an equivalent two-wire single-phase circuit at the same line-to-ground voltage because it uses less conductor material to transmit a given amount of electrical power. Three-phase systems are used to directly power large induction motors and other heavy loads. Small loads often use only a two-wire single-phase circuit, which could be derived from a 3-phase system.

Power Grid Map of India

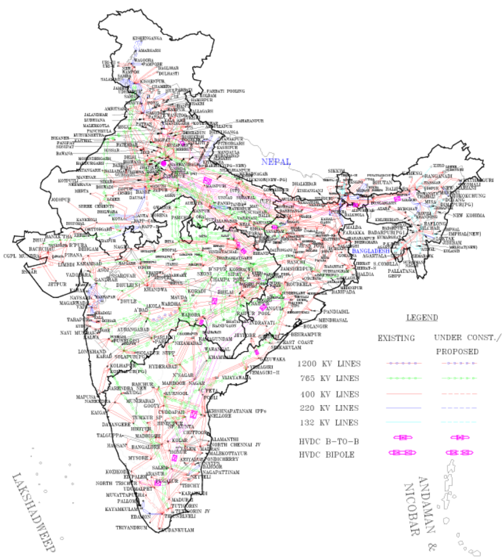


Figure 1: Power Grid Map of India

Transmission and Distribution in India happen at a common average frequency of 50 Hz. High voltage interconnections across regions make up a large, synchronous electric network that spans the entire country. It is a meshed network with multiple paths. This system has a tighter frequency control compared to the older transmission network. The new system allows a frequency regulation ranging from 49.95 Hz to 50.05 Hz and a transient minimum of 49.5 Hz.

Voltages of various lines used in the T & D system are as follows:

1. 1200 kV, 765kV, 400 kV, 220 kV: Inter-region lines
2. 132kV, 110 kV: Intra-region lines
3. 66kV, 33kV, 22 kV, 11 kV: Distribution system

Inertia in Power Grids

1. In power grids, inertia refers to the kinetic energy stored in spinning generators. This inertia is derived from hundreds or thousands of generators that are synchronized, meaning they are all rotating in lockstep at the same frequency.
2. Inertia gives the system operator a chance to respond to power plant failures or contingencies.
3. One of the key processes used to respond to events that might change frequency is PFR (Primary Frequency Response). PFR detects changes in frequency automatically, without action from the system operator, and adjusts operations of online generators to maintain frequency within the desired range. Historically, primary frequency response was provided by a series of mechanical systems in power plants- like by using a flyball governor.

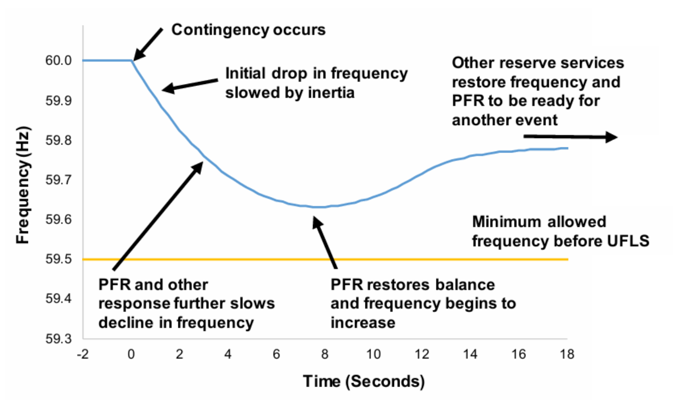


Figure 2: Time response during a successful recovery from a contingency

4. Any discussion of inertia must include the interplay of inertia and the many factors that determine the ability of the grid to successfully respond to a contingency event. Some of these are as follows:

Factor	Impact of Greater Amount[a]
Generator inertia	Slows down frequency decline
Load inertia and load damping	Slows down frequency decline
Contingency size	Increases frequency decline
Underfrequency limits (UFLS settings)	Lower UFLS settings provides more time for overall response
Frequency response speed	Responds faster to a decline in frequency

[a] Assumes no other factors change

2 Design and Construction of Solar Cells

2.1 Making a solar cell from Silicon

Solar cells are usually fabricated from low-cost silicon. Silicon obtained from rocks is purified, and molten silicon is created. Molten silicon is made into wafers using a process called the *Czochralski method*, also known as *crystal pulling*. The wafers are then doped with p-type (elements like Boron (B) and Gallium(Ga) belonging to Group 13 of the periodic table) and n-type (elements like Phosphorus (P) belonging to Group 15 of the periodic table) materials on the two sides to create a p-n junction. Electrical contacts and anti-reflective coatings are finally applied to make the solar cells.

2.2 Working of a solar cell

- Solar cells are primarily made up of semiconductors, which have a bandgap intermediate between conductors and insulators.
- In semiconductors, under high-temperature conditions, the number of electrons knocked off is high but still much lesser than the free electrons in conductors.
- Electrons with sufficient energy reach the conduction band of the semiconductor material, and the subsequent movement of such electrons causes a current flow in the semiconductor material.
- Under very high applied voltage conditions, Zener and Avalanche breakdowns might occur in semiconductors.

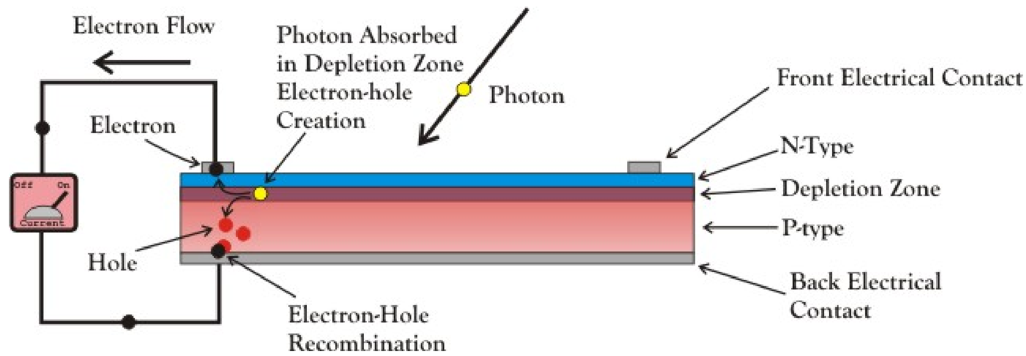


Figure 3: Working of a PV cell

- When photons of sunlight hit the surface of solar cells, their energy creates electron-hole pairs in the n and p regions.
- Electrons move to the n region and holes to the p region, producing a potential difference in the PV cell.
- When an external load is connected across the cell, electrons flow, resulting in a current in the external load.
- Solar cells use the **photovoltaic mode** of operation that is, no reverse bias is applied across their terminals.

2.3 Materials used to make solar cells

Silicon, in its various forms, is the most common material used to make solar cells. However, recently, some other materials have also been explored as potential alternatives to Silicon and modern technologies like PERC, HJT, and multi-junction cells have been developed. These are described below. A detailed comparison between Polycrystalline and Monocrystalline Silicon, two of the most popularly used materials to make solar PVs, follows this.

Materials used to make solar cells should have high-absorption and low-temperature coefficients, *which more power production at higher temperatures.* The material should be easy to manufacture, cost-efficient, and non-toxic.

The various materials used are as follows:

1. **Amorphous Silicon** - This is the least efficient (5-7%) but cheapest form of silicon. It is not usually used in commercial PVs, instead is used in pocket calculators, or other small electronic devices
2. **Polycrystalline Silicon** - Also known as multicrystalline silicon, it has a flaky appearance, and is comparatively much more efficient than amorphous silicon, with an efficiency of about 15-17%. It is cheaper than monocrystalline silicon and its production requires less energy. It is used in commercial applications
3. **Monocrystalline Silicon** - Its overall appearance is uniform, flat, black, and non-flaky. It is even more efficient (15-22%). However, it is more expensive than polycrystalline silicon, leading to its limited use.
4. **CIGS** - CIGS solar cells have semiconducting layers of copper indium gallium selenide. These cells are very efficient (22%).
5. **Gallium Arsenide ($GaAs$)** - Cells made of gallium arsenide are also highly efficient with efficiency of up to 29%.
6. **Cadmium Telluride ($CdTe$)** - $CdTe$ cells are usually used in the thin-film technology. Cells made from it are also very efficient, having about 22% efficiencies. These cells have the largest non-Si market share.
7. **Perovskites** - Perovskites cells have high efficiencies of around 22%.
8. **Dyes** - Dye-sensitized solar cells are low-cost and thin-film solar cells. Though their efficiency is lesser than many other thin-film cells, they are used in some applications. They are translucent and flexible.

Some of the modern technologies developed for the design of solar cells are as follows:

1. **PERC Technology**:
   - PERC stands for “Passivated Emitter and Rear Cells”.
   - In PERC cells, there is an additional passivation layer on the rear side of the cell, which improves efficiency by reducing electron recombination and reflecting the unused light back into the cell.
   - Electron recombination and reflection of the unused photons prevent heating up of the back sheet and the Al frame.
   - Another advantage of PERC cells is that since they are a mere modification of the conventional cell, they can be manufactured with pretty much the same equipment.
   - However, a disadvantage is that since most of the PERC cells have metal strips or ribbons running through them, if these break, the cells are likely to lose their ability to produce electricity.

2. **HJT**:
   - HJT refers to "Hetero Junction Technology"
   - Heterojunction solar panels are composed of three layers of photovoltaic material - the top layer of amorphous Si, the middle layer of crystalline Si, and the bottom layer of amorphous Si again. HJT cells thus combine two technologies: crystalline silicon and amorphous "thin-film" silicon.
   - The top layer catches sunlight before it hits the crystalline layer, as well as light that reflects off the below layers. The monocrystalline silicon from the middle layer turns most sunlight into electricity. Lastly, the amorphous thin-film silicon layer captures the remaining photons that surpass the first two layers. This means that these solar cells are bifacial.
   - Using these two technologies together allows more energy to be harvested instead of using them individually, reaching 25% or higher efficiencies.
   - Some of the advantages of the HJT include higher efficiency (24-26%), cost savings, resilience, adaptability, and higher life expectancy of cells.

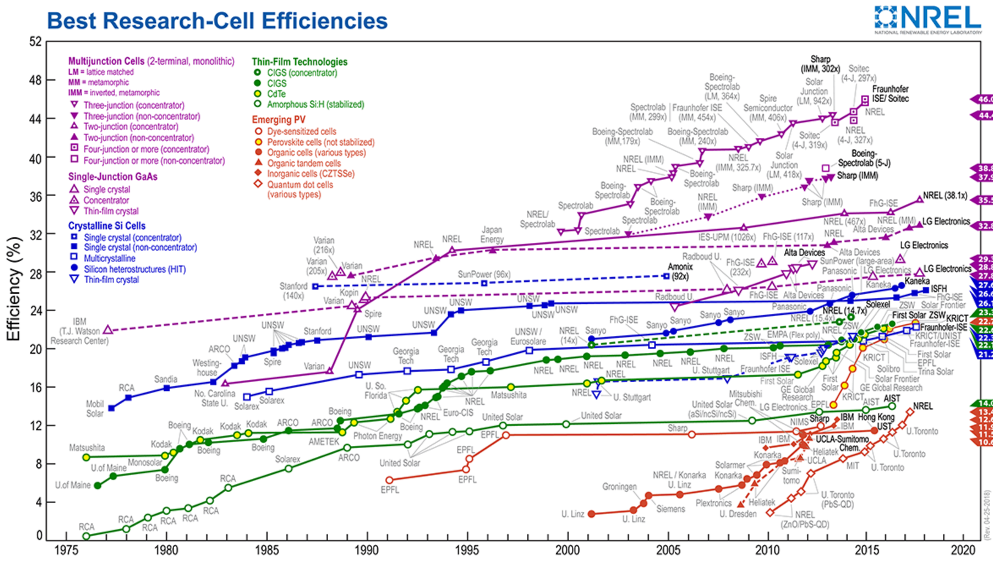


Figure 4: Graph showing efficiencies of cells made of different materials

Monocrysatlline vs Polycrystalline Silicon

A detailed comparison of these two most commonly used materials in manufacture of commercial PVs, based on various aspects is as follows:

1. **Manufacturing**: Polycrystalline Si is made simply by pouring and cooling molten Si and then making their wafers. Monocrystalline Si, on the other hand, is made by using a seed to initiate the formation of a single, continuous crystal. It is then made into ingots and cut into thin wafers.

2. **Cost**: Mono > Poly. However, these days because of sufficient production of monocrystalline Si, their costs are almost the same.

3. **Efficiency**: Mono (15-22%) > Poly (15-17%)

4. **Working under low irradiance conditions**: Under low irradiance, monocrystalline silicon cells are better since their working is very slightly affected by temperature changes as opposed to polycrystalline. Also, the voltage produced by monocrystalline is a little higher than that of polycrystalline.

5. **Spatial constraints**: In limited space, monocrystalline Si is a better option since it has a better power-per-square-foot ratio.

6. **Regions of high temperatures**: Monocrystalline Si is preferred due to its low-temperature coefficient.

7. **Appearance**: Mono - black, octagonal and Poly - blue, square

8. **Durability**: Mono > Poly. Monocrystalline Si is much less susceptible to degradation from heat and UV light.

n-type vs p-type semiconductors

- n-type semiconductors have higher efficiencies than p-type primarily because of the higher mobility of electrons than holes and the lower recombination rates of the former. In silicon, electrons have thrice the mobility of holes.
- The use of n-type materials reduces the occurrence of recombination losses, resulting in improved charge carrier mobility and reduced energy loss resulting in higher power output and increased energy generation potential.
- n-type solar panels also have low susceptibility to damage by LID (light-induced degradation) and have lower temperature coefficients.
- Historically, p-type semiconductors were preferred due to lower costs. However, now the prices have almost become the same and the advantages of n-type materials now dominate over the slight cost difference.

2.4 Efficiency of Solar Cells

The efficiency of solar cells is measured as its power output per unit power input that is incident solar energy measured under the Standard test conditions. Standard test conditions include

- 1000 W/m^2 sunlight
- Air mass 1.5
- Air temperature 25^{o}C

The maximum theoretical efficiency of a PV cell is around 33%. This is referred to as the *Shockley-Queisser limit*.

3 Solar Projects

3.1 Major Steps involved in setting up a solar project

1. **Optimum power plant design**: Designing an optimally balanced power plant, in terms of cost and performance for a specific site.
2. **Project implementation**:
   - Permits and Licensing
   - Selection and Contracting of the EPC (Engineering, Procurement, and Construction) company
   - Power Plant Construction
   - O & M (Operations and Maintenance)
3. **Commercial and Financing Aspects**: Preferential tariffs and other direct and indirect financial supports, Power Purchase Agreements (PPAs)

The actual project involves Site Selection, Acquisition of Land, Storage of Equipment, Erection and setting up of all instruments, and O & M.

Site Selection is a crucial aspect of the project and involves taking into account various parameters like proximity to water resources, transport facilities, and load center. It is also ensured that the land is leveled and permits an easy and safe approach to outlets for EHV lines. Further details about site assessment have been discussed in subsection 3.2.

In MSETCL a land acquisition is carried out by the concerned Civil wing. The proposal for the acquisition of land is submitted to the District Collector in case of Govt. land and to the land acquisition officer in case of private land through the PWD Authorities accompanied by some specified documents. The acquisition of land generally takes quite a long time. Hence, forecasting and planning of substation and selection of substation site needs to be done much in advance taking into account the normal period of acquisition of land.

All the substation equipment/materials received on site should be stored properly, either in the outdoor yard or in the store shade depending on the storage requirement of that particular equipment.

3.2 Site Assessment

Identifying the place and position of the panels is an important step in designing a PV system as the later components will be dependent on this step. Some important technical factors that need to be considered while selecting a site are - shade analysis, sun hours, and tilt angle.

Shade Analysis

Shading is undesirable in solar power plants as it reduces the maximum power that can be generated. It can be caused by neighboring trees, buildings, cloudy weather, or adjacent solar

Figure 5: Solar Pathfinder

plants. Hence, while designing a solar project, it is very important to thoroughly check for shading, and try to minimize it as far as possible.

Solar Pathfinder is one of the most useful tools for doing so. It gives the direction of the sun throughout the year and how much sunlight any specific area will receive. It uses published global weather data to make predictions and can be used to give an accurate solar site analysis. It shows exactly where the sun will travel throughout the year and helps determine which location is suitable for installing solar panels.

After placing the Solar Pathfinder at the desired location, a reflection of the site can be seen from the perspective of the solar panels. Any obstacle that blocks the sunlight can be clearly seen in this reflection. With the help of this, one can determine the best position for the installation of solar panels.

Sun Hours

Sun hours are important to know how much radiance will be required to generate the needed output wattage. Radiance refers to the amount of sunlight received, usually measured in W/m^2.

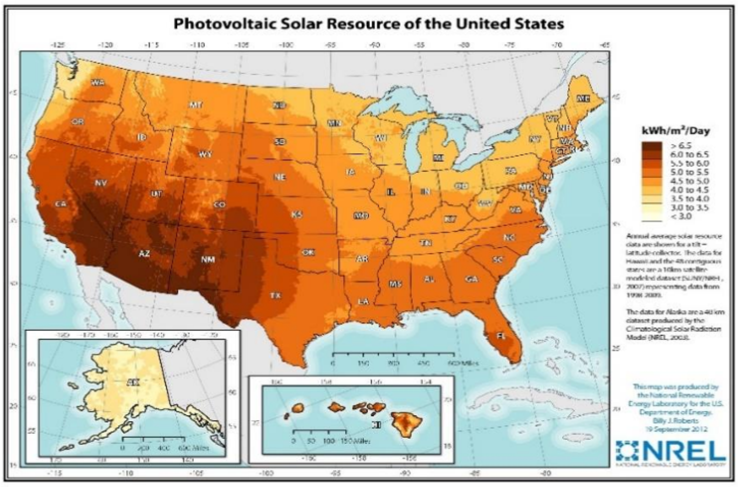


Figure 6: Sun Hours across the USA

Sun hours tell us the number of hours the panels will receive maximum sunlight. This data is now available online and can be used by anyone.

Tilt Angle

Analysis of tilt angle is important for solar panels to get maximum radiance. Ideally, the tilt angle is the latitude of the location. However, it is suggested to have adjustable panel frames since the location of the Sun keeps changing. Panels are generally made to face South, to get the maximum afternoon Sun. *Inclinometer* and *Pyranometer* are used to find the tilt angle and the radiance (in W/m^2) that will fall upon the panel at that tilt angle, respectively.

3.3 Various components used in Solar Projects

1. **Lightning arrestors**: Lightning arrestors are used in the incoming feeders to prevent the high voltage, resulting from *lightning or switching surges*, from entering the main station. The lightning arrestors are grounded to the earth to pull the lightning to the ground. The lightning arrestor works with an angle of 30° to 45° making a cone. *A lightning arrestor is*

the first instrument used in a power station. They are also connected at the terminals of capacitor banks, transformers, generators, etc. They are usually made from metal oxides. Lightning arrestors are sometimes used with earth switch so that lightning would not pass through the instruments in the station.

2. **CVT**: A CVT (capacitor voltage transformer) is used in power systems to *step-down extra high voltage signals* and *provide low voltage signals* either for measurement in the meter or to operate a protective relay. It serves 2 purposes - that of a voltage transformer and for power line communication. CVTs may have 1,2 or 3 cores depending upon their usage. A CVT is connected in parallel to the grid. Hence it has only an incoming conductor since it is connected between the phase and ground as opposed to a current transformer which has both - an incoming as well as an outgoing conductor since it is connected in series. CVTs are single-phase instruments. Thus, for a three-phase supply, we would need 3 CVTs.

   CVT consists of three parts: two capacitors across which the voltage signal is split, an inductive element used to tune the device to the supply frequency, and a transformer used to isolate and further step-down the voltage for the instrumentation or protective relay. The device has at least four terminals, a high-voltage terminal for connection to the high-voltage signal, a ground terminal, and at least one set of secondary terminals for connection to the instrumentation or protective relay. CVTs are used for measuring voltages over hundreds of kVs where the use of voltage transformers would be uneconomical. In practice, the first capacitor, C_1, is often replaced by a stack of capacitors connected in series. This results in a large voltage drop across the stack of capacitors that replaced the first capacitor and a comparatively small voltage drop across the second capacitor, C_2, and hence the secondary terminals.

3. **Wave trap**: A wave trap is an instrument used for tripping the wave. The function of this trap is that it *traps the unwanted waves.* It is connected to the main incoming feeder to trap the waves, which may be dangerous to the instruments in the substation. Usually, they help block the very high-frequency waves, which are used for voice communication (in several kHz), and which might be dangerous for the other equipment used in power grids. They provide an alternative way through the CVTs and communication devices for such high-frequency signals. Not all power stations have wave or line traps - only substations where PLCC (power line carrier communication) takes place have wave traps.

4. **Current transformer**: A CT (Current Transformer) steps down the current of a circuit to a lower value. This is done by constructing the secondary coil consisting of many turns of wire, around the primary coil, which contains only a few turns of wire. In this manner, measurements of high values of current can be obtained.

5. **Circuit breaker**: Circuit breakers are used to break the circuit if any fault occurs in any of the instruments. Circuit breakers also automatically break the circuit when high currents flow. They also have a manual switch which can be opened or closed to repair equipment. There are two types of circuit breakers used for any substations. They are SF_6 circuit breakers and vacuum circuit breakers.

6. **Line isolator**: The line isolators are used to isolate the high voltage from flowing through the line into the bus.

7. **Bus**: The bus is a line in which the incoming feeders come into and get into the instruments for a further step up or down. The first bus is used for putting the incoming feeders in a single line. There may be a double line in the bus so that if any fault occurs in one the other can still have the current and the supply will not stop. The bus carries the output stepped-down voltage to the required place.

8. **Capacitor bank** (attached to the bus): Capacitor banks are used across the bus so that the voltage does not get down till the required place. They help in improving the power factor and hence in improving efficiency.

9. **Potential transformers** (with bus isolators): Two potential transformers are used in the bus, connected to either side of the bus. The potential transformer uses a bus isolator to protect itself. The main use of this transformer is to measure the voltage through the bus.

10. **Isolators**: An isolator is a type of switch used in a substation. It is used to protect the transformer and other instruments in the line. Disconnectors and isolators are used when a particular instrument in the substation needs maintenance. It is ensured using an isolator that the instrument is completely isolated and no trap-charge is present. They are also used to re-route the power flow whenever required.

    A disconnector cannot be opened when the supply is on. This is in contrast with a circuit breaker, which can be opened whenever. Thus, before opening an isolator, the circuit breaker must be opened and while closing, the isolator should be closed first. There are two types of isolators:

    (a) **MGO (Mechanically gang operated) -** Three phases have a common operating mechanism.

    (b) **EGO (Electrically gang operated) -** Each of the phases has a different operating mechanism. This type of isolator also comes with an earth blade or earth switch- thus helping re-direct the trap charges in the transmission line.

11. **Transformer**: There are three transformers in the incoming feeders so that the three lines are stepped down at the same time. In the case of voltages more than 220kv, autotransformers are used. In the case of lower kV lines such as less than 132kv lines, double-winding transformers are used. Further details of the working and construction of a transformer have been discussed in subsection 3.4.

12. **Cables**: Cables used for transmission can be classified based on the following:

    - **Voltage carried**: low voltage (up to 1kV), medium voltage (1-35 kV), HV (35-230 kV), EHV (230-800 kV), SHV (above 800 kV)
    - **Material Used**: XLPE / EPR / PVC cables. XLPE, *cross-linked polyethylene*, cables provide high resistance to moisture, chemicals, and heat because they are made from a thermoset material.
    - Submarine/Overhead/Underground
    - **Multi/single strand wires**: Multistrand wires are useful in applications where there are many vibrations or movements. They can be bent repeatedly and do not break easily. Very flexible. Multiple strands increase the surface area allowing higher current to pass.

    Following are the parts of a cable:

    - **Conductors** – The wires made of Al or Cu which carry current.
    - **Insulation** – Layer of insulation (XLPE or EPR) to prevent leakage of current.
    - **Shielding** – Metallic shielding of Al or Cu to protect from electrical interference.
    - **Jacketing** – Provides mechanical support.
    - **Armoring**- Made of Al or Cu, usually for extra protection from EMI (electromagnetic interference), environmental conditions, etc.
    - **Filling and Binding** – non-conductive materials filled between conductors and binders to hold them in place

- **Insulation Screen -** Protects the cable core from mechanical damage and external electromagnetic interference.

FRLS cables are a special kind of cable. FRLS stands for flame retardant low smoke cables. These are used in areas of high-fire risks like industries, power plants, etc. The substance used to make these wires ensures less release of smoke and other corrosive fumes. Electrolytic grade copper is used to make these cables and an extra thick layer of insulating material is put around it.

3.4 Transformer

Basic Design and Purpose of Transformers

A transformers consist of two or more coils that are electrically insulated but magnetically linked. The primary coil is connected to the power source and the secondary coil connects to the load. For an ideal transformer, it can be shown that the ratio of secondary to primary voltages is equal to the turns ratio defined as the number of turns on the secondary side to that on the primary side. Mathematically,

$$\frac{E_2}{E_1} = \frac{N_2}{N_1} \tag{1}$$

where, E_2, E_1 represent secondary and primary voltages and N_2, N_1 represent the number of turns on the secondary and primary sides.

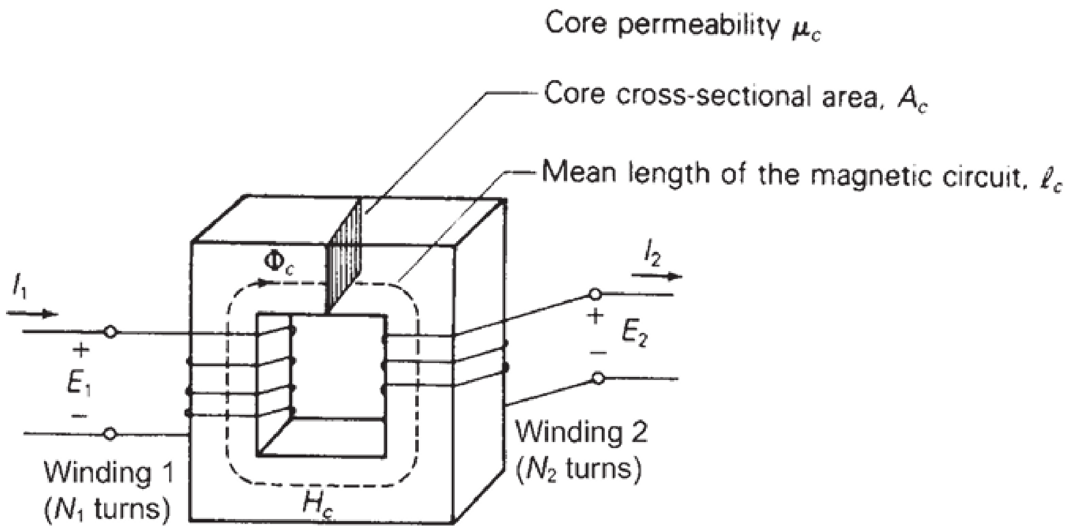


Figure 7: Construction of an ideal transformer

A transformer can accept energy at one voltage and deliver it at another voltage. This means that it can either *step-up* or *step-down* voltage as per requirement. This permits electrical energy to be generated at relatively lower voltages and transmitted at high voltages and low currents, thus reducing line losses and voltage drop, which is the basic requirement of any generation and T & D system.

Transformer losses

The efficiency of transformers depends on their design and effective operating load. Losses in transformers are broadly of two kinds:

- **No-load Loss**: Also called *core losses*, these refer to the power consumed to sustain the magnetic field in the transformer's steel core. Core loss occurs whenever the transformer is energized; core loss does not vary with load. Core losses are primarily caused by two factors: hysteresis (energy lost by reversing the magnetic field in the core as the magnetizing AC rises and falls and reverses direction) and eddy current losses (result of induced currents circulating in the core).
- **Load Loss**: Also known as *copper loss*, it is associated with full-load current flow in the transformer windings. Copper loss is power lost in the primary and secondary windings of a transformer due to the ohmic resistance of the windings. Copper loss varies with the square of the current ($P_{loss} = I^2R$).

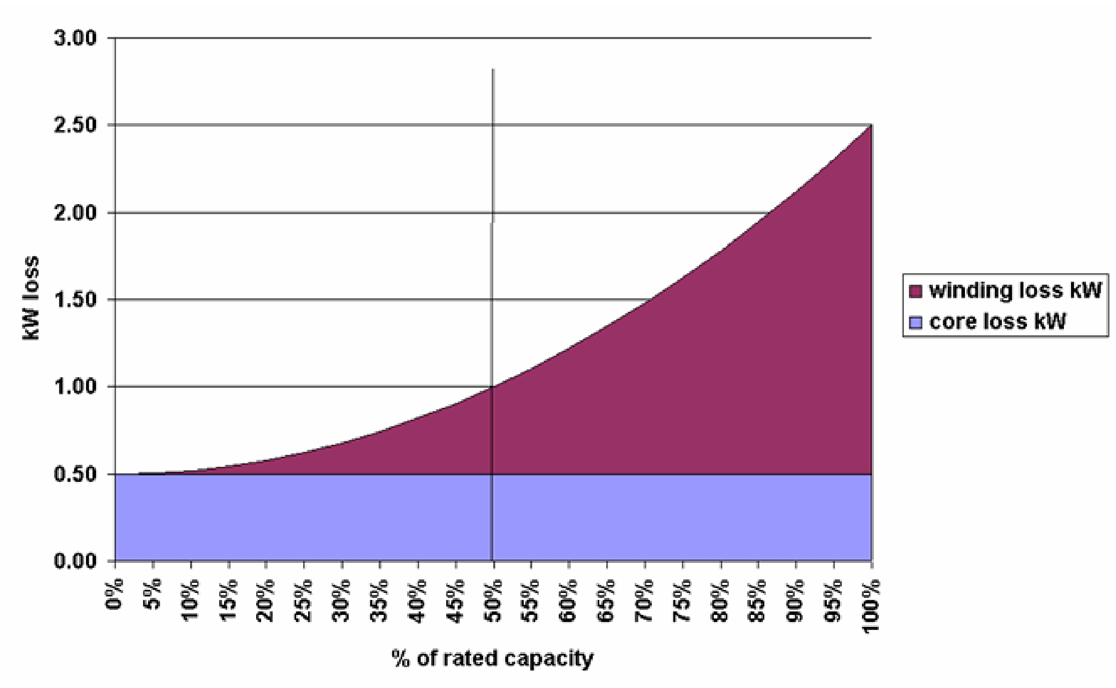


Figure 8: Graph depicting transformer losses as a function of % load

The total power loss at any given % load in a transformer is given by the following formulas, which can be used interchangeably depending on the parameters known.

$$P_{total} = P_{no-load} + (\frac{\%\text{ load}}{100})^2 \times P_{load} \tag{2}$$

$$P_{total} = P_{no-load} + (\frac{\text{kVA load}}{\text{Rated kVA}})^2 \times P_{load} \tag{3}$$

where, $P_{no-load}$ is the no-load power loss and P_{load} is the full load loss, supplied by the manufacturer.

Voltage Fluctuation Control

The control of the voltage of a transformer is important due to frequent changes in supply voltage. Voltage regulation in transformers is done by altering the voltage transformation ratio. This is typically done by changing the number of turns in the primary coil. The process of changing the voltage transformation ratio is called *tapping* or *tap-changing*. Tap-changing can be done by two methods - off-circuit tap changing (voltage levels can be varied only after isolating the primary voltage of the transformer) and on-load tap changing or OLTC (voltage levels can be varied even without isolating the connected load to the transformer).

The main transformer, that is the one that receives power from the grid, should be provided with OLTC. The downstream distribution transformers can be provided with off-circuit tap changers.

Types of Transformers

Transformers are classified into the following two categories.

- **Power transformers**: They are used in transmission networks of higher voltages, and deployed for step-up and step-down transformer applications **(400 kV, 200 kV, 110 kV, 66 kV, 33 kV)**. They are designed for maximum efficiency at full load.
- **Distribution transformers**: These are used for lower voltage distribution networks as a means to end-user connectivity **(11 kV, 6.6 kV, 3.3 kV, 440 V, 230 V)**. They typically operate at lower voltages and are designed for optimal performance at varying load conditions, often closer to half-load.

Terminologies

- **Voltage Regulation**: It is the percent increase in voltage from full load to no load in a transformer.
- **Diversity Factor**: It is defined as the ratio of the overall maximum demand of the plant to the sum of the individual maximum demand of various equipment. It is always less than one.

Reactive Power Compensation - Why and How?

During night-time, no active power is generated. Hence, reactive power is needed. However, sufficient active energy is produced in the daytime. This means that reactive power compensation is required. Reactive power compensation is the process of adding or injecting positive and/or negative VAr's to a power system to essentially attain voltage control.

These days inverters have an inbuilt ability to compensate and adjust reactive power. When the power factor lags ie. current lags the voltage, the inverter can absorb reactive power and when it leads, it can supply reactive power to the grid. Solar power-based systems have a wide range of reactive power compensation - 5-10% during daytime and about 100% during night-time.

Following are some devices used for reactive power compensation:

- **SVC**: An SVC (or Static VAR Compensator) is an electrical device for providing reactive power on transmission networks. "Static" because the SVC has no moving parts (other than circuit breakers and disconnects, which do not move under normal SVC operation). It is an automated impedance-matching device, designed to bring the system closer to unity power factor. Suppose the power system's reactive load is capacitive or leading. In that case, the SVC will use reactors (usually thyristor-controlled Reactors) to consume vars from the system, lowering the system voltage. Under inductive or lagging conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage.

- STATCOM: STATCOM refers to "Static Synchronous condensers". It is used for shunt reactive power compensation. When it absorbs power- it is under-excited and acts like an inductor. When it generates power- it is overexcited and acts like a capacitor.

3.5 LID, PID, and Electric Arcing

LID (Light-induced Degradation)

- Boron is used in solar modules in p-type semiconductors. While manufacturing, oxygen atoms get trapped in the silicon lattice. So, during the initial months of usage of the solar modules, exposure to sunlight causes the formation of boron-oxygen complexes known as B-O pairs or clusters, which act as recombination centers. Due to localized energy levels created by these clusters, the charge carriers – electrons and holes - get trapped in these complexes, leading to immobility. Here, the charge carriers recombine and reduce efficiency. This is because the charge carriers, which were responsible for conduction have now been recombined and immobilized.
- Continuous exposure to sunlight helps activate the silicon lattice, which helps in stabilizing defects and reducing the concentration of the recombination centers. So eventually, continuous exposure to sunlight mitigates LID. The degradation of cells by the Sun is highly dependent on the quality of the wafer manufactured.
- Modules experience power loss rates of approximately 3% within the first year of usage. Typically, after that, power stabilization occurs, which refers to lower levels of power loss in subsequent years of usage at rates usually around 0.8%.

PID (Potential-induced Degradation)

- Solar panels typically operate with a positive voltage potential relative to the grounded frame or structure they are mounted on. This potential difference can induce electrical fields and currents within the solar panel components.
- Due to the low quality of the insulator, charges from a solar cell deviate from their original path (the busbars) and move through the panel frames instead. These charges accumulate at the interfaces or within the semiconductor. This leads to PID (Potential induced degradation) in solar modules.
- High temperature and humidity increase the effects of PID on solar modules.
- Using earthing, the charges that aren't creating energy can be safely deposited into the ground. The mounting structures and inverters are also earthed for further safety.

Electric Arcing

Arcing occurs when there is a breakdown of the dielectric, like air, surrounding the conductors, resulting in an electric current flow between two conductors. Electrical discharge leads to sparks or open fires.

Figure 9: Solar Panels being damaged due to Electric Arcing

Compression wire connections, soldered joints, and connectors that attach to the PV modules can create intermittent connections and generate series arcs. Arcing is caused due to installation issues, defects in the equipment, wear, and tear of material, and voltage fluctuations.

3.6 Earthing

Earthing and its purpose

- Earthing is the connection of the neutral point of the supply system or the *non-current-carrying parts* to the earth to cause immediate discharge of current.
- Earthing ensures that the fault current does not endanger the user and helps maintain the system voltage at known values, preventing excessive voltage. High fault current compared to full load current automatically melts the fuse and breaks the circuit. It also protects against static electricity, produced by friction.
- Good earthing demands the equipment be disconnected in less than 0.4 seconds. This requires the earthing system to have *low electrical resistance* and *good corrosion resistance*.
- Earthing helps prevent electric shocks and dissipate short circuit currents.

  Electric shock is caused when two parts of the human body are in contact with conductors at different potentials. This potential difference causes a current to flow within the body. The resistance of the human body can vary from 500-60,000 Ω. It drops if the skin is moist and might drop further if there is sweat, due to the presence of salts.

  A short circuit occurs when there is an unintended connection across the circuit conductors between the power source and load. Short circuits are classified as – phase to phase, phase to ground, and phase to neutral.
- Grounding and earthing, though very similar, are slightly different. Grounding involves the connection of current-carrying conductors (neutral) of the electrical system to the ground, while earthing involves the connection of non-current-carrying conductors to the ground. Also, the typical purpose of earthing is to prevent electric shocks, while the purpose of grounding is to stabilize the voltage levels.
- In solar cells, sometimes due to the low quality of the insulator, charges within it deviate from their original path (the busbars) and move through the panel frames instead. This leads to PID (Potential induced degradation) in solar modules. Using earthing, the charges that aren't creating energy can be safely deposited into the ground. The mounting structures and inverters are also earthed for further safety.

  Hence, in solar power plants, at the AC side, the solar inverters are grounded and at the DC side, earthing is done to the mounting structures through LAs.

Components of Earthing

- **Earth Bars** – They serve as a common point for equipotential busbar conductors which can be grouped forward for onward connection.
- **Earthing conductors/wires** – Earthing conductors are used to connect the earth bar to the earthing electrode.
- **Earth electrode** – It is the final component of the earthing system that dissipates lightning discharge or other faults.
- **Inspection pits** – They are placed between the earth conductors and earth electrodes, they serve as a test point for the earthing system.

- **Soil enhancers -** These are used as backfills in holes or trenches to lower the resistance of the soil, surrounding the earth electrode. By encasing the metal electrode in a highly conductive medium and increasing the surface area, they help improve dissipation.

Types of Earthing

1. **Plate earthing** – A metal plate made of Cu or galvanized iron is buried in the ground.
2. **Chemical earthing -** Chemicals are put in the earth surrounding the electrode. These chemicals conduct electricity and provide a low-resistance connection to the earth.

   Various chemicals like marconite, betonite, graphite, etc. are popular for chemical earthing. Marconite earthing is very effective. Marconite is a conductive material used as a backfill for increasing the effects of earth electrodes. It provides low-resistance paths for electricity to flow.
3. **Strip earthing -** Metal strips made of Cu or Al are buried close to the surface of the earth to maximize contact with soil.
4. **Rod earthing** – A rod made of Cu or galvanized iron is buried vertically, usually preferred for soils of low resistivity since rods are cheaper than pipes.

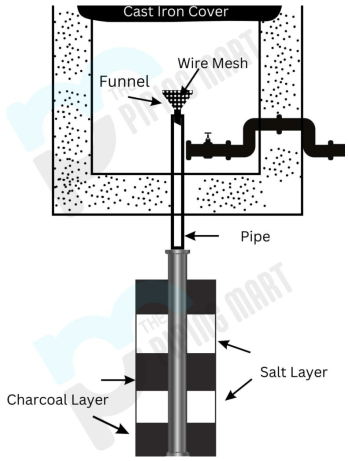


Figure 10: Parts of Pipe Earthing

5. **Pipe earthing** – A pipe made of Cu or galvanized iron is buried vertically, useful for high resistivity soils, since the pipe provides a low resistance path for electricity to pass. It is costlier compared to rod earthing.

Charcoal and salt are used in alternate layers around the earthing electrode. Charcoal helps retain moisture and salt increases the conductivity of the soil. Cement concrete casing is used to encase the electrode pipe and surrounding components. It helps protect the electrode from physical damage and prevents moisture from coming directly in contact with it.

The depth of the pipe, rod, or plates is typically around 2-3m, depending on moisture content, soil resistivity, type of soil, etc. At around 2-3m depth, there is sufficient moisture in the soil. Moisture is important because *wet soils have lower resistivity than dry soils.* An example of how moisture affects the depth of the earthing electrode is as follows: in coastal regions where moisture content is high, depths of around 2m or less would also suffice. However, regions where groundwater content is less may need depths more than even 3m.

Deeper earthing systems reduce the risks of earthing electrodes being damaged by any activities like construction. However, going very deep inside the soil is not recommended because after about

2-3m depth, going further down doesn't come with many additional benefits because going very deep requires a lot of sophisticated labor and machinery.

Tests done for Earthing

1. **Soil resistivity test** – Soil resistivity is determined using several methods, like the Werner 4-pin method, in which, 4 pins are placed in a straight line with equal gaps between adjacent pins. Through the outer pins, a current source is connected and the voltage is measured using a voltmeter through the inner 2 pins.
2. **Inspection** - Soil in which earthing is done, is periodically tested and inspected.
3. **Fall-of-potential test** – It is used to measure the earthing resistance of the ground system, a known amount of current is sent through the ground, and the voltage drop is measured. Using this, resistance is found.
4. **Galvanic corrosion protection** – Earthing electrodes are protected from corrosion using corrosion-resistant materials.

3.7 Clipping in Solar Systems

- Inverters have a maximum capacity, and can only convert DC power up to its maximum capacity, thus clipping away the rest. This is called *Solar Clipping* and causes power losses.

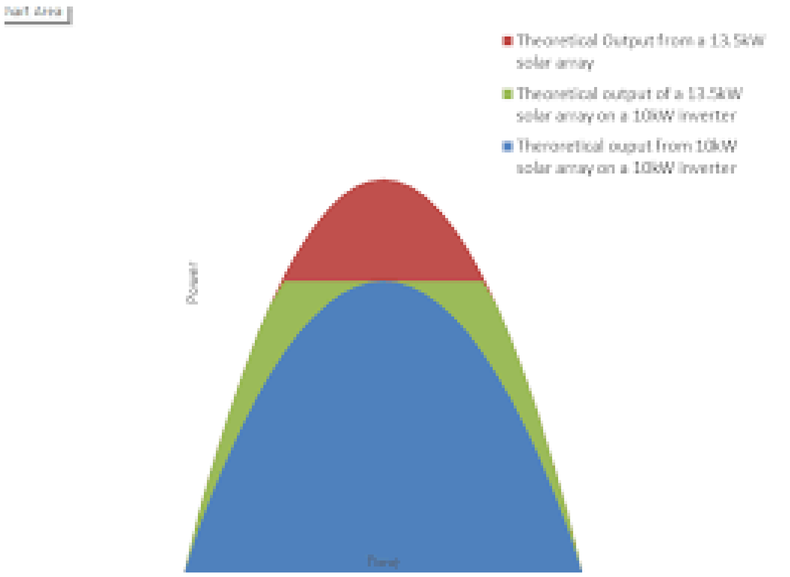


Figure 11: Graph depicting Solar Clipping

- To avoid solar clipping, it is important to ensure a correct balance between the energy captured by solar panels and that which can be converted by the inverter.
- Hence, to avoid solar clipping, we have two options. We can either downsize the solar array or upsize the inverters. However, the cost of installation of a larger inverter is more than that of a smaller one. So, considering the energy and power requirements, necessary steps should be taken.

Numerical example explaining Solar Clipping

Assume that we have a 100 MW project needed to generate:

1. 15 Cr units
2. 16 Cr units
3. 20 Cr units

where 1 unit means 1 kWh energy. Also, assume that a 1 MW project produces 15 lakh units a year. Assume the following regarding solar clipping: for every 10% rise in DC power generated, there is a 1% increase in solar clipping. Determine whether it is better to have a 16 Cr units project or a 20 Cr project.

Explanation

By using the simple logic that 15 Cr units correspond to 100 MW, we can find the DC power in MW required for the 16 and 20 Cr projects, which turn out to be the following: At 100 MW

AC (in MW)	DC (in MW)	Cr units
100	100	15
100	106.66	16
100	133.33	20

DC, we have 0% clipping. As per the given assumption, at 106.66 MW, we will have 0.0066%, and at 133.33, we will have 3.33% clipping. Thus, the actual required DC will be as follows:

DC (in MW)	Cr units
100	15
106.66*1.0066=107.3639	16
133.33*1.033= 137.7298	20

Hence, comparing the two projects, we see that: For 137.7298 DC MW, we produce 20 Cr units. Hence, for 1 DC MW invested, we get 20/137.7298 or 0.156 units and for 107.3639 DC MW, we produce 16 Cr units, hence for 1 DC MW invested, we get 16/107.3639 or 0.149 units.

Thus, we conclude that *the 20 Cr units project is better.*

4 Site Visit

4.1 Introduction

During my internship, on 13th June 2024, I got the opportunity to visit the company's site at Tuljapur, Maharashtra. There were two projects - *Vinati and Maurya*. This was followed by a visit to a GSS (Grid Substation).

Figure 12: Power Plant

4.2 Details of the Project

Following are some details of the projects:

- 33 kV transmission from plant-end switchyard to the PSS (Pooling Sub-Station).
- 33/132 kV PSS
- 132 kV transmission lines from PSS to 220/132/33 kV bay at Tuljapur Sub-station
- 132 kV bay at receving end sub-station
- SLDC communication

1. ***Vinati***:
    - *Project Capacity*: 4.6 MW AC, 6.9 MWp DC
    - *PV Modules*: 665 Wp/670 Wp Mono Crystalline
    - *Inverter type*: String Inverter
    - *MMS* : Seasonal Tilt
    - *System Voltage*: 1500 V
    - *HT Yard System Voltage*: 33 kV
    - *Power Evacuation Voltage*: 132 kV
    - *Location*: Tuljapur

IDT at the HT Yard

Various Equipment at the HT Yard

Figure 13: Images from the HT Yard

2. ***Maurya***:
   - *Project Capacity*: 4 MW AC, 6 MWp DC
   - *PV Modules*: 665 Wp/670 Wp Mono Crystalline
   - *Inverter type*: String Inverter
   - *MMS* : Fixed Tilt
   - *System Voltage*: 1500 V
   - *HT Yard System Voltage*: 33 kV
   - *Power Evacuation Voltage*: 132 kV
   - *Location*: Tuljapur

Solar Panels

Inverter

Figure 14: Technical Specifications

4.3 My learnings at the site

1. I understood how power generated by the solar panels reaches the substation and how it is sent further from there to the grid.

2. I also saw and understood the components in a power station- CTs, PTs, Inverter Duty Transformers, LAs, circuit breakers, isolators, earthing switches, etc.

3. I also studied the structure and design of solar panels - tilting angle, capacity ratings, material(mono/polycrystalline) and the MMS, the string inverters attached to the solar panels, and their benefits over usual inverters.

4.4 My learnings at the GSS

1. I understood the various components like bus, bay, live tank and dead tank CTs, PTs, LAs, transformers, circuit breakers, gantry, and towers.

2. I also learned about the towers, bus insulators, and wires carrying power at different voltages ranging from 11kV to several hundreds of kV.

Transformer

1, 2, 3, 4 depict ***Checking CT, PT and Main CT, PT*** respectively

Figure 15: Images from the GSS

5 Study of a Tender Document

5.1 About the Project

The tender document was for the bid of Design, Engineering, Supply, Erection, Testing, and Commissioning of ***62 MW AC Cumulative Capacity*** crystalline solar PV technology grid interactive Solar PV power plant with associated HT (High transmission) overhead transmission line or underground cable along with all required electrical equipment, construction of bays up to the point of interconnection at 220 kV bays at Paras Substation including 5 years of Operation & Maintenance of Solar Power Plant and Evacuation System up to the point of interconnection on EPC basis at Village: Paras, Taluka: Balapur, Dist.- Akola, Maharashtra, India under Local Competitive Bidding from prospective Bidders.

5.2 Project Requirements

1. **Project Name**: Maharashtra State Power Generation (MAHAGENCO)
2. **Capacity**: 62 MW AC
3. **DC Loading**: Ratio less than 1.4
4. **Generation**: 122.25 Million Units
5. **Substation Rating**: 220 kV

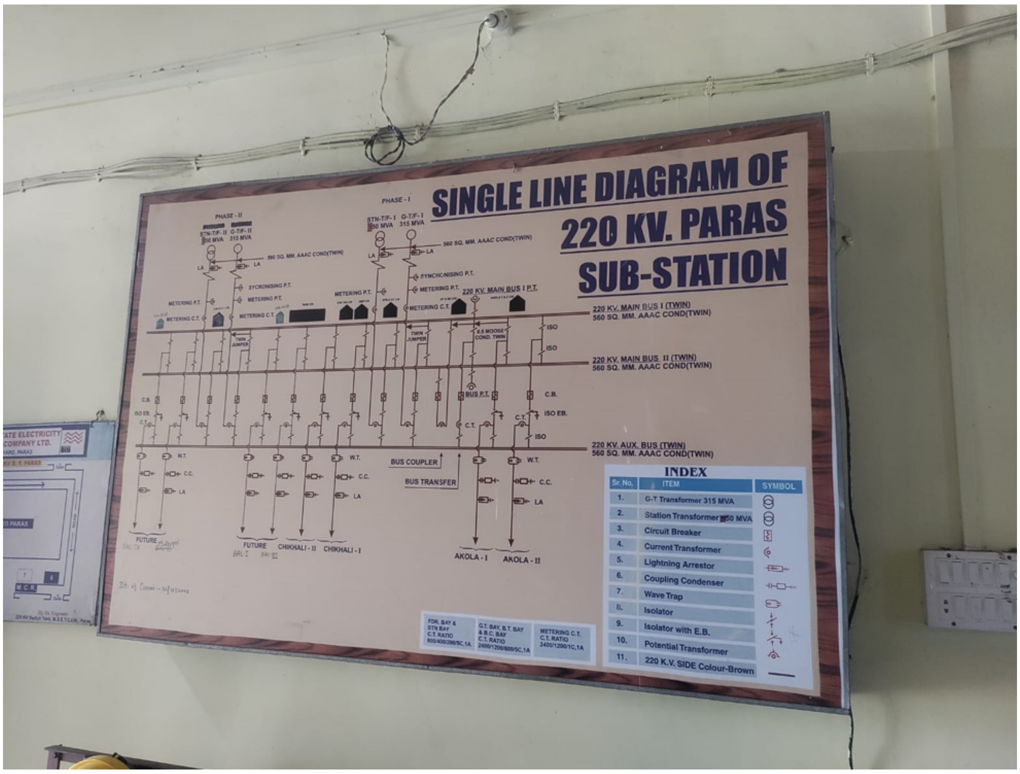


Figure 16: Substation SLD

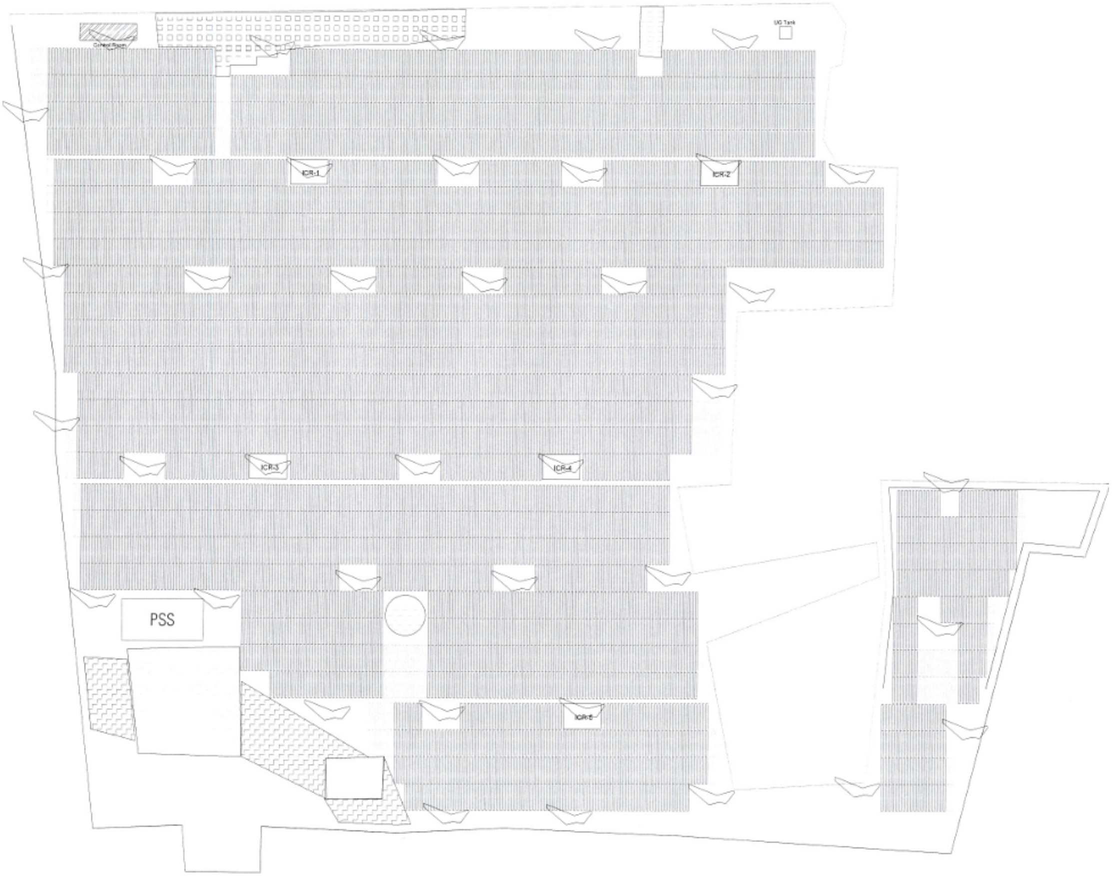


Figure 17: GA (General Arrangement) Layout of the Project

5.3 My learnings

I studied the tender for this bid, followed by study of the pre-bid queries, and their responses, the SLD of the project, and the safety terms and conditions. Following this, I studied the BOQ (Bill of Quantity) and DBR (Design Basis Report) and prepared for the same.

The BOQ consisted of the tentative material requirement and budget of the project. The DBR consisted of various project requirements – internal distribution scheme and evacuation, MMS (module mounting structure) and HSAT to maximize the yield, metering scheme, SLDC communication philosophy, and bay extension at GSS.

5.4 Technical Specifications of some components

1. **Lightning Arrestors:**

   - Maximum continuous operating voltage – 24 kV rms.
   - Nominal or Maximum discharge current – 10 kA.
   - Response time - 8/20 μs. *Here, 8/20 means it takes 8 μs to rise to peak value and 20 μs to fall back to half of this.*
   - Should be capable of discharging over-voltages occurring during switching of unloaded transformers, and long lines.

- Should have self-contained discharge counters.

2. **Transformers:**
   - Should be built according to IS:2026 and IS: 3639.
   - Should have an off-circuit tap changer - 15% with steps of +-2.5%.
   - Rated power – maximum power the transformer can handle. Various transformers in the project have specified rated powers.
   - Buchholz relay and conservator tank for oil accommodation.
   - Voltage rating (Primary and Secondary) - 3 phase, 240-800 V/33 kV.
   - Windings – fully insulated and dustproof.
   - The transformer tank should be subjected to a vacuum test.
   - Core insulation level – 2 kV RMS for 1 minute in air.
3. **Instrument Transformers:**
   - Common marshaling box for a set of three single-phase units of CTs and PTs.
   - For CTs: Rated short-time thermal current – 25 kA for 1 sec, Rated dynamic current – 63 kA peak current, Highest system voltage – 36 kV, should be effectively earthed, Rated frequency – 50 Hz.
   - For PTs: Rated minimum power frequency voltage – 70 kV, Rated lightning impulse withstand voltage – 170 kV, should be effectively earthed, System fault level (max current that can flow during a fault) – 25 kA.
4. **Circuit Breakers:**
   - Arc quenching mechanism – could be SF_6 breaker or vacuum breaker.
   - Tripping (for 70%) and closing coils (for 85%).
   - Ultimate breaking capacity of the circuit breaker.
   - An earth bus to carry maximum fault current.
   - Opening time should be $<$ 60 ms and closing time $<$ 100 ms.
5. **SCBs (String Connector Boxes) and String Monitoring Systems:**
   - Input-output strings in SCBs – 10 inputs, 1 output.
   - Minimum protection of SCBs – IP 65. *Here, IP stands for ingress protection. And 6 and 5 represent digits denoting the scale of protection from dust and water respectively. 6 means full protection from dust and 5 means protection from low-pressure jets from any direction.*
   - Should be able to operate at ambient temperatures of 60^oC in summer.
6. **Inverter:**
   - Inverter output should follow the voltage and frequency of the grid. For this grid voltage is sensed and sent to the feedback loop of the inverter.
   - Nominal AC output can be 1000 kW to 6874 kW.
   - Maximum input voltage – 1200 V DC.
   - Nominal output voltage – 240 to 800 V AC.
   - At 75% load, minimum efficiency should be 98%.
7. **IDT (Inverter Duty Transformer):**
   - Rated Frequency – 50 Hz.
   - Method of connection – Star-Delta.
   - Primary and secondary side voltages.

6 Use of Nanotechnology to solve energy problems

The combustion of fossil fuels mainly fulfills the world's energy demands. However, this approach has several disadvantages – limited availability of fossil fuels coupled with growing energy demands and the environmental degradation caused by fossil fuels.

To resolve this energy shortage problem. Solar energy and hydrogen fuel cell technologies have been seen as potential alternatives. However, solar projects have their disadvantage in terms of low efficiency of photovoltaics, energy storage issues, etc. Nanotechnology offers to provide solutions to many of these issues. This report describes in detail the use of nanotechnology for the same.

6.1 Problems with Solar Energy

The development of devices for the efficient and cost-effective conversion of solar energy to electricity is a major problem. Another problem is the storage and transport of the produced electricity since the regions where solar has the most potential is deserts, so transporting this energy becomes a concern.

6.2 Photovoltaics (PVs)

Conventional photovoltaics (PVs) consist of p and n-type semiconductors. All semiconductors absorb only a fraction of the total solar energy available – some absorb visible light only, while some absorb UV. For example, Titanium Dioxide (TiO_2), a non-toxic semiconductor can only absorb the UV portion of the solar energy. This is just 5% of the total. So, TiO_2 solar PVs, though cheap, have very low conversion efficiencies. Currently, a maximum efficiency of 15–20% in a PV cell is obtained using crystalline silicon (Si). But, these PV cells have the disadvantage of being expensive, thus limiting their application. To meet energy demands we need at least about 45% efficiency of solar cells. Various nanomaterials are being investigated to achieve this. The devices must be made of materials that absorb visible light, which constitutes a 46% portion of the solar spectrum. There are two approaches employed for the same:

1. **Development of silicon nanocrystals which are designed to absorb more solar energy:**

   The lower efficiency of silicon PVs can be linked to the indirect bandgap of silicon crystals, resulting in weak absorption of light. The use of nanocrystals in these cells can significantly increase their light-absorbing capacities. This is because, in sufficiently small nanocrystals, the band gap is quasi-direct instead of indirect. This enhances the optical properties of the silicon PVs.

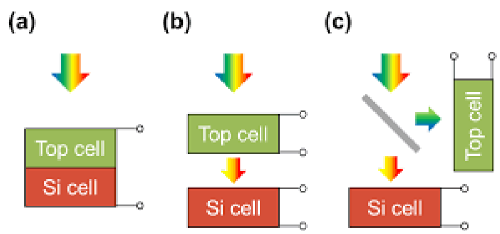


Figure 18: Various configurations of Tandem Solar Cells

   An example of the use of nanocrystals in solar PVs is in silicon-based tandem solar cells, which have an upper layer based on nanocrystals and the bottom layer of standard silicon cells. Within solar cells, nanocrystals help in increasing the generation of electric current.

2. **Biomimetic approaches where PV devices are made to mimic "photosynthesis", the best-known solar conversion process:**

   QDSSCs use semiconductor nanocrystals, coated to the surface of a mesoporous TiO_2. They are similar to Graztel Cells which use dye coated on TiO_2 surface. However, QDSSCs have many advantages over these Graztel cells. They can match the solar spectrum better because their absorption spectrum can be tuned with particle size. It was found that when PbSe nanocrystals of diameter less than 10nm absorbed a photon, they could produce up to 3 electrons. This is much more compared to the conventional PV solar cells, which just produce 1 electron upon absorption of 1 photon. The production of 3 electrons is called "carrier multiplication".

6.3 Solar Heating

Solar heating involves a material that absorbs sunlight and releases that directly as heat into a water source or heat exchange material. Many nanomaterials can be used to enhance this process because of their large surface area and improved absorption properties. Nanotechnologies can be used to engineer complex nano-structured mirrors and lenses to optimize solar thermal collection. Also, aerogels with nanopores are used as transparent and thermally isolating materials to cover solar collectors.

7 Some recent technologies

7.1 Hybrid Solar and Wind Projects

- This involves using a solar power plant along with windmills. It helps to generate more reliable power than standalone solar power plants or standalone windmills since solar energy and wind often complement each other.
- In most regions of the world, wind speeds are low in the summer when the sun shines brightest and longest. The wind is strong in the winter when less sunlight is available. So, hybrid models work well in these regions.
- The solar arrays and windmills send their power to an electric power controller, which supplies the power according to the needs and even provides power from a battery if required.
- However, hybrid models do offer some disadvantages as well in terms of the cost of installation, maintenance costs, and noise pollution of the rotating windmills.
- A hybrid solar and wind plant offers better reliability, is more efficient and reduces the capital cost of investment. Due to a comparatively stable output, the reliability of other power sources is reduced.
- A hybrid plant can share the infrastructure such as land, transmission lines, and maintenance facilities, hence saving costs. Combining solar panels and windmills on the same site proves to be beneficial in terms of land utilization.
- Large hybrid plants can also benefit from economies of scale, hence reducing the per-watt cost of production of power.

7.2 FDRE

FDRE stands for *Firm and Dispatchable Energy*. FDRE provides dispatchable and controllable power reliably 24/7, using green sources. FDRE thus helps address challenges like grid balancing and underutilized transmission systems. Variable renewable energy is transformed into FDRE through integration with energy storage systems (ESSs). Thus, FDRE provides round-the-clock renewable energy to consumers.

7.3 RTC

RTC projects are meant and designed to supply a continuous and reliable power source and use renewable sources of energy like solar and wind and sometimes even conventional sources like coal. The main aim is to ensure a continuous supply of power. However, due to the project's complexity, the costs are very high and involve complex maintenance. In RTC, both solar and wind are used to reduce the reliability of external power sources and make them more beneficial.

7.4 Green Hydorgen

- There are several types of hydrogen used in the industry as a fuel, the most common one being grey hydrogen (about 95%).
- Grey hydrogen production, however, involves the use of fossil fuels like coal. These processes release a lot of CO_2, contributing to greenhouse gas emissions and making it a non-low-carbon fuel.
- Blue hydrogen is another type, which is similar to grey hydrogen except that it involves carbon capture and storage.

- To lower greenhouse emissions, green hydrogen is produced from the electrolysis of water using renewable sources of energy like solar and wind. This electrolysis from renewable energy is carbon neutral.
- The electrolyzer for green hydrogen production operates during day hours when the solar/wind generation is at its peak and is used to power industries or other equipment during the night.
- Green hydrogen is used to power trucks, buses, spaceships, airships, and even cars. It also finds use in the production of green ammonia which can be used as a fertiliser.
- Green hydrogen is easily compressible and can be stored for a long time. Also, hydrogen being light, can be transported relatively easily than lithium-ion batteries.
- However, the development of green hydrogen as a fuel, faces some challenges. Its manufacture is very expensive and its implementation requires significant investments.

7.5 GEC

GEC stands for *Green Energy Corridor*. The Green Energy Corridor (GEC) is an initiative by the Government of India to transfer renewable energy from areas with abundant resources to areas with high electricity demand. The project aims to create a reliable grid that can efficiently integrate renewable energy sources, such as solar and wind, with conventional power stations. This means that electricity produced from renewable sources like solar and wind needs to be synchronized with that from conventional power grids. This initiative will also help reduce carbon losses.

7.6 Hypact switchgears

- Hybrid switchgear is a modern technology *combining the modular advantages of AIS and enabling a compact and simple design using GIS (insulation of SF_6).*
- A hybrid switchgear comprises a single module's disconnecting switch, current transformers, and circuit breakers.
- To meet growing electric power demands, hybrid switchgears offer a great opportunity to adjust the pre-existing main and transfer bus arrangement to double bus double breaker arrangement in almost the same area available.

Following is a brief comparison of AIS, GIS, and hybrid switchgears, which shows that hybrid switchgears are an excellent alternative to conventional ones:

1. **Price**: GIS > hybrid switchgears > AIS
2. **Flexibility**: hybrid switchgears > AIS and GIS
3. **Construction and installation time**: GIS > AIS > hybrid switchgears
4. **Availability**: The availability of hybrid switchgears is also much higher than the conventional disconnection switches due to the exposed primary contacts in the latter.

In the Nakhon Chaisri substation, the adjustment of the main and transfer bus arrangement to the double bus double breaker arrangement has been carried out without any further area requirement by using hybrid switchgears. The double bus double breaker arrangement is more reliable than the main and transfer bus arrangement.

7.7 Cogeneration

Cogeneration or CHP (Combined Heat and Power) is defined as the sequential generation of two different forms of useful energy from a single primary energy source, typically mechanical energy and thermal energy. Cogeneration provides a wide range of technologies for application in various domains of economic activities. In some cases, the overall efficiency of energy use in cogeneration mode can be up to 85 percent and above.

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