2. INTRODUCTION

In recent years, because of global warming and the rise in crude oil price, countries worldwide have begun to invest heavily in research and development related to renewable energy sources [2]. Among renewable energy generation systems, solar power generation has received the most attention; from small-scale applications (e.g., energy provision to consumer electronics) to large scale operations (e.g., solar power plants), the scope of solar power applications is broad. The characteristic curves of a solar cell are nonlinear and depend on the irradiance level and ambient temperature, resulting in a unique current−voltage (I−V) curve [3].

Solar Photovoltaic cell
A solar cell, or photovoltaic cell, is an electrical device that converts the energy of light directly into electricity by the photovoltaic effect, which is a physical and chemical phenomenon [2]. It is a form of photoelectric cell, defined as a device whose electrical characteristics, such as current, voltage, or resistance, vary when exposed to light. Solar cells are the building blocks of photovoltaic modules, otherwise known as solar panels. Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light [2]. They are used as a photo-detector detecting light or other electromagnetic radiation near the visible range, or measuring light intensity [1].

The operation of a Photo-Voltaic (PV) cell requires 3 basic attributes:

- The absorption of light, generating either electron-hole pairs or excitons.
- The separation of charge carriers of opposite types.
- The separate extraction of those carriers to an external circuit.

In contrast, a solar thermal collector supplies heat by absorbing sunlight, for the purpose of either direct heating or indirect electrical power generation from heat. A "photo electrolytic cell" (photo electrochemical), on the other hand, refers either to a type of photovoltaic cell (like that developed by Edmond Becquerel and modern dye-sensitized solar cells), or to a device that splits water directly into hydrogen and oxygen using only solar illumination [5].

Conventional Crystalline Silicon Solar Cell
Objective of MPPT Charge Controller:
The objective of MPPT charge controller is to ensure that the system can always harvest the maximum power generated by the PV arrays. However, due to the varying environmental condition, namely temperature and solar isolation, the P–V characteristic curve exhibits a maximum power point (MPP) that varies nonlinearly with these conditions thus posing a challenge for the tracking algorithm. The algorithms are proposed by various researchers like P&O algorithm, Inc-Con Method, Hill-Climbing method etc [7].

Traditional solar inverters perform MPPT for the entire PV array (module association) as a whole. In such systems the same current, dictated by the inverter, flows through all modules in the string (series). Because different modules have different I–V curves and different MPPs (due to manufacturing tolerance, partial shading etc.) this architecture means some modules will be performing below their MPP, resulting in the loss of energy [7].

Requirement of MPPT
A considerable amount of effort is necessary to maintain an electric power supply within the requirements of various types of consumers. Some of the requirements of a MPPTs system are: proper voltage, Extraction of more power from PV panel, and reliability [7].

(i) Proper Voltage: One important requirement of a MPPT is that voltage variations at consumers’ terminals should be as low as possible. The changes in voltage are generally caused due to the Steady state oscillation, large fluctuations of isolation, Partial shading condition of the PV array, inevitable trade off between the MPPT speed and oscillation.

(ii) Extraction of more power from PV panel: The high investment cost required by this technology makes extracting a large amount of available power from PV panels necessary. As a result, maximum power point tracking (MPPT) strategies should be deployed to ensure the tracking of the maximum power point (MPP) of nonlinear PV characteristics. The major challenges of MPPT lie in its dependence on the environmental parameters of the PV curve (i.e., temperature and insolation dependence)

(iii) Reliability: Maximum Power Point Tracking (MPPT) can be more cost effective, has a higher reliability and can improve the quality of life in remote areas. A high efficient power electronic converter, for converting the output voltage of a solar panel, or wind generator, to the required DC battery bus voltage has been realized. The converter is controlled to track the maximum power point of the input source under varying input and output parameters.
Maximum power point tracking for relative small systems is achieved by maximization of the output current in a battery-charging regulator [6].

**Classification of solar cells**

Solar cells are typically named after the semiconducting material they are made of. These materials must have certain characteristics in order to absorb sunlight. Some cells are designed to handle sunlight that reaches the Earth's surface, while others are optimized for use in space. Solar cells can be made of only one single layer of light-absorbing material (single-junction) or use multiple physical configurations (multi-junctions) to take advantage of various absorption and charge separation mechanisms [9].

Solar cells can be classified into first, second and third generation cells. The first generation cells also called conventional, traditional or wafer-based cells are made of crystalline silicon, the commercially predominant PV technology, that includes materials such as poly-silicon and mono-crystalline silicon. Second generation cells are thin film solar cells, that include amorphous silicon, CdTe and CIGS cells and are commercially significant in utility-scale photovoltaic power stations, building integrated photovoltaic or in small stand-alone power system. The third generation of solar cells includes a number of thin-film technologies often described as emerging photovoltaic most of them have not yet been commercially applied and are still in the research or development phase.
Silicon wafer based solar cells:

By far, the most prevalent bulk material for solar cells is crystalline silicon (c-Si), also known as "solar grade silicon". Bulk silicon is separated into multiple categories according to crystallinity and crystal size in the resulting ingot, ribbon or wafer. These cells are entirely based around the concept of a p-n junction. Solar cells made of c-Si are made from wafers between 160 to 240 micrometers thick [9].

Mono-crystalline silicon: Mono-crystalline silicon (mono-Si) solar cells are more efficient and more expensive than most other types of cells. The corners of the cells look clipped, like an octagon, because the wafer material is cut from cylindrical ingots, which are grown typically by the Czochralski process. Solar panels using mono-Si cells display a distinctive pattern of small white diamonds [10].

Poly-crystalline silicon: Poly-crystalline silicon or multi-crystalline silicon (multi-Si) cells are made from cast square ingots which are large blocks of molten silicon carefully cooled and solidified. They consist of small crystals giving the material its typical metal flake effect. Poly-silicon cells are the most common type used in photovoltaic and are less expensive, yet less efficient than those made from mono-crystalline silicon [10].

Thin-film solar cells:

The silicon wafer based technologies are expensive because of the high cost of high purity Si used in the solar cells. The thin film solar cell technology has potential to bring down the cost. This is possible because the thin film solar cell technologies offer significant advantage, both in terms of material and in terms of fabrication, as compared to wafer-based technologies. Thin film solar cell technologies have many advantages such as [6].

- Consume less amount of material per unit solar cell area than wafer-based solar cell technologies.
- Large area modules can be fabricated to give cost advantage.
- In fabrication of thin film solar cell low temperature (<500oC) processes is used.
- Transparent modules can be made to give the advantage of both light and electricity during the day time.
- Solar cells can be integrated (connected in series) as module at time of fabrication called as monolithic integration. It gives the additional cost benefit.

Amorphous Si solar cells: The amorphous Si (or a-Si) material has become an interesting material when it was discovered that its conductivity can be changed. It can be made to p-type or n-type, thus allowing the formation of junction [7]. It has large number of defects
(1021 cm\(^{-3}\)) due to this it has very bad electrical properties but defect density decrease up to 1016 cm\(^{-3}\) or less on alloying with hydrogen by making hydrogenated a-Si or a-Si:H. The a-Si:H shows very high absorption coefficient in visible range it requires only 1 micron thick layer to absorb almost 90% of solar spectrum. Amorphous Si solar cell is commercialized.

**Compound Semiconductor solar cells:** A compound semiconductor is a semiconductor composed of two or more elements. Some commonly used semiconductor material used for solar cell are discussed below:

- **Cadmium Telluride (CdTe):** It is a binary compound semiconductor of cadmium (Cd, group II) and Tellurium (Te, group VI) commonly referred as II-VI semiconductor. It is typically deposited in poly-crystalline form. It is a direct band gap material having high absorption coefficient for most of the spectra which get absorbed. The bond energy of CdTe is quite high, about 5.75 eV. Because of this it is a very chemically and thermally stable material, hence suitable for space application. However, cadmium is highly toxic and tellurium (anion: "telluride") supplies are limited. The cadmium present in the cells would be toxic if released [10].

- **Chalcopyrite (CIGS):** Such thin film solar cells have potential for high and stable efficiency. The most important chalcopyrite compound for solar cell applications are CuInSe\(_2\) (copper indium selenide), CuInS\(_2\) (copper indium sulphide) and CuGaSe\(_2\) (copper gallium selenide). The band gap of CIGS material can be tailored by alloying with other elements [10].

**Thin film crystalline Si solar cells:** It refers to the cell technologies that are based on thin film Si which at least has some crystalline phase. Except microcrystalline Si or crystalline Si (c-Si) in most cases, it is 100%. Thin film crystalline solar cell technologies have many advantages some of them are discussed as follows:

- Si is the single most abundant material available in the earth’s crust, So the large scale fabrication is feasible.
- Silicon is a non-toxic material.
- Crystalline Si film-based solar cell provides high solar cell stability and reliability.
- It can really be cost effective because of lower production cost as well as low material cost.
- The theoretical efficiency of a thin-film solar cell is higher than that of bulk silicon solar cell.
Emerging solar cells:
New technologies have potential to be more cost effective. These technologies are different either in terms of materials used in solar cell formation or in terms of the operation principle of the device. Few emerging technologies are discussed below [17].

Organic Solar cells: An organic photovoltaic cell (OPVC) is a photovoltaic cell that uses organic electronics--a branch of electronics that deals with conductive organic polymers or small organic molecules for light absorption and charge transport. The solar cells based on organic semiconductor can provide a low-cost alternative for solar cell PV because of low material consumption per solar cell and relatively simpler cell processing (low temperature without vacuum). The plastic itself has low production costs in high volumes. Combined with the flexibility of organic molecules, this makes it potentially lucrative for photovoltaic applications. Although it faces stability problem and possess very low efficiency. Material commonly used for organic solar cells are P3HT (poly-3-hexylthiophene), PCBM (6,6-phenyl-C61-butryic acid methyl ester), PPV (polyphenylenevinylene), BBL (poly (benzimidazobenzophenanthroline ladder)), CuPc (copper phthalocyanine), C60 (fullerene) etc. This technology is not yet commercialized [17].

Dye-Sensitized cells (DSC): The DSC is a photo-electro-chemical device. In its operation it involves a photon, an electron and a chemical reaction. Its operation is considered similar to that of the photosynthesis process. The DSC can be considered as thin film solar cell device. This technology is also not commercialized but is on the verge of commercialization. The DSC solar cells can be made flexible and has good potential for being a low cost solar cell technology. This is possible because of the large availability and low cost of the ingredient material as well as due to the low processing temperatures. Normally liquid electrolyte is used, and in long term operation its leakage is one of the main concern as well as its long term stability. Functions of light absorption and charge transportation are done by two different materials, unlike in other semiconductor based solar cell where both these jobs are done by the same material. The material, which absorbs the light, is called Dye and a wide band gap material is used to transport the carrier. Three types of material (dye) which is most commonly used are ruthenium-based metal-organic complexes N-3 [RuL’ (NCS)3, the red dye], N-749 (RuL2(NCS)2, the black dye) and Z-907. The most extensively applied and successful semiconductor wide band gap material used in DSC is TiO2 (3.2 eV) [17].

Hybrid Solar cells (HSC): A hybrid solar cell consists of both organic and inorganic materials and hence combines the unique properties of inorganic semiconductor with the film forming properties of the conjugated polymers (organic materials). Organic materials are
inexpensive; easily process able and their functionality can be tailored by molecular design and chemical synthesis. On the other hand, inorganic semiconductors nano-particles offer the advantage of having high absorption coefficients and size tenability. By varying the size of nano-particles the band gap can be tuned therefore, the absorption range can be tailored. It converts the light that goes unused by solar cell into heat and then converts the heat into electricity [19].

**Losses in Solar Cells**

A loss in a solar cell refers to loss of photon energy (partial or full) which, due to some reason, is not able to deliver an electron out of a solar cell. This loss could be due to the fundamental reason (limited by material properties) or it could be due to the technological reason (limited by cell processing capabilities). There are several ways in which photon energy loss could occur [20].

**Fundamental losses:** These losses cannot be avoided or cannot be minimized beyond their fundamental limits. Different fundamental losses are given as follows:

**Loss of low energy photons:** The photons having energy less than the band gap energy do not get absorbed in the material and, therefore do not produce electron-hole pairs. This is referred as transmission loss [20].

**Loss due to excess energy of photons:** In an ideal case only, photon of energy equal to the band gap energy is required to excite an electron from valence band to conduction band. When the photon of energy $E$ is higher than the band gap energy $E_g$, the excess energy $= E - E_g$ is given off as a heat to the material. This loss is referred as thermalization loss.

**Voltage loss:** The voltage corresponding to the band gap of a material is obtained by dividing the band gap (potential energy) by charge i.e. $E_g/q$. This is referred as band gap voltage. The actual voltage obtained from a solar cell is $V_{oc}$. This happen due to the unavoidable intrinsic Auger recombination [14].

**Fill factor loss:** The I-V curve of ideal solar cell is square i.e $FF=1$, but in reality, the solar cell I-V curve is given by the exponential behavior. In the best case, the FF could be 0.89. This type of loss arises from the parasitic resistance (series or shunt resistance) of the solar cell.

**Technological losses:** Following given points are technological losses, which can be avoided by adopting special fabrication techniques. It can be categorized as optical losses and electrical losses.
**Optical losses:** It is referred as the loss of photons, which may result in the generation of electron-holes pair such as:

- Loss by reflection: A part of incident photons is reflected from the cell surface. The reflection can be minimized by using anti-reflecting coating and surface texturing.

- Loss due to metal coverage: In wafer-based solar cell, the contact to the front side of the cell (from where light enters) is made in the form of finger and busbar. This metal contact shadows some light which can be up to 10%. Several approaches have been adopted to minimize this loss which includes one-side contacted cell, buried-contact solar cell or transparent contact as used in thin film solar cells [13].

**Multilevel Inverter:**

Micro inverter, is a device used in photovoltaic that converts direct current (DC) generated by a single solar module to alternating current (AC). The output from several micro inverters is combined and often fed to the electrical grid. Micro inverters contrast with conventional string and central solar inverters, which are connected to multiple solar modules or panels of the PV system. Micro inverters have several advantages over conventional inverters. The main advantage is that small amounts of shading, debris or snow lines on any one solar module, or even a complete module failure, do not disproportionately reduce the output of the entire array. Each micro inverter harvests optimum power by performing maximum power point tracking (MPPT) for its connected module. Simplicity in system design, lower amperage wires, simplified stock management, and added safety are other factors introduced with the micro inverter solution. The primary disadvantages of a micro inverter include a higher initial equipment cost per peak watt than the equivalent power of a central inverter since each inverter needs to be installed adjacent to a panel (usually on a roof). This also makes them harder to maintain and more costly to remove and replace (O&M). Some manufacturers have addressed these issues with panels with built-in micro inverters. Micro-inverters, ranging from 150 W to 300 W, have become the focus of residential PV systems due to several advantages such as improved energy harvest, lower installation cost, and plug-and-play feature. In grid connected single phase inverters, power decoupling is required to attenuate the reflection of pulsating load power on PV outputs. An energy storage element, usually a capacitor, is used for this application. Based on the decoupling capacitor location three decoupling techniques are identified: 1) PV side decoupling, 2) Embedded DC link decoupling and 3) AC side decoupling [16].
**Diode Clamped Multilevel Inverter:**
The main concept of this inverter is to use diodes and provides the multiple voltage levels through the different phases to the capacitor banks which are in series. A diode transfers a limited amount of voltage, thereby reducing the stress on other electrical devices. The maximum output voltage is half of the input DC voltage. It is the main drawback of the diode clamped multilevel inverter. This problem can be solved by increasing the switches, diodes, capacitors. Due to the capacitor balancing issues, these are limited to the three levels. This type of inverters provides the high efficiency because the fundamental frequency used for all the switching devices and it is a simple method of the back to back power transfer systems [19].

**Flying Capacitors Multilevel Inverter:**
The main concept of this inverter is to use capacitors. It is of series connection of capacitor clamped switching cells. The capacitors transfer the limited amount of voltage to electrical devices. In this inverter switching states are like in the diode clamped inverter. Clamping diodes are not required in this type of multilevel inverters. The output is half of the input DC voltage. It is drawback of the flying capacitors multi level inverter. It also has the switching redundancy within phase to balance the flaying capacitors. It can control both the active and reactive power flow. But due to the high frequency switching, switching losses will takes place [19].

**Cascaded H-Bridge Multilevel Inverter:**
The cascaded H-bridge multi level inverter is to use capacitors and switches and requires less number of components in each level. This topology consists of series of power conversion cells and power can be easily scaled. The combination of capacitors and switches pair is called an H-bridge and gives the separate input DC voltage for each H-bridge. It consists of H-bridge cells and each cell can provide the three different voltages like zero, positive DC and negative DC voltages. One of the advantages of this type of multi level inverter is that it needs less number of components compared with diode clamped and flying capacitor inverters. The price and weight of the inverter are less than those of the two inverters. Soft-switching is possible by the some of the new switching methods.

Multilevel cascade inverters are used to eliminate the bulky transformer required in case of conventional multi phase inverters, clamping diodes required in case of diode clamped inverters and flying capacitors required in case of flying capacitor inverters. But these require large number of isolated voltages to supply the each cell [19].