CHAPTER 1
INTRODUCTION

1.1 OVERVIEW

Renewable energy sources have become more abundant compared to the conventional fossil fuels and going with theory, they can provide an easy supply of the world's energy requirements (Larcher & Tarascon 2015). The surface of the Earth gets 89 PW of an overall inbound solar insolation. It is impossible to exploit all of it, but even if a portion of it is captured, even lesser than 0.02%, would be sufficient to satisfy our needs (Sharma et al. 2016). The solar radiations obtained can be transformed into electrical energy by making use of Photo-Voltaic Cells or Solar Cells that generate electrical energy by means of Photo-Voltaic effect i.e. creation of Voltage or Direct Electric Current in a semi-conductor material with exposure to light (Badescu 2014). The generation of Photovoltaic power is accomplished employing solar panels that consist of multiple solar cells that are formed with a photovoltaic material. Materials presently utilized for photovoltaic are inclusive of amorphous silicon, copper indium gallium selenide/sulphide, cadmium telluride, monocrystalline silicon, and polycrystalline silicon (Sugiyama 2016).

Owing to the constant rise in demand for renewable energy sources, manufacturing Solar Cells and Photo-Voltaic Arrays has significantly seen advancements over the last few years (Papavasiliou & Oren 2014). The output obtained from a PhotoVoltaic panel is characteristically non-linear and also the output largely differs with changes in environment such as temperature,
solar insolation, etc. This imposes a critical danger when exploiting it. The whole Photo-voltaic array does not get equivalent amount of radiations during all the time. At times, portions of the array come under shading owing to clouds, tree, towers, dust, etc. This leads to multiple peaks occurrence in the Power v/s Voltage characteristics of the array that, in turn, prevents the correct functioning on the maximum power point tracker (Sharma 2016).

Significant power loss will be observed when the local maximum power point is tracked and not the global maximum (Rao et al. 2013). Therefore, tracking the optimal operating voltage of the Photo-Voltaic array is important for having efficient PV generators. The PV array provides varied output at various times of the day for diverse orientations based on the amount of sunlight that falls on the module as well as the angle of the rays falling on it. Therefore, the angle at which the module is positioned corresponding to the ground could be optimized so that a maximum output from the module is obtained at all times (Kanchev et al. 2014).

1.2 INTRODUCTION

The issue of energy has always remained a crucial topic of interest in the development of human species (D’Ambrosio et al. 2017). Domination held by fire, employing the wind for sailing or mechanical purposes, water mills, thermo electrical power plants and nuclear energy constitute some important topics in the history that denote the development of the human being over a huge period of time. Presently, in the 21st century, the entire universe has been facing fresh problems. Energy has rose to be a priority, not just to satisfy the energy requirements of industrial countries, but also to satisfy the energy needs of the rising population in the world. Fossil fuels, due to their immeasurable contribution towards supplying energy to the world, are anticipated to possess less reserve, imposing a threat to the future of the development of the world at the current rate. Fossil fuels also have a part to
play in polluting the atmosphere and are also associated with global warming (Rutherford & Jaglin 2015).

In order to surpass these challenges, just before it leads to a huge threat, man has shifted his focus on developing fresh energy sources that will indicate the forward step in human history. Among these, it is with no doubt it can be said that directly or indirectly, the sun’s energy, has an important role to play in the future. Recently, the use of photovoltaic systems that direct collect the sun’s energy are seeing an increase and indicate a rising grounds of the solar industry and research in the scientific community. The increase in the energy gain, through solar tracking systems, is one among the researched topics in this area and has been in the discussion owing to many kinds of statements that have been formed regarding its efficiency.

1.3 SOLAR ENERGY

The debate pertaining to global warming, in addition to the increasing oil prices observed in the year 2008, has stirred on the discussion corresponding to the means of satisfying the rising demand in power all around the universe (Redweik et al. 2013). Therefore, renewable energy sources have emerged to be more vital and more number of economic resources are being utilized in order to support the research activities. Few countries have even provided remarkable incentives to grow the power generation capacity employing renewable energy sources (Twidell & Weir 2015).

1.3.1 Power Sources

The important power sources that are in use currently and their significance in the primary energy supply of the world can be observed at Figure 1.1. Fossil fuels remain the primary sources presently and they are anticipated to continue so for the next 25 years to come (Safdarnejad 2015).
The limit in the resources of fossil fuels predicted in the world in addition to a rising quest for power and the greater degrees of environmental pollution happening in the world are pushing the politicians and researchers to work on renewable energy sources. The intent is to reduce the usage of fossil fuels like oil, coal and gas in the future and to improve the utilization of renewable energy sources such as hydropower, biomass, wind, solar power and geothermal. Nuclear power, which is not considered to be a fossil fuel and also not in the form of a renewable energy source, predicts an indefinite future, as there are several opinions that have been floated about its evolution.

(SOURCE: WBGU 2003)

Figure 1.1 Evolution of world total primary energy supply

With the focus now on renewable energy sources, there is much hope on solar energy in the long run, more clearly in the collection of solar radiation, the energy source having the highest potential development, with due consideration to the large amount of solar energy that is available (data and predictions based on the German Advisory Council on Global Change,
WBGU 2003). Few other global organizations associated with the research on the international energy development such as the International Energy Agency and the Energy Information Administration (official energy statistics from the U.S. Government) are in disagreement with few of the statements made by the WBGU in ideas like the improvement of the participation of the nuclear energy in the days to come. These organizations also accept that the development of renewable energy sources will be lesser compared to the predictions of the WBGU and are not involved with the predictions made for beyond 2030.

1.3.2 Solar Energy at the Present Time

“Solar energy”, as stated previously, signifies the radiation energy of the sun, which can be transformed into power with specialized devices (Quaschning 2016). Figure 1.2 depicts the irradiance levels in India, as the amount of available solar energy varies in a dramatic manner. The devices can be categorized based on the technology employed or the means of which the energy is utilized, for instance, for generating electricity or for solar thermal heating.

The solar thermal energy is generally utilized for heating up the water or air, with the help of solar thermal panels for providing domestic hot water or space heating. Under the electricity generation group, the concentrating plants and the photovoltaic (PV) panels are the popular ones.
Figure 1.2  Local solar irradiance averaged over three years from 2005 to 2010 (24 hours a day), taking into account the cloud coverage available from weather satellites

While the first ones are utilized on bigger fields in the form of power plants for generating the power that is connected to the grid, the second ones are not necessarily utilized in bigger power plants but also in less big systems for domestic usage, either in the form of grid-tied or off-grid PV systems (Ghafoor & Munir 2015). A model of the installed capacity of global PV systems can be observed in Figure 1.3. The tendency indicates that grid-connected systems are emerging to be much more significant compared to off-grid systems, when the rising tendency has improved considerably. The grid-connected solar PV installed capacity in the year 2008 worldwide was estimated to be 12,950 MW. Germany, being the country having the biggest installed capacity, possessed 5,400 MW. Based on the BMU from the
73.400PJ of primary energy that was supplied to Europe, just 6.5% arrived from renewable energy sources. Just a 0.7% of this renewable supply arrived from solar power typically.

![Worldwide growth of photovoltaics](image)

**Figure 1.3 Installed power capacity of Solar PV in the world**

Solar power plants that are either or not connected to the grid, possess an identical component configuration. Here the focus is just on the grid connected ones (Kuravi et al. 2013). The power plants chiefly comprises of solar modules, the inverter, the data logger, few sensors, a grid supply meter, the mounting parts and other elements, which could be utilized. Generally, the solar modules accumulate the solar radiation and generate DC current that is converted into AC current by means of the inverter and thereafter supplied to the grid. For the solar modules, there are several types of cell whose efficiency differ considerably, like single-crystalline silicon ($\eta=$
14% to 18%), polycrystalline (η = 13% to 15.5%), thin films (η = 10% to 12%) and amorphous silicon (η = 6% to 8%). There are several prospects for connecting the solar modules to the inverter (either in series, in parallel or combined) and which extra parts has to be used, generally for the purposes of measurement. Nonetheless, these connecting options are mainly associated with the characteristics of inverters’ or on how many number solar modules are being utilized. In order to improve the amount of energy collected, with suitable consideration to a pre-defined amount of solar panels, one among the options available is to improve the orientation of the panel. This can be accomplished by installing stationary systems at an optimal angle of orientation or by employing tracking systems that follow the sun.

1.3.3 Concepts on Solar Radiation

Before discussing about the solar tracking systems, few fundamental concepts concerned with solar radiation are reviewed and some of the essential values for understanding the results of this technical work in a better manner have been examined. The sun, with an estimated temperature of 5800 K, emits large amounts of energy as radiation that, in turn, touches the planets of the solar system. The sun’s radiation reaches the earth by the intensity of 1367 W/m² as per the World Radiation Center (Tchaya et al. 2017). This value, referred to as the Solar Constant Gsc, denotes the energy per unit time obtained from the sun on a unit area of surface in a perpendicular orientation to the direction of the sun radiation external to the atmosphere. However, this value is not fixed and varies during the year and as the years passes by. The solar radiation is spread over a wavelength range, inclusive of the visible wavelength that ranges between 0.37μm till 0.78 μm. The general wavelength utilized for the extra-terrestrial radiation of the sun ranges from 0.25 μm to 3 μm, regarded to be the short wave radiation. The
radiation having a wavelength greater than 3 μm is regarded to be long wave radiation.

The short wave radiation can be classified into three groups: The ultraviolet radiation (0.28 – 0.38 μm) with a 7% of the overall short wave radiation’s energy, the visible wavelength having a 47% of the energy and the infrared radiation (0.78 – 3.00 μm) along with a 46% of the energy (Goldstein et al. 2015). Because of the elements in the atmosphere, just a portion of the extra-terrestrial sun’s radiation hits the surface of the earth. When the radiation infiltrates the atmosphere, a portion of the radiation gets absorbed by ozone present in the ultraviolet range, through water vapour and carbon dioxide existing in the infrared range. The radiation that reaches is also distributed in the atmosphere by air molecules, water vapour and small particles. This way, the solar radiation, which arrives at the earth’s surface is lesser compared to the Solar Constant.

Few significant concepts regarding the radiation incident on a surface are also discussed. Direct radiation (also referred to as beam radiation) (Khan & Gibbons 2014) is defined as the solar radiation of the sun, which has not been distributed (results in shadow). The diffuse radiation refers to the sun radiation, which has been distributed (absolute radiation on cloudy times). Reflected radiation refers to the incident radiation (beam and diffuse), which gets reflected by the earth and is incident on the surface. The total of beams, diffuse and reflected radiation is regarded to be the global radiation on a surface.

1.4 SOLAR TRACKING SYSTEMS

Solar tracking systems are exploited to enhance the amount of power generated by a solar plant (Okandan & Nielson 2016). Various techniques are used around the world, with diverse performance studies.
associated with them. Moreover, the solar industry has performed its individual assessments on this problem that is not always in coincidence with the results of scientific experiments.

Photovoltaic, or PV for short, is a technology, where light is transformed into electrical power (Archer & Green 2014). It is best referred to as a technique for the generation of solar power by utilizing the solar cells that are packaged in photovoltaic modules, frequently connected electrically either in multiples in the form of solar photovoltaic arrays to transform the energy obtained from the sun into electricity. Photovoltaic modules are particularly helpful in conditions in which the demand for electrical power is considerably less and can be exploited for utilizing less number of modules. Solar tracker is one among the applications of PV module.

A solar tracker is typically a device used to operate a solar photovoltaic panel or concentrate the solar reflector or lens (Bentaheh et al. 2014). Solar tracker was discovered as the solar panel does not move towards the sunlight if the sun travels from east to west. With the aim of generating the maximum power output, solar tracker is designed along with motor such that the solar panel will move towards the position of sun and it operates with sensors and microcontroller. Solar tracker has several variations but with the purpose of producing the maximum power output, active trackers are used.

The need for electricity has seen manifold increase year after year. New factories, houses, hotels and more number of buildings and activity have grown, which demand electricity. Since Malaysia is a developing country, the electricity generator cannot completely provide for the demanded power. With the purpose of ensuring the fulfilment of the demand for electricity, solar power is utilized in the form of renewable energy. PhotoVoltaic (PV) modules are typically devices, which clearly transform sunlight into electricity and provide a feasible solution to the challenge of power
generation in remote locations. They are particularly helpful in conditions where the need for electrical power is considerably less and can be exploited for utilizing less number of modules.

Powering up lights, a refrigerator, a television and heating the water in a small home are few instances of tasks, which can be managed by a small array of solar modules. As to the part of increasing the electricity, the solar tracker has a huge role to play in generating electricity. The solar tracker helps in tracking the sun and then focuses the maximum sunlight onto the PV module for generating electricity. Since the solar tracker is employed, the electricity could be producing more than the usual quantity of electricity in a year. It can fulfil the electricity needed such that the citizens can lead a better life without the electricity being disrupted and it can handle crucial conditions if technical issues exist with the primary electric generator. On the whole, the solar tracker is efficient and must be commercialized much more.

1.4.1 Applications of Photovoltaic Power

Below listed are the examples of the applications of photovoltaic power or solar power (Ge et al. 2013).

Photovoltaic in transport: Photovoltaic power has conventionally been utilized for auxiliary power in space. Photovoltaic power is seldom utilized to generate motive power in transport applications, but is considerably used for the generation of auxiliary power in boats and cars.

Photovoltaic power in standalone devices: Photovoltaic power has been in use for several years in power calculators and fancy devices. Enhancements in integrated circuits and low power LCD displays have made it feasible to run a calculator for many years along with battery changes, rendering solar calculators to be less prevalent. On the contrary, solar
powered remote stationary devices have been used increasingly in the recent times, owing to the growing cost of labour for connecting the mains of electricity or having a regular maintenance scheduled. Few instances include parking meters, emergency telephones, and temporary traffic signs.

1.4.2 Advantages of Solar Electricity

The 89 peta watts of sunlight hitting the earth's surface are ample nearly 6,000 times more in comparison with the 15 terawatts of average power taken up by human beings (Hernandez et al. 2014). Moreover, solar electric generation possesses the greatest power density (global mean of 170 W/m²) among the renewable energy sources. While usage, solar power is pollution free. Generation end wastes and emissions are within manageable limits employing the available pollution controls. End-of-use recycling technologies are being developed (Hamakawa 2013). The built facilities can work with very less maintenance or interruption once the initial setup is done. Solar electric generation is appreciably economic where the grid connection or fuel transport is tedious, expensive or not possible. Examples are satellites, island communities, remote locations and ocean vessels.

While grid-connected, solar electric generation can replace the huge cost of electricity during periods of peak necessity (in many climatic regions), it can decrease grid loading, and can reduce the necessity for local battery power for usage during times of darkness and huge local demand; such an application is improved by net metering. Time-of-use net metering can be greatly desirable in portable photovoltaic systems. Grid-connected solar electricity can be utilized locally, thereby minimizing the transmission/distribution losses (transmission losses were approximately 7.2% in 1995) (Adaramola 2014). When the initial capital expense of constructing a solar power plant has been finished, operational expenses are significantly less in comparison with the available power technologies.
1.4.3 Disadvantages of Solar Electricity

Solar electricity is mostly always costlier compared to the electricity produced by other sources (Ellabban et al. 2014). Solar electricity cannot be availed during night and there is less availability during conditions of cloudy weather. Hence, a storage or complementary power system is necessary. Low power density: Average daily isolation in the contiguous U.S. arrives to 3-7 kW·h/m² and is on an average lesser in Europe. Solar cells generate DC that has to be converted into AC (employing a grid tie inverter) while being utilized in the presently available distribution grids. This leads to an energy loss of about 4-12%.

1.5 SOLAR POWER DEVELOPMENT

The Greeks and Romans in the Ancient times perceived plenty of advantages in what is now referred to as passive solar design—the utilization of architecture to use the sun’s capacity for lighting and heating indoor spaces. Mouchout designed a steam engine that was powered completely by the sun (Michael et al. 2016). But its high expenditures along with the declining price of English coal failed his invention to remain just a footnote in the history of energy. However, solar energy stayed to interest and motivates the European scientists through the 19th century. Scientists designed huge cone-shaped collectors, which could boil ammonia to carry out jobs such as locomotion and refrigeration. France and England pinned brief hopes on solar energy that it could be the power behind their expanding operations in the hot colonies of Africa and East Asia. Solar power can brag about some principal benefits throughout the first half of the 20th century, even though the pursuit in a solar-powered civilization has never disappeared completely.

Actually, Albert Einstein was awarded with the 1921 Nobel Prize in physics for his research about the photoelectric effect—a phenomenon
focused on the production of electricity by means of solar cells. In 1953, Bell Laboratories (now AT &T labs) scientists Gerald Pearson, Daryl Chapin and Calvin Fuller designed the first silicon solar cell with the capability of producing a measurable electric current (Patterson 2014). The New York Times described the invention to be “the start of a new era, eventually resulting in the realization of harnessing the almost limitless energy of the sun for the uses of civilization.” (Kazmerski 2017).

In 1956, solar photovoltaic (PV) cells were nearly economically impractical. The electricity generated from solar cells powered about $300 per watt. (For the sake of comparison, the present market rates for a watt of solar PV dangle around $5.) The “Space Race” of the 1950s and 60s provided moderate chances for improvements in solar, as satellites and crafts utilized solar paneling for the generation of electricity. During the 1990s, the fact was that the expenses of solar energy had reduced as per prediction, but the expenditure of fossil fuels had also reduced—solar was contending with a slipping standard. Nonetheless, large PV market expanse in Japan and Germany from the 1990s to the current times has given a new lease of life to the solar industry. In 2002, Japan had 25,000 solar roof tops installed. Such huge PV orders have created economies of scale, thereby decreasing the costs steadily. Currently, the PV market is developing at a rapid 30 percent each year, added with the hopes of continuously reducing expenditure. At the same time, solar thermal water heating is an enormously cost-efficient way of reducing the gas and electricity needs (Greening & Azapagic 2014).

1.5.1 Photovoltaic Technology

Photovoltaic is the best known technique for producing electric power by employing solar cells that are packed in photovoltaic modules, frequently with an electrical connection in multiples in the form of solar photovoltaic arrays to transform energy from the sun into electricity (Singh
In order to have a simple explanation of the photovoltaic solar panel, the photons from sunlight knock the electrons into one higher state of energy, thus generating electricity. The term photovoltaic represents the unbiased operating mode of a photodiode, where the current passing through the device is completely because of the released light energy. Nearly all of the photovoltaic devices are some kind of photodiode. Solar cells generate direct current electricity from light that, in turn, can be utilized to power the equipment or for recharging a battery. The first feasible application of photovoltaic was to provide power to the orbiting satellites and other kinds of spacecraft, though currently, a major part of photovoltaic modules is exploited for the generation of grid connected power. Here, an inverter is needed for converting the DC to AC. There is a small market for off grid power for remote dwelling, roadside emergency telephones, remote sensing, and cathodic protection of pipelines (Park 2015).

1.5.2 Solar Panel

In the photovoltaic field, a photovoltaic module or photovoltaic panel is basically a packaged interconnected assembly consisting of photovoltaic cells, also referred to as solar cells. An installation comprising of photovoltaic modules or panels is referred to as a photovoltaic array. Photovoltaic cells generally demand protection from the surroundings. For reasons involving expense and feasibility, multiple cells are electrically connected and then packaged in a photovoltaic module, when an assembly of these modules, which are mechanically tied together, wired, and then designed to act as a field-installable unit, at times with a glass covering and a frame and backing that is made up of metal, plastic or fibre glass, are referred to as a photovoltaic panel or just solar panel (Hu et al. 2016).
1.6 SOLAR TRACKER FUNDAMENTALS

A solar tracker is generally a device for directing a day lighting reflector, solar photovoltaic panel or for guiding the solar reflector or lens towards the sun. The position of the sun in the sky differs both with the seasons (elevation) and also the time of day with the sun’s movement across the sky. Solar powered equipment functions the best when directed at or close to the sun, such that a solar tracker can improve the efficiency of such equipment over any stable position, at the expense of extra system complexity. There are several kinds of solar trackers, of different costs, complexity, and performance. One popular kind of solar tracker includes the heliostat, a movable mirror, which provides the reflection of the moving sun to a stable location, but several other techniques are also employed (Solanki 2015).

The necessary accuracy of the solar tracker is dependent on the application. Concentrators, particularly in solar cell applications, need a greater level of accuracy to make sure that the concentrated sunlight is oriented with precision onto the powered device that is at (or close to) the focal point of the reflector or lens. Generally, without tracking, concentrator systems will not operate at all, therefore at least single-axis tracking is compulsory.

Non-concentrating applications need lesser accuracy, and several can operate with no tracking. Nonetheless, tracking can significantly increase both the amount of total power generated by a system and that generated during crucial system demand times (generally late afternoons in humid climates). The usage of trackers in non-concentrating applications is typically an engineering decision made on the basis of economics. In comparison with photovoltaic, trackers can be quite economic. This renders them specifically efficient for photovoltaic systems that use high-efficiency (and therefore costly) panels. Even though trackers do not have a critical role in a P.V
system, their implementation can substantially increase the power output of a system by maintaining the sun in focus all through the day. Efficiency is certainly increased in the morning and afternoon periods during which a stable panel will be in a position that faces well away from the rays of the sun.

In fact, photovoltaic modules are costly and in many cases, the expense incurred in the modules themselves will be more than the tracker system expense. In addition, a well-developed system that uses a tracker will require less number of panels owing to improved efficiency, leading to a decrease in the initial implementation expenditure (Marugán et al. 2016).

1.7 OVERVIEW ON TRACKER MOUNT TYPES

Solar trackers can be active or passive and also single axis or dual axis. Generally, Single axis trackers employ a polar mount for getting maximum solar efficiency. Single axis trackers will typically possess a manual elevation (axis tilt) adjustment over a second axis that is adjusted on periodic intervals all through the year. In comparison with a fixed amount, a single axis tracker improves the annual output nearly by 30% and a dual axis tracker with an extra 6%. Two kinds of dual axis trackers, namely, polar and altitude-azimuth exist (Mohammed 2016).

1.7.1 Polar

In Polar trackers, one axis is aligned to be approximately parallel to the earth’s axis of rotation around the north and south poles, therefore the name polar. (With telescopes, this is known as an equatorial mount.) Single axis tracking is frequently employed in combination with time-of-use metering, as a potential afternoon performance is especially favourable for grid-tied photovoltaic systems, since generation at this period will match with the peak demand time for summer season air-conditioning. A fixed system
that is oriented in order to optimize this restricted time performance will indicate a substantially lesser annual generation. The polar axis has to be angled towards the north direction, and the angle between this axis and the vertical has to equal your latitude.

Simple polar trackers with single axis tracking may also have an adjustment along a second axis: the angle of declination. It might be set with manual or automated adjustments, depending on your polar-tracking device shown in Figure 1.4. If one is not planning on adjusting this angle of declination at all during the year, it is normally set to zero degrees, facing your panel straight out perpendicular to the polar axis, as that is where the mean path of the sun is found.

Figure 1.4 Polar tracker

Occasional or continuous adjustments to the declination compensate for the northward and southward shift in the sun's path through the sky as it moves through the seasons (and around the ecliptic) over the course of the year (Yu et al. 2014).
1.7.2 Horizontal Axle

Many manufacturers can supply single axis horizontal trackers that might be oriented by means of either passive or active techniques, based upon the manufacturer. Here, a long horizontal tube is supported over bearings, which are mounted with support from pylons or frames shown in Figure 1.5. The axis of the tube is over a North-South line. Panels are then placed upon the tube, and the tube will rotate on its axis in order to track the evident motion of the sun throughout the day.

![Figure 1.5 Horizontal axle of solar tracker](image)

As these do not incline towards the equator, they are not particularly efficient during the mid day of winter (unless located close to the equator), but adds a considerable amount of productivity during the time of spring and summer seasons when the solar path is high along the sky. These devices offer less efficiency at greater latitudes.

The important advantage is the intrinsic reliability of the supporting structure and also the simplicity offered by the technique. As the panels are
mounted horizontally, they can be placed compact on the axle tube without any risk of self-shading and can also be readily accessed for cleaning purposes (Song et al. 2014).

1.7.3 Two Axes Mount Type

Confined to active trackers, this mount is also emerging to be widely popular in the form of a huge telescope mount because of its structural simplicity and smaller dimensions. One axis is a typical vertical pivot shaft or horizontal ring mount, which lets the device to get swung to a compass point.

![Figure 1.6 Two axes mount type solar tracker](image)

The second axis is basically a horizontal elevation pivot that is mounted upon the azimuth platform. By utilizing the combinations consisting of the two axes, any location in the upward hemisphere may be directed to.
Such kind of systems might be worked under computerized control based on the anticipated solar orientation, or might make use of a tracking sensor to control the motor drives, which place the orientation of the panels towards the sun shown in Figure 1.6. This kind of mount is also employed for orienting parabolic reflectors, which mount a Stirling engine to generate electricity at the device (Yao et al. 2014).

1.8 OVERVIEW OF CURRENT DRIVER TRACKER TYPES

Solar trackers can be classified into three primary kinds based on the drive type and the sensing or positioning system incorporated by them. Passive trackers utilize the sun’s radiation to heat the gasses, which make the tracker move the sky. Active trackers employ electric or hydraulic drives and some sort of gearing or actuator for moving the tracker. No sensing is used by Open loop trackers rather, position of the sun is determined through pre-recorded information for a specific site (Huynh et al. 2013).

1.8.1 Gas Trackers (Passive Trackers)

Passive trackers employ a compressed gas fluid for tilting the panel. A canister placed on the direction of the sun of the tracker is heated leading to an increase in gas pressure and the liquid to be propelled from tracker’s one side to the other shown in Figure 1.7. This impacts the tracker’s balance and make sit to tilt. This system offers robustness and requires less maintenance. Even the passive gas tracker being robust and nearly free of maintenance, it will seldom orient the solar modules right towards the sun. This is because of the fact that the temperature differs each day and the system cannot take this variable into consideration. Overcast days also pose a challenge during the appearance and disappearance of the behind clouds resulting in the gas present in the liquid in the holding cylinders to experience expansion and contraction leading to an unpredictable movement of the
device. However, Passive trackers offer an efficient and considerably economic means of improving the power output obtained from a solar array.

The tracker commences the day facing the west direction. Since the sun rises in the east, it heats up the unshaded west-side canister, pushing the liquid into the shaded east-side canister. The liquid, which is pushed into the east side canister, modifies the balance of the tracker and the nit swings towards the east. More than an hour is taken to achieve the move from the west direction towards the east.

![Passive tracker](image)

**Figure 1.7 Passive tracker**

The heating up of the liquid is regulated by the aluminium shadow plates. If one canister gets exposed to the sun more than another, its vapour pressure rises, pushing the liquid to the cooler, shaded side.
Then the shifting weight of the liquid makes the rack to rotate till the canisters are equally shaded. The rack finishes its daily cycle facing the west direction. It stays in this position overnight till it is "awakened" by the rising sun in the next morning (Parmar et al. 2015).

1.8.2 Active Trackers

Active trackers provide the measurement of the light intensity from the sun to decide which direction the solar modules have to point. Light sensors are placed on the tracker at different locations or in specifically shaped holders shown in Figure 1.8.

![Figure 1.8 Active solar tracker](image)

When the sun is not directly facing the tracker, a difference in light intensity on one light sensor is seen in comparison with another. This difference can be utilized to decide where the tracker has to slant so as to face the sun (Ferdaus et al. 2014).
1.8.3 **Open Loop Trackers**

Open loop trackers decide the position of the sun employing computer controlled algorithms or simple timing systems. Timed Trackers—these utilizes a timer for moving the tracker across the sky. Incremental movement all through the day maintains the solar modules to face the usual direction of the sun. Trackers of this kind can use one or two axes based on their application and the cost that the consumer is ready to pay. The important drawback of timed systems is that their motion does not consider the seasonal variation in the sun’s position. Not until measures are made to adjust the tracker position in a seasonal manner, substantial difference in inefficiency will be observed based on the season.

1.9 **PROBLEM DEFINITION**

Even though several research proposals are seen in literature that address the performance of the Solar tracking devices, still it needs few improvements to guarantee a better power generation result. Owing to continual movement and temperature changes existing in the environment, stationary setting up of solar tracking devices would not result in a better outcome. The power generation capacity would be decreased during the continual movement of sun, in condition of which the sun’s energy usage cannot be carried out with efficiency.

1.10 **OBJECTIVES OF THE RESEARCH**

The important goal of the research work is the implementation of an optimal and robust solar tracking system with the aim of attaining the maximum power point and the increased level of battery performance. This is achieved by bringing in the different newly introduced research techniques, taking the optimal location and angle of solar tracking devices into
consideration, such that the maximum power level can be accomplished. Moreover, the objective of this research work is to optimize the storage by focusing on the energy storage, and this way the optimization of battery performance could be done.

1.11 RESEARCH CONTRIBUTION

The important contributions made by this technical work is listed as below,

- Optimal decision making of angle and location of the solar panels employing Hybridized Improved Genetic Algorithm with Differential Evolution function (HIG-DEF)
- Optimal decision making of angle and location of the solar panels utilizing Hybridized BAT with Differential Evolution function (HBAT-DEF)
- Storage optimized reliable decision making of angle and location of the solar panels employing Battery Performance aware Optimal Solar Tracking System (BPOSTS).

1.12 ORGANISATION OF THE THESIS

Chapter 1 provides the summary of the solar system and its advantages and application in various fields. Various solar approaches and methodologies have been explained with appropriate examples.

Chapter 2 provides the brief survey of the various contributions related to solar tracking methods.

Chapter 3, Chapter 4 and Chapter 5 describes the research contributions which are mentioned in the previous section.