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Abstract

In this work, we have tried to establish the structure of the solar tree by optimizing the tilt angle of a solar panel which is to be fabricated in the solar tree for the attainment of maximum irradiance at a particular location during different months of the year. We have designed the same for different places situated at north, south, east, west of the country so that an optimized result could be drawn out for all the locations. This work is done by the help of MATLAB codes. The MATLAB code is written for different diffused radiation models namely isotropic and anisotropic models and the study is done by the plots obtained by the code. The estimation of the area acquired by the solar panel is also calculated with the help of the global irradiance data provided. The estimations done in this project will help the society since it provides a generalized mathematical modeling of the solar irradiance which helps to optimize the tilt angle of a particular place. The detailed work was done for Jasidih, Jharkhand, India situated at a latitude of 24.48°N but for generalized result optimization was done for places with different latitudes Delhi, Kerala as well as Jaipur. A tracking system no doubt can be installed in a solar tree, but if we follow this optimizing technique for placing the solar panels with a tilt then the solar tree could be made cost effective.

CHAPTER 1

1.1 INTRODUCTION

The sunlight is often deemed as the only abundant and truly free energy resource. Amongst all the different techniques available to harness solar energy, the most popular technology is the photovoltaic conversion of sunlight into electricity. Solar photovoltaic cells arranged in complex three-dimensional leaf-like configurations-referred to as a solar tree - can potentially collect more sunlight than traditionally used flat configurations. PV trees are artificial solar structures that look like sculptural trees and are available in small scale to large scale. This paper compares the different structures of solar tree which is existing in the present world and various aspects is been verified in terms of area ratio, footprint area etc. The solar tree is to be used for the electric vehicle charging, so desired mathematical calculations are done for the same. Photovoltaic Trees (PV Trees) are artificial solar structures that look like sculptural trees and exist from small scale (size of a bonsai tree) to large scale (about the size of a wind turbine). The aesthetics of solar trees differ and they have been designed to provide different means of power to different urban and built environments. These range from powering mobile phones, electric cars, buildings and street lights covering small and large scale. There is a big hue and cry over energy crisis from all over the world mainly for two reasons, firstly the natural resources are going to be exhausted very soon and the other is whether we should continue with the available natural resources of carbonaceous compound which is posing threat of greenhouse gas effect to human being every day. People are trying over different sources to find out non conventional energies, mainly some sort of renewable source of energy or the green energy like solar energy, wind energy, tidal power, hydro power etc. Power from sun, as it is thought today, is the only major alternative in comparison to other sources of renewable energies presently being tried to replace the conventional source of energies like coal, gas, oil etc. The tilt angle has a considerable impact on the solar radiation on the surface of the solar module. The maximum power for a year will be obtained when the angle of the solar module together with the location's latitude.

1.2 Motivation

The motivation of doing this project came from the present world scenario. Despite of availability of solar energy in abundant, we are not using it. The efficient use of the solar energy can solve the major issue as the world will soon run out of its conventional energy resources because of the rapid depletion of fossil fuel reserves. This future scenario and the risks associated with CO2 emissions and global warming have increased the interest in renewable energy. The major renewable energy systems include photovoltaics (PVs), solar thermal, wind, biomass, hydroelectric, and geothermal. However, among various renewable energy sources, the photovoltaic technology for power generation is considered to be the best, particularly for distributed power generation. Solar panel is the energy conversion fundamental component of PV systems or solar collectors. Solar panels use light energy from the sun to generate electricity through the photovoltaic effect, whereas solar thermal systems generate heat.

One need to erect the PV panels under the sun so that the surface of panel gets the maximum sun of the day being laid at an angle. The general method is that hut like inclined structures which are made over the land surface to hold the solar panels. The generation of 2MW power from PV module system requires the land of 10 Acres approx. for housing the panels only. But land is going to be the greatest crisis of the earth rather it is already a burning crisis in most of the countries. The cultivable land which is going to be the costliest commodity in the near future, if used for other than agriculture, it will be an uncountable loss. Our many national projects are facing the severe problem of acquisition of land. Therefore if land area is used for capturing the solar power it would never be cost effective and viable for the human society. Therefore ,there is a need for devising a method and fabricating a suitable device so that the solar power can be absorbed without occupying much surface area, rather utilizing the minimum amount of land and the electricity must be economically viable.

And hence the idea of a Solar Power Tree a new technique of installing PV modules came on which the PV modules are mounted on a tall pole like structure with leaf like branches surrounding it following a pattern of Spiralling Phyllotaxy as found in a natural tree. It would take only 1% of land area in comparison to general PV housing layout as being practiced at present.

CHAPTER 2

LITERATURE SURVEY

Renewable energy sources are vital to meet the energy demand of the future with solar photovoltaics being one of the prime sources due to abundant availability of solar energy. In order to obtain maximum power from the Sun, it is essential that the solar panels are oriented so as to focus the Sun rays on its surface. This can be achieved by tracking the Sun continuously. However, tracking systems which involve large moving parts have certain disadvantages due to structural instability concerns, especially at high wind velocities, reduced life of the system and also increased maintenance cost. Therefore, solar panels with fixed orientation or with minimal seasonal adjustments are preferred to obtain maximum annual average solar irradiation [7].

The best way to collect the maximum solar energy is by using solar tracking systems to follow the sun as it moves each day, and thus to maximize the collected beam radiation. It is possible to collect 40% more solar energy by using a two-axis tracking system [1] and it is estimated that in sunny climates, a flat-plate collector moved to face the sun twice a day can intercept nearly 95% of the energy collected using a fully automatic solar tracking system [1]. Tracking systems are expensive, need energy (usually solar energy is used) for their operation and they cannot easily be made applicable to solar collectors used for water heating purposes. Therefore, we follow the technique of optimizing the tilt angle.

Following methods have been adopted in order to achieve optimum tilt [4]:

(1) Monthly based optimization: Both manual and automatic tracking system can be used for monthly based optimization.

(2) Season based optimization: In this case also manual and automatic both tracking systems can be used. Automatic tracking system will be expensive as compared to manual one.

(3) Annual based: In this case, there is no need of automatic tracking system and hence only manual tracking system is used.

Solar radiation data is usually measured in the form of global and diffuse radiation on a horizontal surface at the latitude of interest. Flat-plate solar collectors are tilted so that they capture the maximum radiation and the problem of calculating solar radiation on a tilted surface is in determining the relative amount of beam and diffuse radiation contained in the measured horizontal global radiation. Since the flat plate solar collectors are positioned at an angle to the horizontal, it is necessary to calculate the optimum tilt angle which maximizes the amount of collected energy. It is generally known that in the northern hemisphere, the optimum collector orientation is south facing (γ=0) and the optimum tilt depends upon the latitude and the day of the year [12].

Changing the tilt angle, every month to follow changes in sun declination needs to be done so that the energy produced by PV is more optimum [10]. Declination is the angular distance of the sun north or south of the earth's equator. The earth's equator is tilted 23.45 degrees with respect to the plane of the earth's orbit around the sun, so at various times during the year, as the earth orbits the sun, declination varies from 23.45 degrees north to 23.45 degrees south [1]. This gives rise to the seasons. Around December 21, the northern hemisphere of the earth is tilted 23.45 degrees away from the sun, which is the winter solstice for the northern hemisphere and the summer solstice for the southern hemisphere. Around June 21, the southern hemisphere is tilted 23.45 degrees away from the sun, which is the summer solstice for the northern hemisphere and winter solstice for the southern hemisphere. On March 21 and September 21 are the fall and spring equinoxes when the sun is passing directly over the equator [5].

A numerical approach was used to calculate the solar radiation on sloped planes by integrating the measured sky radiance distributions [2]. The annual total solar yield at different sloped surfaces facing various orientations and monthly solar radiations at the optimal tilt surface and three vertical planes facing east, south, and west were determined. The global solar radiation for inclined surfaces can be calculated by the values of direct and diffuse solar radiation on the corresponding horizontal surface [14].

CHAPTER 3

SOLAR TREE

3.1 INTRODUCTION

Solar tree represents a metal construction that resembles a real tree. Solar panels are put on top of its “branches”. Utilizing the sunlight energy, solar panels produce electric energy which is then used for charging batteries of mobile phones, tablets, laptops etc. and, additionally, as an element of street lighting. Its attractive and modern design will complement the public areas of our campus alongside the promotion of renewable sources of energy, Solar tree also promotes the use of energy efficient technologies, i.e. LED street lighting. Solar Tree is an environmental enterprise, an ecological sculpture, an artificial solar structure that looks like sculptural trees and exists from small scale (size of a bonsai tree) to large scale (about the size of a wind turbine) power plant. It is an independent unit that produces green energy and provides a place of comfort and energy for a wide variety of services. The structure is ground mounted solar system with a pole that supports many individual panels up in the air. The aesthetics of solar trees differ and they have been designed to provide different means of power to different urban and built environments. It can be placed in residential areas and in urban areas, courtyards, schools and universities, parks and along hiking trails. It can also be placed in cultural institutions as an icon and a symbol of community, environment and green education

Solar tree represents an autonomous photovoltaic system. It is equipped with a system of solar panels which, as long as they’re illuminated by the sunlight, produce voltage at their respective endings. That voltage can then be used for charging batteries. Accumulated energy from those batteries is then used for various purposes. Neglecting the necessary replacement of the batteries every few years, electric energy produced by this system is completely cost-free. Additional automatic control of charging and discharging process of the batteries can guarantee maximum lifetime of the batteries.

The solar power trees can be planted without any acquisition of vast land exclusively for this purpose in a particular place. They can be installed on the road sides as they consume around 4 Sq. Feet of area for a single tree. The village roads and the big boundary walls of paddy lands can provide sufficient space for planting solar power trees that can supply enough power for electrification of villages and irrigation activities. The state and national highways are big sources for Solar Power Tree (SPT) plantations. Two sides of single road high ways and the three sides of double road highways including island in between can be utilised for solar power tree. A simple calculation shows that if the National Highway is used for plantation of solar power trees from Kolkata to Asansol which is around 300 kms in length it would be possible to produce 110 MW by installing solar power trees of 2KW capacity through the road sides at a certain interval (say 15 meter between two trees). This would actually require 660 Acres of land for the same power generation at a single place by the existing method of laying out solar panels in a conventional way i.e. over the roofs of low height fixed structures. Hopefully if this new method of SPT plantation is adopted widely it would be possible to produce sufficient energy and to satisfy the demand of power for the world keeping the best ecological balance and preserving the nature as it is.

3.2 Working of a solar tree

Solar tree can be designed both for standalone and in synchronization with the power grid. It uses the generated energy form the solar panels and store the energy to the battery by a DC Charge controller. The controller may MPPT or PWM type. During the daytime when the sunlight is sufficient to meet the loads, the generated solar energy directly feed to the loads. Any excess solar energy after meeting the loads should be stored in the battery. The stored energy into the battery can be utilized when the generation from the PV is not sufficient. The inverter has proposed here to convert DC power to AC as most of the common appliances are AC and also facilitate to charge the Mobile, laptops under the shade of the solar tree. The Solar tree used for lighting purpose is a sensor based lighting system. The automatic control and monitoring unit monitor the Solar panel output and at dusk, the solar tree switches on LED automatically. A sensor measure the amount of light at atmosphere and triggers the switch on automatically at sunset and off at dawn.

3.3 Solar Tree Installation Areas

Solar tree can be installed in Urban and Rural Areas, Recreational parks, balconies, Airports, in Mountainous regions and on Coastlines, on Highways, in De-forested areas.

3.4 Application of Solar tree

Solar Tree provides green energy and a place of comfort in diverse settings and according to different requirements, night illumination (bright top lighting / LED lamps), all possible electrical consumers such as a pump to operate the fountain, shaded recreation area with benches offers a meeting place and social sharing, Docking station to charge smart phones and tablets, Services Free Wi Fi-charging station for an electric vehicle etc.

3.5 Advantages

It gives more solar power compared to conventional SPV layout – consumes 1% of land surface for same power. It holds the panels at a higher height – gets more sun. It can be facilitated with water sprinkler at the top of the SPT. Even the paddy lands, agro-gardens, roads or parks can be utilized for production of megawatts of solar power without hampering any cultivation work. It can produce 25% to 30% more power as because - all panels may be rotated by 180 in the afternoon and morning towards the east and the west by an easy mechanism

3.6 Disadvantages

In spite of numerous advantages, this energy has few limitations too. The solar energy doesn't radiate at night and the solar energy is almost not constant all the time.

There must be plenty of sunlight available to generate electrical energy from a solar PV device. Moreover, apart from daily fluctuations in the intensity of radiant energy, the solar energy is hindered to reach the earth during bad climatic conditions.

For example, the amount of sunlight reaching the earth's surface depends on location, time as well as weather as it falls during winter season as compared to the summer, and the Sun's radiation is less intense. To overcome these demerits of this technology, solar energy must be stored elsewhere at night and the highly efficient solar cells and modules needs to be developed.

CHAPTER 4

4.1 COMPONENTS OF SOLAR TREE

4.1(a) Photovoltaic Modules

A solar cell is an electronic device which directly converts sunlight into electricity. Light shining on the solar cell produces both a current and a voltage to generate electric power. This process requires firstly, a material in which the absorption of light raises an electron to a higher energy state, and secondly, the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell. A variety of materials and processes can potentially satisfy the requirements for photovoltaic energy conversion, but in practice nearly all photovoltaic energy conversion uses semiconductor. 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. 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. They are used as a photo detector (for example infrared detectors), detecting light or other electromagnetic radiation near the visible range, or measuring light intensity. The fabrication of solar cells has passed through a large number of improvement steps from one generation to another. Silicon based solar cells were the first generation solar cells grown on Si wafers, mainly single crystals. Further development to thin films, dye sensitized solar cells and organic solar cells enhanced the cell efficiency. The major benefit of solar energy over other conventional power generators is that the sunlight can be directly harvested into solar energy with the use of small and tiny photovoltaic (PV) solar cells. These small and tiny solar cells produce no noise during their operation Nowadays, due to the decreasing amount of renewable energy resources, the per watt cost of solar energy device has become more important in the last decade, and is definitely set to become economical in the coming years and grow as better technology in terms of both cost and applications.

The working mechanism of solar cells is based on the three factors:

(1) Adsorption of light in order to generate the charge careers, holes (p-type) and electrons (n-type)

(2) Separation of charge careers

(3) The collection of charge careers at the respective electrodes establishing the potential difference across the p-n junction.

The generation of voltage difference noticed at the p-n junction of the cell in response to visible radiation is utilized to do the work. In the past, various kinds of semiconductor materials and technologies are devised to design solar cells with low cost as well as high conversion efficiency.

Traditional solar panels made from silicon crystalline wafer modules are heavier which makes the transportation difficult. These are generally the large sized solar panels covered with glass sheets. A heavier and bulky solar panel requires a lot of space and sometime big roofs to fit these bulky and large solar panels in case of high power applications.

TYPES

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. 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 polysilicon and monocrystalline silicon. Second generation cells are thin film solar cells, that include amorphous silicon, CIGS cells and are commercially significant in utility-scale photovoltaic power stations, building integrated photovoltaics or in small standalone power system. The third generation of solar cells includes a number of thin-film technologies often described as emerging photovoltaics—most of them have not yet been commercially applied and are still in the research or development phase. Many use organic materials, often organometallic compounds as well as inorganic substances. Despite the fact that their efficiencies had been low and the stability of the absorber material was often too short for commercial applications, there is a lot of research invested into these technologies as they promise to achieve the goal of producing low-cost, high-efficient solar cells. "First generation" panels include silicon solar cells. They are made from a single silicon crystal (mono-crystalline), or cut from a block of silicon that is made up of many crystals (multi-crystalline - shown at right). "Second generation" thin-film solar cells are less expensive to produce than traditional silicon solar cells as they require a decreased amount of materials for construction. The thin-film PV cells are, just as the name implies, a physically thin technology that has been applied to photovoltaics. They are only slightly less efficient than other types but do require more surface area to generate the same amount of power.

The following are the types of solar cells:

Amorphous Silicon Solar Cell (A-Si), Biohybrid Solar, Buried Contact Solar Cell, Cadmium Telluride Solar Cell (CdTe), Toxicity of Cadmium, Concentrated PV Cell (CVP and HCVP), Copper Indium Gallium Selenide Solar Cells (CI (G) S), Dye-Sensitized Solar Cell (DSSC), Gallium Arsenide Germanium Solar Cell (GaAs), Hybrid Solar Cell, Luminescent Solar Concentrator Cell (LSC), Monocrystalline Solar Cell (Mono-Si), Multijunction Solar Cell (MJ), Nanocrystal Solar Cell, Perovskite Solar Cell, Photoelectrochemical Cell (PEC), Polymer Solar Cell, Polycrystalline Solar Cell (Multi-Si), Quantum Dot Solar Cell, Thin Film Solar Cell (TFSC), Black Silicon Solar Cells

Despite such developments, silicon continues to be most widely used.

Mono crystalline solar cell

During the manufacturing process, Si crystals are sliced from the big sized ingots. These large single crystal productions require precise processing as the process of “recrystallizing” the cell is more expensive and multi process. The efficiency of mono-crystalline single-crystalline silicon solar cells lies between 17% - 18%.

Polycrystalline Silicon Solar Cell (Poly-Si or Mc-Si)

Polycrystalline PV modules are generally composed of a number of different crystals, coupled to one another in a single cell. The processing of polycrystalline Si solar cells is more economical, which are produced by cooling a graphite mold cells and a-Si are second generation solar cells, and are more economical as compared to the first generation silicon wafer solar cells. Silicon wafer cells have light absorbing layers up to 350 μm thick, while thin-film solar cells have a very thin light absorbing layers, generally of the order of 1 μm thickness.

4.1(b) Cables for connecting modules

PV modules are subjected to atmospheric conditions like solar irradiations, high temperature, precipitation, etc. To have a secure connection, between modules there exist a need for cables with excellent mechanical strength for use in conditions with dry and wet conditions higher temperature conditions and high solar insolation.

Cables used in DC side shall have the following characteristics:

- Insulation resistance: when 20°C >4.6100Ω.KM
- Nominal voltage: 1100V
- Without melting and flow at high temperature.
- Conforming IS1554
- Conductors are insulated with XLPE.
- Resistant for heat, temperature, abrasion, UV, Ozon and hydrolysis
- With high mechanical strength water oil and chemical resistance.

4.1(c) Batteries

In solar PV systems, batteries used must adhere to demands of “unstable grid energy, heavy ceiling and irregular full charging”. Deep-cycle batteries have been used in renewable and sustainable energy applications throughout the world for decades. Some of the popularly used batteries in solar PV system applications are “lead acid batteries, lithium ion batteries, lithium ion polymer batteries, nickel cadmium batteries” etc. The Battery shall be Tubular Gel (VRLA) and the battery bank should be able to provide backup for at least 24 hours with connected load which is around 48V .The batteries can be installed at the base of the solar tree and should be protected from the environment

PV Batteries

Batteries accumulate excess energy created by your PV system and store it to be used at night or when there is no other energy input. Batteries can discharge rapidly and yield more current that the charging source can produce by itself, so pumps or motors can be run intermittently. The battery's capacity for holding energy is rated in amp-hours: 1 amp delivered for 1 hour = 1-amp hour. The rating is designed only as a means to compare different batteries to the same standard and is not to be taken as a performance guarantee. Batteries are electrochemical devices sensitive to climate, charge/discharge cycle history, temperature, and age. The performance of our battery depends on climate, location and usage patterns.

Battery Types

Different chemicals can be combined to make batteries. Some combinations are low cost but low power also, others can store huge power at huge prices. Lead-acid batteries offer the best balance of capacity per dollar and it's a common battery used in stand-alone power systems.

Lead-Acid Batteries

The lead-acid battery cell consists of positive and negative lead plates of different composition suspended in a sulfuric acid solution called electrolyte. When cells discharge, sulfur molecules from the electrolyte bond with the lead plates and releases electrons. When the cell recharges, excess electrons go back to the electrolyte. A battery develops voltage from this chemical reaction. Electricity is the flow of electrons. In a typical lead-acid battery, the voltage is approximately 2 volts per cell regardless of cell size. Electricity flows from the battery as soon as there is a circuit between the positive and negative terminals. This happens when any load (appliance) that needs electricity is connected to the battery. Good care and caution should be used at all times when handling a battery. Improper battery use can result in explosion.

4.1(d) Inverter

The power generated as we know is DC and it is to be converted into AC. For that purpose, we use Inverter. Conversion efficiency is the most important characteristic of an inverter. The other important tasks of the inverter are power optimization i.e. maximum power point tracking, monitoring the energy yield of the PV plant and securing the plant in a fault situation by disconnecting it from the grid.

4.1(e) Lightning Protection

The Solar tree should be provided with Lightning protection. The Lightning Conductors are made as per applicable Indian Standards in order to protect the entire Array Yard from Lightning stroke. Necessary concrete foundation for holding the lightning conductor in position will be made after giving due consideration to maximum wind speed and maintenance requirement at site in future. Each Lightning Conductor shall be fitted with individual earth pit as per required Standards including accessories, and providing masonry enclosure with cast iron cover plate having locking arrangement, watering pipe using charcoal or coke and salt as per required provisions of IS.

4.1(f) Earthing

The earthing for solar array & structure shall be as required as per provisions of IS 3043:1987. Necessary provision shall be made for bolted isolating joints of each earthing pit for periodic checking of earth resistance. The complete earthing system shall be mechanically and electrically connected to provide independent return to earth. All non-current carrying metal parts shall be earthed with two separate and distinct earth continuity conductors to an efficient earth electrode.

4.1(g) Body structure

There is no standard structure for the solar tree, it can be creatively designed in order to make it look pleasing to the public eye and consume less area while avoiding shading effect of leaves. Mostly the body is of Steel, Aluminium, wood.

4.1(h) Controller

The purpose of a controller is to monitor the yield of every PV leaf/panel, maintain maximum power extraction from the PV panels, which is done through an MPPT based on maximum power transfer theorem [28]. It also monitors the charging and discharging of the battery. Fig. 10 shows an intelligent charge monitor and controller which controls the output of PV Leafs, prevents overcharging and undercharging of the battery, extracts smoothened signal from LDR(light dependent resistor), and controls the operation of LED (light emitting diode).

4.2 SOLAR TREE STRUCTURE

It’s structure is designed with keeping in mind the purpose of making it that are higher efficiency, more insolation, avoiding shading effects.

Some structural designs are:

• Spiralling Phyllotaxy : Solar tree have successive leaves forming a spiral on the stem. This arrangement improves the sunlight capturing of solar tree.

•Fibonacci Patter solar tree: This pattern is commonly seen in natural trees that they form to improve sunlight capture and it has been seen that same can be applied in solar tree.

•Single trunk with branches: It is an imitation of natural trees consisting of a central pole as the trunk and branches surrounding it. It consists of all panels oriented at a particular set of angles.

•Panels on natural tree: panels on natural tree can be installed with fewer branches. This reduce the cost and resource requirement The shape of tree plays an important role in the orientation of panels.

4.3 The plans to make the solar tree a bit different from the pre-existing solar trees

The use of wooden structure with plastic reinforcements will be a step towards making it cost effective. A simple design with all panels facing a common direction of the sun path of the location with different optimized tilt angles will be used so that it is efficient for usage. A battery for energy storage and for supplying a constant and uniform power without any distortion to the inverter will be added with the construction. Since panels are at various angles, the reflection can be harmful to human eyes, so for careful design of solar tree panels to avoid shading effect on panel anti reflection coating on panel surface will be done.

4.3(a) Orientation

The orientation of a solar tree majorly contributes in the amount of solar irradiation captured by it. In a typical solar tree, the panels must be arranged such that no panels are under the shadow of other panels. But it is also necessary to consider other factors like complexity of the arrangement and cost effectiveness. There are mainly six types of solar orientation design in use which are Spiralling Phyllotaxy Solar Tree, Fibonacci pattern solar tree, single trunk with branches, 3 axis symmetric design, panels on natural tree and hemispherical semi-dome design.

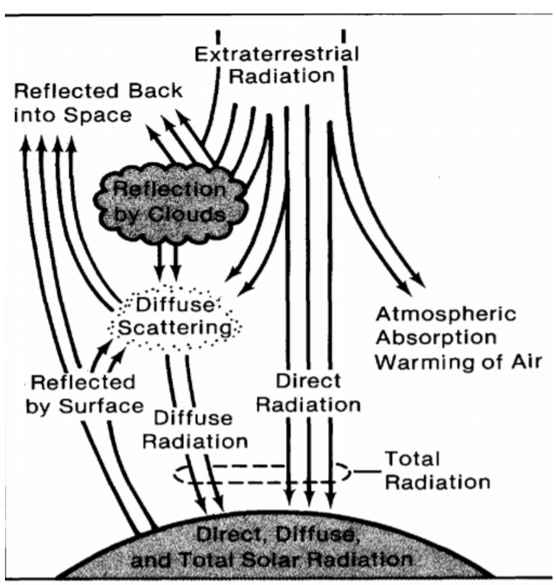
Out of these when it comes to effective light capturing, then, spiralling phyllotaxy technique, Fibonacci pattern and hemispherical semi-dome design are the most efficient designs. All three have a high-power yield due to good solar capture. But, spiralling phyllotaxy technique and Fibonacci pattern have a relatively complex design than the hemispherical dome design. Also due to the use of more panels they get little costlier but which can be ignored when comparing with the higher output. As an opinion, hemispherical dome design has an edge over the other two because of its high-power output and simple design. The idea behind this design is to track the complete Sun path traversed by the Sun at a particular location. It consists of panels oriented in the south, southeast and southwest directions to capture Sunlight from morning to evening. While as per requirement, if low power output is needed, say, for mobile charging etc., then a simpler design like 3-axis symmetric design can be used.

CHAPTER 5

Proposed Work:

In this project work, we have tried to know the structure of solar tree and the main focus is been set upon tilt angle of the panels so that the output which will be attained could be the maximum possible at a particular time. This optimization is an alternate to the tracking system which is effective but a very expensive method. So, this work has been done for attainment of a generalized mathematical model so that anyone can estimate the area acquired and tilt angle of a solar tree.

5.1 SOLAR IRRADIANCE



Solar irradiance is the power per unit area (watt per square metre, W/m^2), received from the Sun in the form of electromagnetic radiation as reported in the wavelength range of the measuring instrument. Solar irradiance is often integrated over a given time period in order to report the radiant energy emitted into the surrounding environment (joule per square metre, J/m^2), during that time period. This integrated solar irradiance is called solar irradiation, solar exposure, solar insolation, or insolation. It is the amount of light energy from one thing hitting a square meter of another each second. Photons that carry this energy have wavelengths from energetic X-rays and gamma rays to visible light to the infrared and radio. The solar irradiance is the output of light energy from the entire disk of the Sun, measured at the Earth. The solar spectral irradiance is a measure of the brightness of the entire Sun at a wavelength of light. Important spectral irradiance variations are seen in many wavelengths, from the visible and IR, through the UV, to EUV and X-ray. The primary source of energy to the Earth is radiant energy from the Sun. This radiant energy is measured and reported as the solar irradiance. When all of the radiation is measured it is called the Total Solar Irradiance (TSI); when measured as a function of wavelength it is the spectral irradiance. Light of different wavelengths reaches different parts of the Earth's atmosphere. Visible light and infrared radiation reach the surface, warming the surface to livable conditions. Ultraviolet radiation in the UV-A, B, and C wavelengths is absorbed at higher and higher altitudes. Irradiance may be measured in space or at the Earth's surface after atmospheric absorption and scattering. Irradiance in space is a function of distance from the Sun, the solar cycle, and cross-cycle changes .Irradiance on the Earth's surface additionally depends on the tilt of the measuring surface, the height of the sun above the horizon, and atmospheric conditions.

The SI unit of irradiance is watt per square metre (W/m^2, which may also be written Wm^{-2}).An alternative unit of measure is the Langley (1 thermochemical calorie per square centimeter or 41,840 J/m2) per unit time. The solar energy industry uses watt-hour per square metre (Wh/m^2) per unit time.

5.1(a): Types of solar irradiance

1. Total Solar Irradiance (TSI)

It is a measure of the solar power over all wavelengths per unit area incident on the Earth's upper atmosphere. It is measured perpendicular to the incoming sunlight. The solar constant is a conventional measure of mean TSI at a distance of one astronomical unit (AU).It is the main contributor of energy to Earth. We are fortunate that visible and IR light, which contribute the majority of energy to Earth, exhibit the smallest relative variation. But, although TSI varies by only a fraction of a percent, it has the greatest magnitude of change. This may be enough to cause observable changes at Earth.

2. Direct Normal Irradiance (DNI)

It is measured at the surface of the Earth at a given location with a surface element perpendicular to the Sun. It excludes diffuse solar radiation (radiation that is scattered or reflected by atmospheric components). Direct irradiance is equal to the extraterrestrial irradiance above the atmosphere minus the atmospheric losses due to absorption and scattering. Losses depend on time of day (length of light's path through the atmosphere depending on the solar elevation angle), cloud cover, moisture content and other contents. The irradiance above the atmosphere also varies with time of year (because the distance to the sun varies), although this effect is generally less significant compared to the effect of losses on DNI.

3. Diffuse Horizontal Irradiance (DHI)

It is the radiation at the Earth's surface from light scattered by the atmosphere. It is measured on a horizontal surface with radiation coming from all points in the sky excluding circumsolar radiation (radiation coming from the sun disk).There would be almost no DHI in the absence of atmosphere.

4. Global Horizontal Irradiance (GHI)

It is the total irradiance from the sun on a horizontal surface on Earth. It is the sum of direct irradiance (after accounting for the solar zenith angle of the sun z) and diffuse horizontal irradiance.

GHI = DHI+ DNI x (cos(z))

5. Global Normal Irradiance (GNI)

It is the total irradiance from the sun at the surface of Earth at a given location with a surface element perpendicular to the Sun.

5.2 Terms related to solar geometry

Extra Terrestial Radiation

The extra-terrestrial radiation is defined as the radiation that passes perpendicularly through an imaginary surface just outside the earth's atmosphere. It varies from day to day, depending on the distance between the sun and the earth.

$$I = SC[1 + 0.034\, cos\frac{2\pi n}{365}]$$

where,

SC = solar constant

n = day number (starting from the 1st of January)

The solar constant is an estimate of the average annual extra-terrestrial radiation, having a generally accepted numerical value of 1377 W/m^2.

Terrestial Radiation:

There are two types of radiations:

1) Beam radiation.

2) Diffuse radiation.

Beam or direct radiation

Solar radiation received at earth surface without changes of direction i.e. in the line with the sun.

Diffuse radiation

The radiation received by the earth, from all parts of the sky hemisphere (after being subjected to the scattering in the atmosphere).

Declination angle (δ): It is the angle made by the line joining the centre of the sun and the earth with the projection of this line on the equatorial plane. $\delta = 23.45 * \sin(360*(284 + n)/365)$

Hour Angle (ωs): It is the angular measure of time and it is equivalent to 15 degrees per hour. It also varies from -180°to +180°

$\omega s = \cos^{-1}(-\tan\phi \tan\delta)$

Slope / Tilt (β): It is the angle made by the plane surface with the horizontal. It can vary from 0 to 180°.

Angle of incidence (θ): It is the angle between an incident beam of flux and the normal to a plane surface.

Latitude(ϕ): The latitude is the angle made by the radial line joining the location to the centre of the earth with the projection of the line on the equatorial plane.

Surface azimuth angle (γ): It is the angle made in the horizontal plane between the horizontal line due south and the projection of the normal to the surface on the horizontal plane.

Zenith angle (θ_z): It is the angle made by the sun's rays with the normal to a horizontal surface.

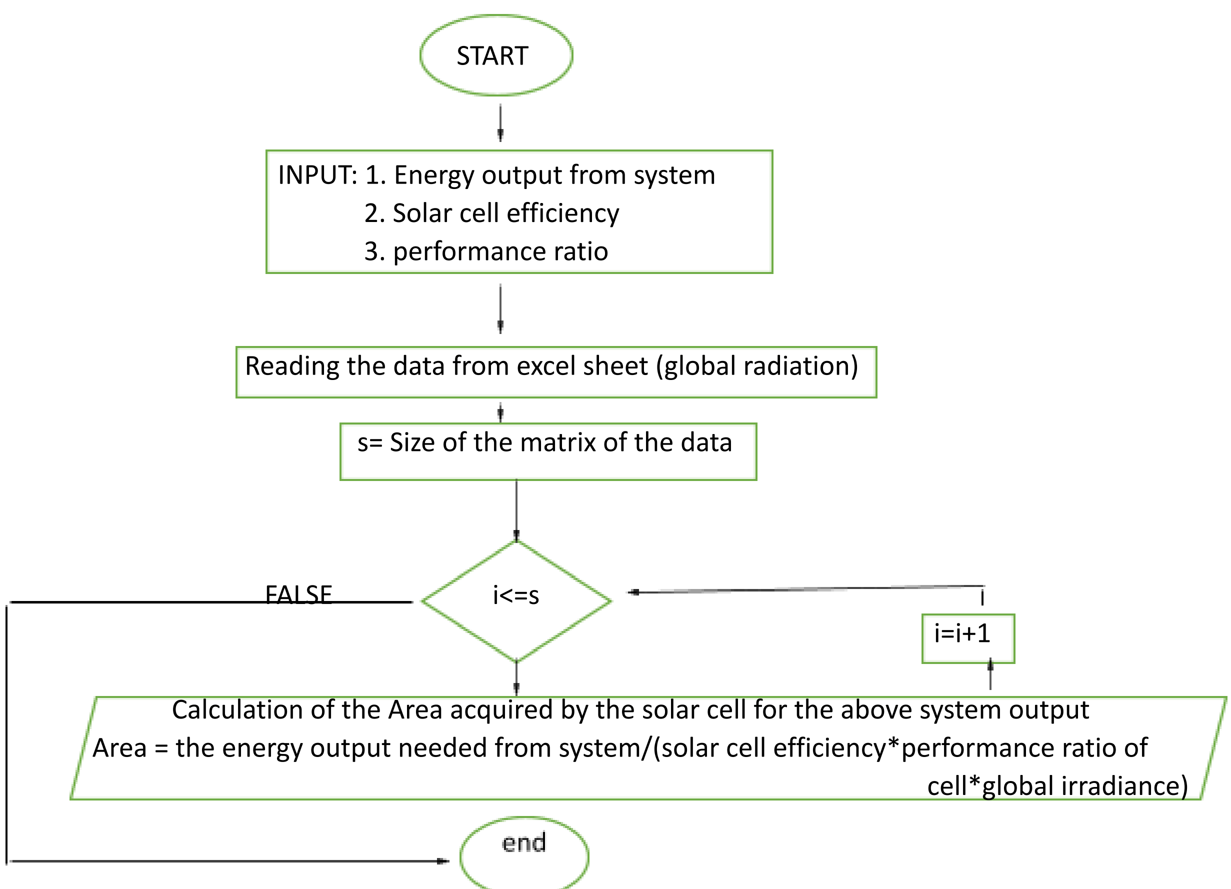
Solar altitude angle (αa): It is the complement of the zenith angle

Tilt angle: The angle made by the ground surface to the surface of the solar photo voltaic plate is called tilt angle.

5.3 Estimation of area as per the global irradiance

As per the flowchart we enter the value of the needed system output from the tree, the performance ratio of the cells, the efficiency of the particular PV cell then import the different solar parameters from excel data and as per the data available from run the loop to calculate the area have to be acquired by cells in order to give the desirable system output.

Flowchart:



Result: From the information of the global irradiance of the location and the efficiency of the pv cell the area to be covered by that particular cell to give out the system output can be calculated.

5.4 Estimation Technique of the tilt angle of solar panel

The methods to estimate the ratio of diffuse solar radiation on a tilted surface to that of a horizontal are classified as isotropic and anisotropic models.

Isotropic Models:

The isotropic models assume that the intensity of diffuse sky radiation is uniform over the sky dome. Hence, the diffuse radiation incident on a tilted surface depends on the fraction of the sky dome seen by it. Isotropic models assume there is uniformity in the distribution of diffuse radiation intensity over the sky. Various researchers gave the equations for the same, Badescu's model, Koronaki's model, Liu and Jordan's model, Tian's model. Out of all these, Liu and Jordan's model is taken into account in the present work.

Liu and Jordan model (1962):

$Rd = [1+\cos \beta] / 2$

Anisotropic Models:

The anisotropic models assume the anisotropy of the diffuse sky radiation in the circumsolar region (sky near the solar disc) plus and isotropically distributed diffuse component from the rest of the sky dome. Generally, diffuse radiation models for inclined surfaces can be classified into two groups: isotropic and anisotropic models. They differ in the division of the sky into regions with normal and elevated diffuse radiation intensities. Anisotropic models include appropriate modules for representing areas of elevated diffuse radiation. Bugler's model, Temps and Coulson's model, Hay's model, Reindl's model, Klucher's model, The HDKR model ,Skartveit and Olseth's model ,Steven and Unsworth's model ,Wilmott's model ,Perez' model are some of the anisotropic models designed by the researchers. Out of which the Hay's model is taken into account:

Hay's model:

$$Rd = (Hb/Ho)\, Rb + (1+ (Hb/Ho))\, [1+\cos \beta] / 2$$

A surface tilted at a slope angle from the horizontal, the incident total radiation is given by,

$$H_t = H_b + H_s + H_r$$

Where,

H_r – reflected component of the radiation on tilted surface

H_b – Direct beam of the radiation on tilted surface

H_s – Diffused beam of the radiation on tilted surface

H_t – Monthly average of the daily total radiation on the tilted surface

The daily beam radiation H_b can be compressed as,

$$H_b = (H - H_d) * R_b$$

Where,

H – monthly mean global

H_d – diffused radiation of horizontal surface (monthly mean)

R_b – ratio of the average daily beam radiation on tilted surface

The daily ground reflected model can be given as,

$H_r = H\rho\ (1\text{-}\cos\beta)/2$

$$Rb = \frac{[\ cos\ (\Phi-\beta)*cos\delta*\ sin\ \omega s + \omega s\ sin(\Phi-\beta)*sin\delta}{cos\Phi*cos\delta*sin\omega s+\omega s*sin\Phi*sin\delta}$$

Where,

$\omega_s = \min\{\ \cos^{-1}(-\tan\Phi\ \tan\delta)\ ,\ \cos^{-1}(-\tan(\Phi-\beta)*\ \tan\delta)\ \}$

ω_s is the sunset hour angle for the tilted surface for the mean day of the month. 'min' means the smaller of the two terms in the bracket.

Φ is the latitude

δ is the declination angle

is the angle from local solar noon

The declination angle $\delta = 23.45 \sin [360(284+ n)/365]$

where,

n is the nth day of the year.

The sky diffuse radiation can be expressed as:

$H_s = R_d\, H_d$

R_d is the ratio of the average daily diffused radiation on a tilted surfaceto that on a horizontal surface.

$R_d = [1+\cos\beta] / 2$, (for isotropic medium)

$R_d = [(H_b/H_o) R_b + (1+ (H_b/H_o))]*[1+\cos\beta] / 2$, (for anisotropic medium)

Where,

H_o = monthly average of extraterrestrial daily radiation

$H_0 = H (1.00 - 1.13 K_T)$

where, $K_T = H / H_o$

Total radiation on a tilted surface, can thus be expressed as

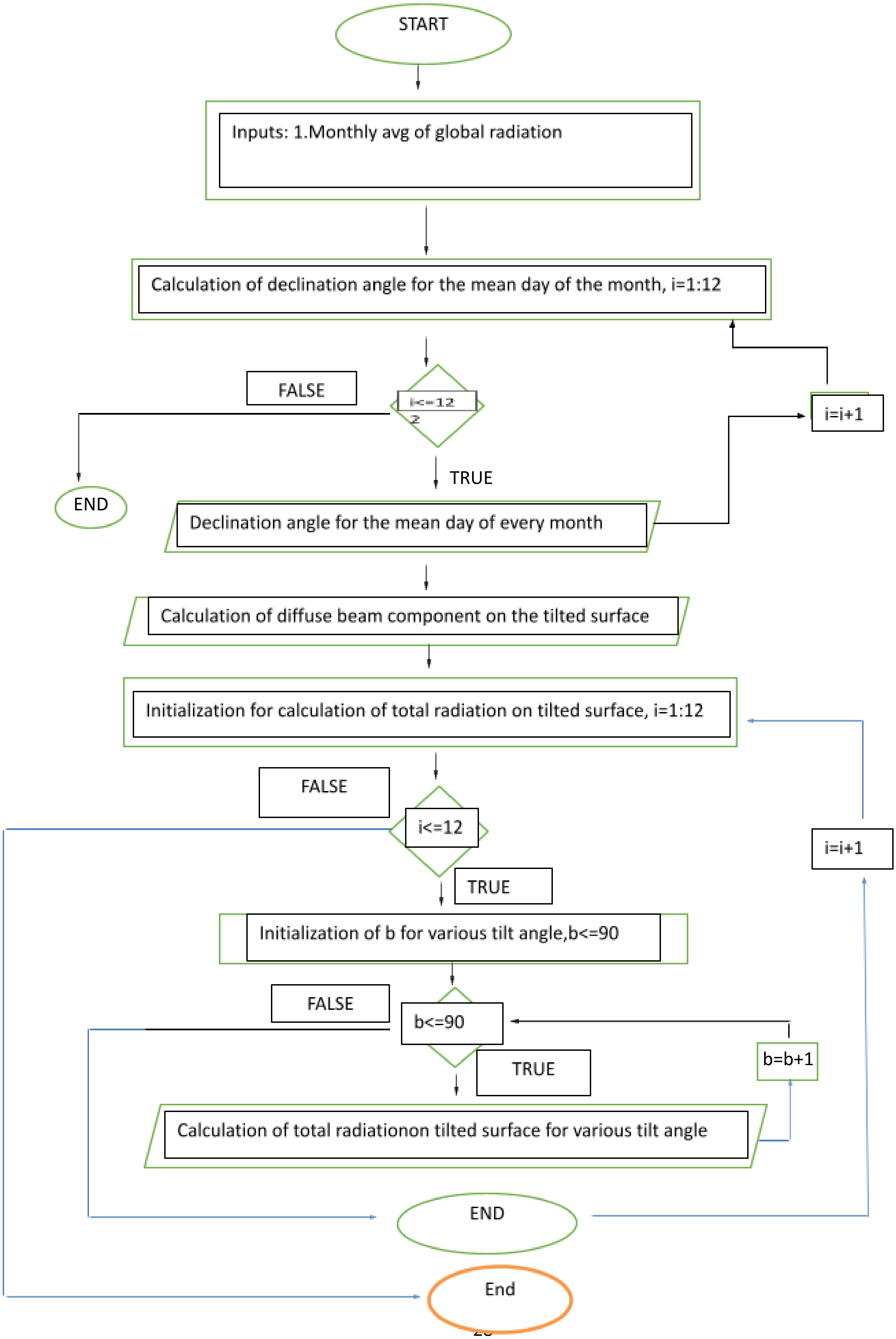
$H_T = (H - H_d) R_b + H\rho [1+\cos\beta] / 2 + R_d H_d$

5.4(a) Methodology of estimation of tilt angle

In case of Indian stations, long term monthly-mean hourly global radiation data for measuring site are obtained from hourly global radiation by averaging hourly values for each month over a period of year. These data along with extraterrestrial radiation data were gathered from database for Jasidih along with four different locations of the country; Kerala, Jaipur, Delhi. Total solar radiation falling on tilted surface was computed for tilt angle 0 to 90 degrees at an incremental value of 10 degrees. Programming in MATLAB was done in order to get the results for all these four places. Using Equations above, total solar radiation falling on tilted surface was computed for tilt angle 0, 10, 20, 30, 40, 50, 60, 70, 80 and 90 degrees for each month of the year and for each station. Using MSEXCEL software package, graphs were plotted between the total insolation versus tilt angle for each month and each station. Second order polynomial equations were developed to fit the curves. These polynomial equations were differentiated with respect to tilt angle and then equated to zero to obtain the optimum tilt angle corresponding to maximum insolation. Thus optimum tilt angle was computed for each month and for each station. Computer programme in MATLAB were developed using the above formulae to calculate the monthly average daily total radiation on a surface facing towards equator as the tilt angle is changed from 0 to 90°. The solar reflectivity was assumed to be 0.2

5.4 (b) Code Explanation:

The monthly average of global radiation on a horizontal surfaces, the monthly extraterrestrial radiation value in form of array is taken from user along with the latitude of the location. A loop is run to calculate the declination for the mean day of month for all the 12 months of year. The diffuse beam component of the radiation on a tilted surface is calculated from the array input by the user. Nested loop is run in order to calculate the average global radiation on tilted surface for tilt angle varying from 1 degree to 90 degree and finally the plot of radiation as per the tilt angle is plotted for all the month. The flowchart of the code is shown below:


START
Inputs: 1.Monthly avg of global radiation
Calculation of declination angle for the mean day of the month, i=1:12
FALSE
i<=12
i=i+1
END
TRUE
Declination angle for the mean day of every month
Calculation of diffuse beam component on the tilted surface
Initialization for calculation of total radiation on tilted surface, i=1:12
FALSE
i<=12
i=i+1
TRUE
Initialization of b for various tilt angle,b<=90
FALSE
b<=90
b=b+1
TRUE
Calculation of total radiationon tilted surface for various tilt angle
END
End

CHAPTER 6

RESULTS

6.1 Jasidih

The Table 1 gives a summary list of solar irradiance for each month of the year at Jasidih, Jharkhand situated at a latitude of 24.482775° N and the graphical representation for the same is shown in fig1. Fig. (2)shows the monthly average daily global solar radiation H and the monthly average extra-terrestrial daily radiation Ho on a horizontal surface in the city of Jasidih, Jharkhand in India. The average of H is 5.24 MJ/m2day. The average of the total monthly solar radiation falling on the collector surface at this tilt is 1067.91W/m2. During the month of June to August the extraterrestrial daily radiation is more than the global radiation. In winter months, the beam and diffuse components are nearly equal, and thus both components make the same contribution to the global radiation. In summer months, the beam component is more than diffuse component and thus the main contribution comes from the beam component. In monsoon season, the diffuse component is more than beam component.

Table 1

Months	Monthly solar Irradiance (W/m^2)
Jan	1072
Feb	1084
March	1083
April	1076
May	1061
June	1050
July	1046
August	1052
September	1063
Oct	1071
November	1076
December	1088

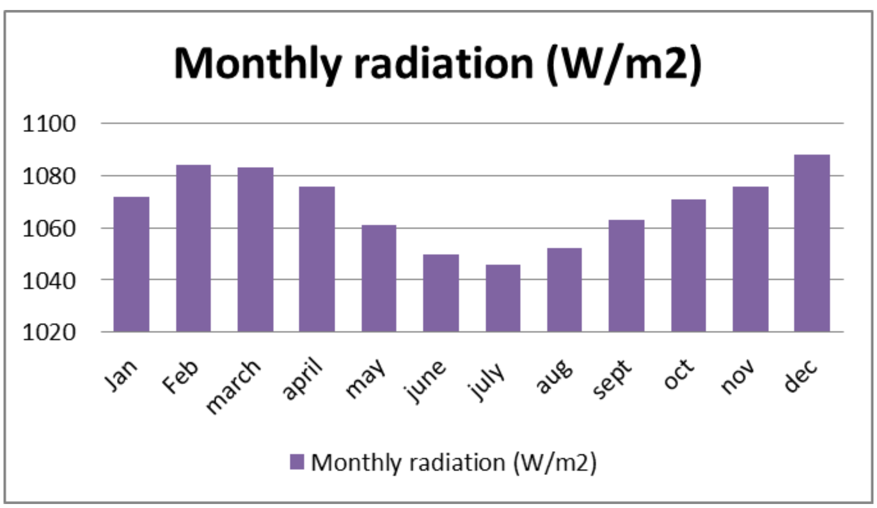


Fig1

Table 2

Months	Avg.Global radiation	Extraterrestial radiation
Jan	4.18	2.89
Feb	5.19	3.404
March	6.2	4.73
April	6.81	5.35
May	6.81	6.11
June	5.63	6.19
July	4.33	5.68
Aug	5.05	5.05
Sept	5.11	4.53
Oct	4.96	3.921
Nov	4.65	3.01
Dec	3.99	2.72

This particular table is obtained by the meterological data provided to us which comprised of diiferent solar radiation database.

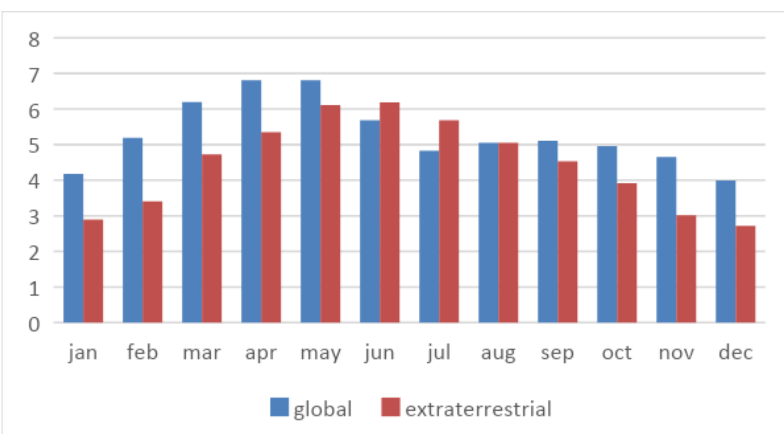


fig 2

After the analysis of the database, MATLAB code has been written for the particular location and graphs have been plotted representing the optimum tilt of solar panel for the isotropic as well as anisotropic models on a monthly basis for the whole year. This analysis helps to gather the very important information about the estimation of the angle of solar panels for fabricating them onto a solar tree.

Figs 3(a) shows the average daily total radiation at Jasidih as the angle of tilt varies from 10 to 90 degree for an isotropic medium .It is clear from the graph that a unique optimum tilt angle exists for each month of the year and show the average daily total solar radiation at Jasidih on a south facing surface as the angle of tilt is varied from 0 to 90° in steps of 10°. It is clear from these graphs that a unique optimum angle exists for each month of the year for which the solar radiation is at a peak for the given month. The same is done in fig 3(b) considering the model of diffused radiation to be anisotropic.

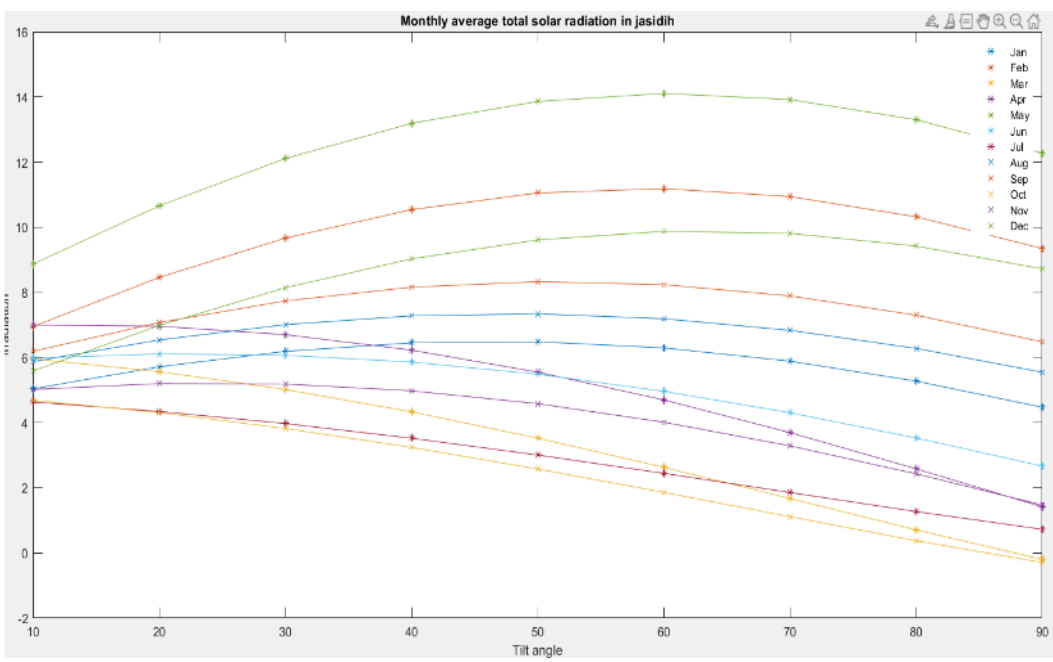


Fig 3(a)

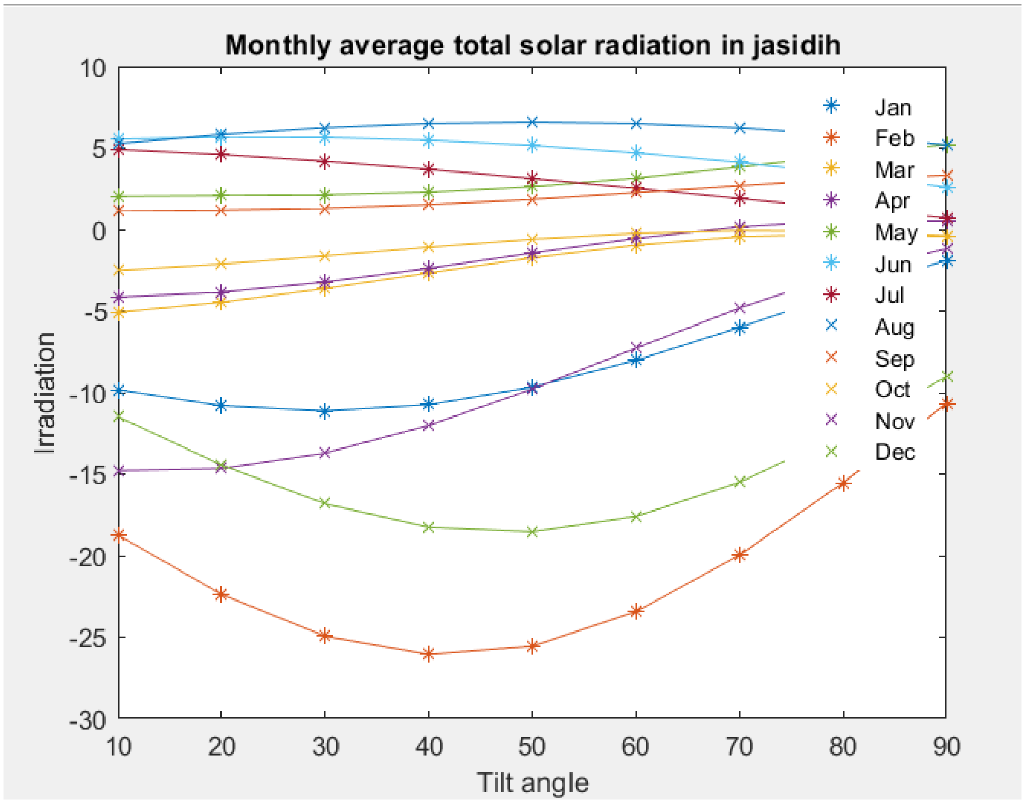

Monthly average total solar radiation in jasidih
Irradiation
Tilt angle
10
5
0
-5
-10
-15
-20
-25
-30
10
20
30
40
50
60
70
80
90
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Fig 3(b)

Table 3

Months	Isotropic medium	
	Radiation (kwh/month)	Tilt angle
Jan	6.5	50°
Feb	10.5	60°
March	6.0	5°
April	7.0	8°
May	13.8	60°
June	6.0	30°
July	4.6	10°
Aug	6.7	40°
Sept	7.8	50°
Oct	4.8	10°
Nov	5.2	30°
Dec	8.6	60°

The following tilt angle is the optimized tilt angle which is found with the help of MATLAB and a little bit of analysis. The solar panels are found to be tilted at 50° during January,60° in February,5° in march,8° in april,60° in May, 30° in june,10° in july,40° in Aug,50° in sept,10° in October,30° in November and 60° in December which is shown in the table 3 above.

With the help of plot obtained, we can get maximum global radiation at particular tilt angle during any month and the same information about the radiation obtained is tabulated in the above. The table tells about the angle of placing of solar panel so that the maximum radiation could be achieved by it in a particular month. The procedure is followed for four other locations of the country namely Delhi which is situated at a latitude of 28.7041°N,Kerala with a latitude of 10.8505°N and Jaipur with a latitude of 26.9124°N.The tilt angle is obtained at these locations with matlab code and with the help of plot maximum radiation is obtained at the tilted surface.

6.2 Delhi

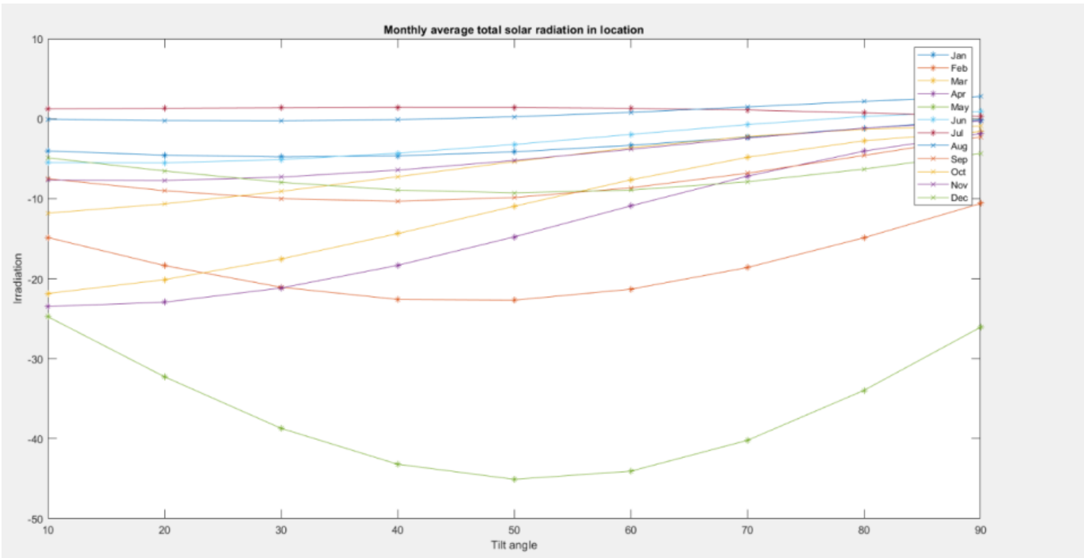


Fig 4a

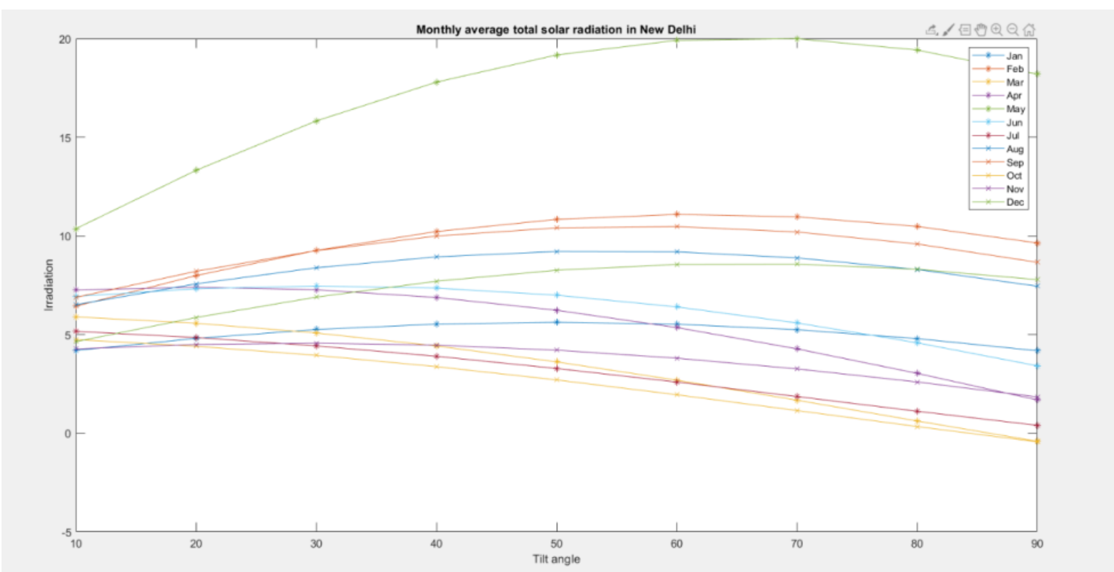


Fig 4b

Table 4

Months	Isotropic medium	
	Tilt angle	Radiation (kwh/month)
Jan	60˚	6.4
Feb	60˚	9.6
March	10˚	5.5
April	30˚	7
May	70˚	20
June	60˚	6.2
July	2˚	5.2
Aug	60˚	8
Sept	60˚	7.6
Oct	10˚	4.86
Nov	50˚	4.8
Dec	60˚	6.2

The table 4 above mentioned tells about the maximum radiation at New Delhi when the arrangement of the solar panels is done with the help of optimized tilt angle for every month for isotropic medium. The figure 4 (a) and fig 4(b) are the plots of the isotropic and anisotropic medium respectively.

6.3 Kerala

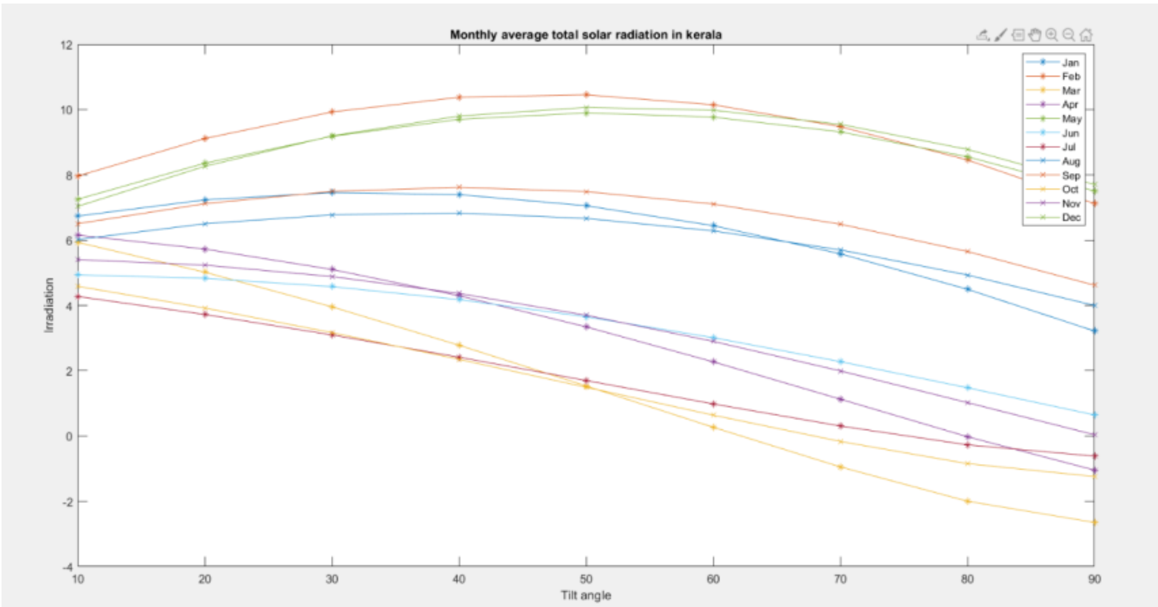


Fig 5(a)

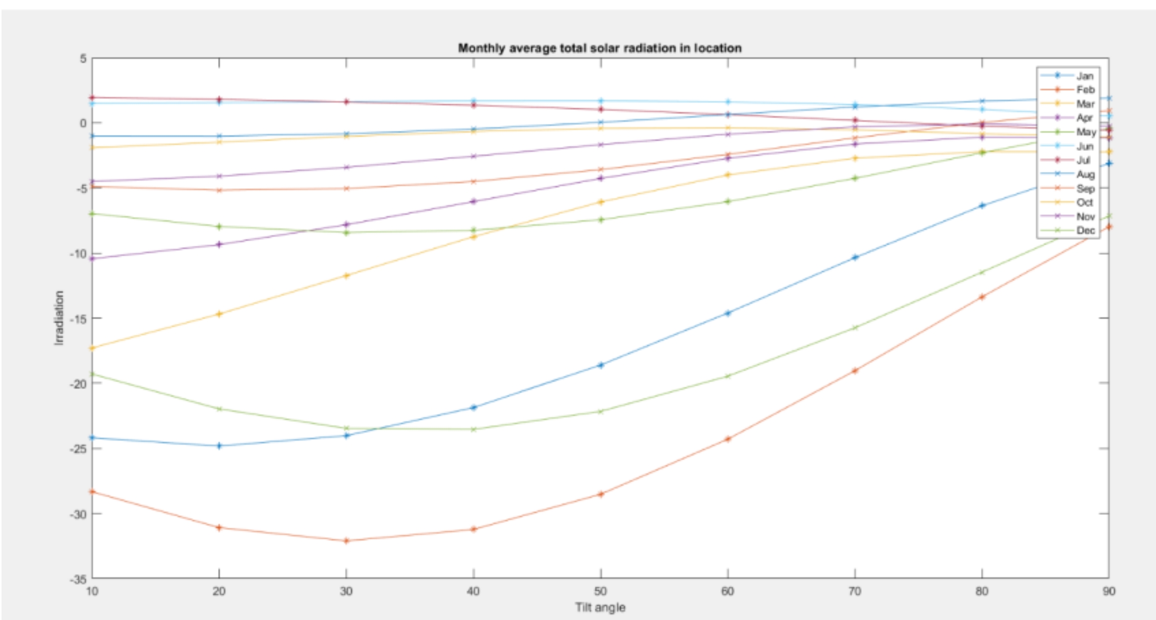


Fig 5(b)

TABLE 5

Months	Isotropic medium	
	Tilt angle	Radiation (kwh/month)
Jan	40˚	7.2
Feb	50˚	10.4
March	5˚	6.0
April	8˚	6.2
May	50˚	9.2
June	40˚	7.2
July	10˚	4.4
Aug	40˚	6.8
Sept	50˚	7.2
Oct	10˚	4.4
Nov	10˚	7.6
Dec	50˚	8.8

The table 5 above mentioned tells about the radiation received at a tilted surface in the southern part of our country India with a latitude of 10.8505˚N,Kerala.The fig 5a and fig 5b represents the plots of isotropic and anisotropic models respectively.

6.4 Jaipur

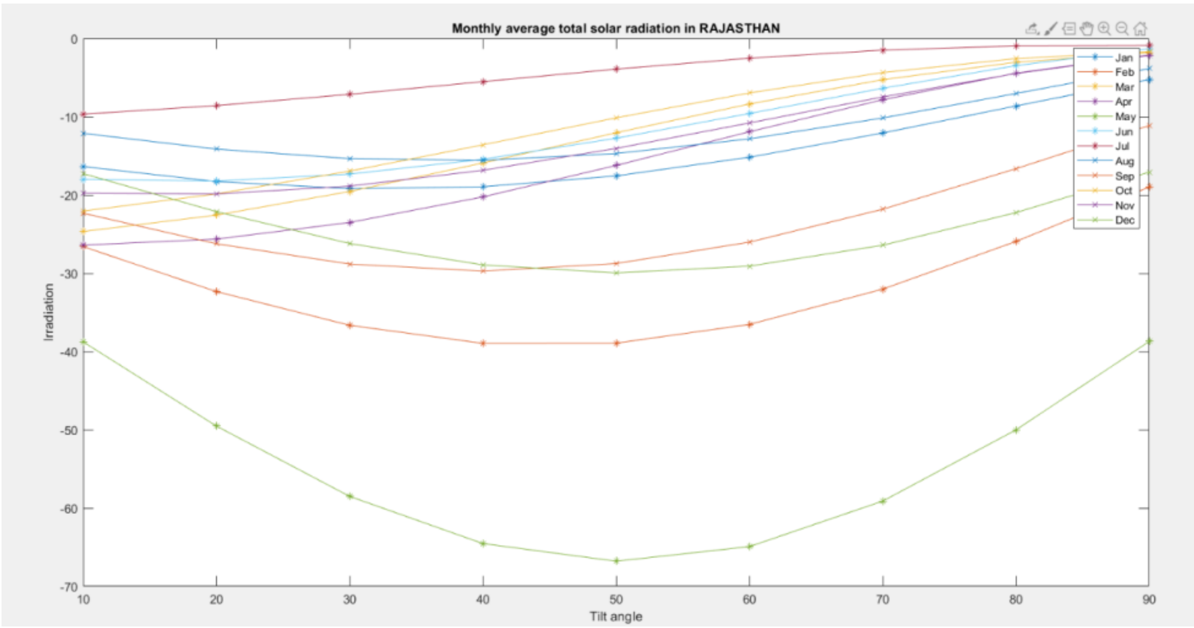


Fig 6(a)

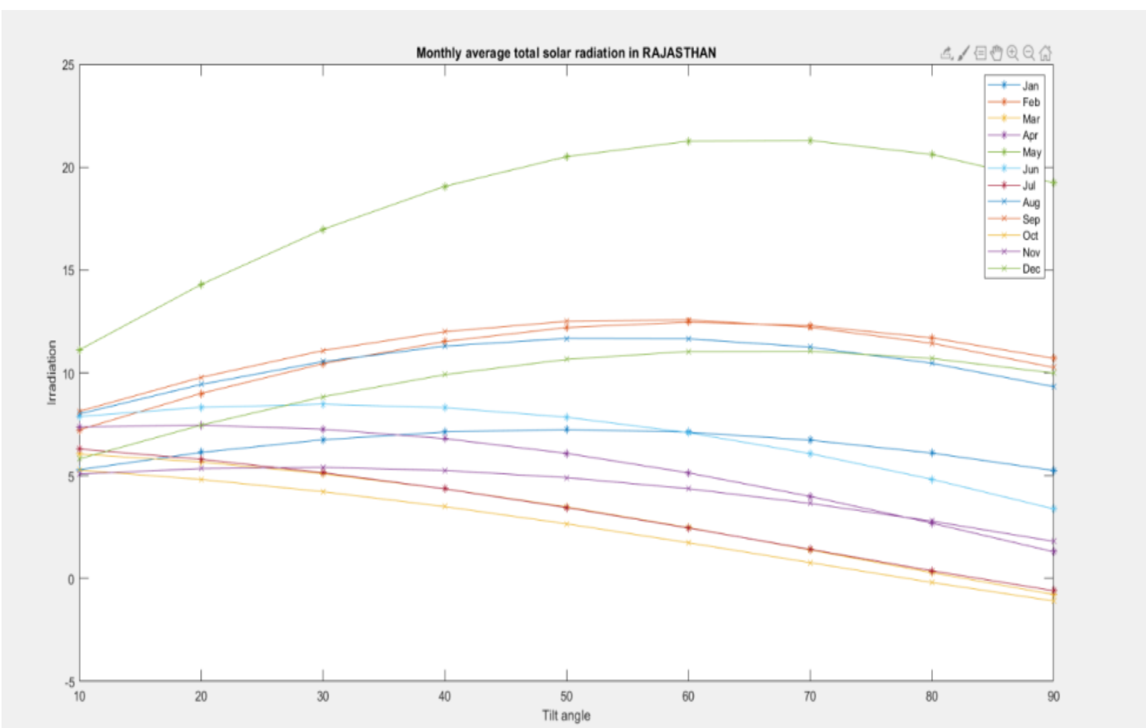


Fig 6(b)

Table 6

Months	Isotropic medium	
	Tilt angle	Radiation (kwh/month)
Jan	60˚	6.2
Feb	60˚	11.2
March	10˚	6.2
April	20˚	7.8
May	70˚	22.2
June	60˚	6.2
July	10˚	6.8
Aug	50˚	10.2
Sept	60˚	11.2
Oct	10˚	6.8
Nov	30˚	5.8
Dec	60˚	9.4

The table 6 above mentioned tells about the maximum radiation at Jaipur when the arrangement of the solar panels is done with the help of optimized tilt angle for every month for isotropic medium. the plots of isotropic and anisotropic models are shown in fig 6a and 6b respectively.

CHAPTER 7

CONCLUSION

Optimization of the angle of the solar panel proposed show better results and can increase the energy that can be accepted by the panel 8-65%. For Jasidih, a monthly optimal tilt angle of the panel in January to March, the optimum tilt angle of 5°-60° facing south, April to May tilt angle of 8°-60° and August to September with the optimal tilt angle of 40-50° facing south. In June and July, the optimum tilt angle of 10-30° facing north. While in November and December, the optimum tilt angle is 30° - 60° facing south. This project gave a mathematical model of solar irradiance received by solar tree for deciding its structure. Basically, the modeling of area and tilt angle is been done. So that anybody at any place could get to know about the optimal tilt of a place and can design a solar tree just by knowing the latitude of a particular place and following the methods suggested in this paper.

APPENDIX

MATLAB CODE FOR ISOTROPIC MEDIUM

```
clear all;
close all;
clc;
H=input('the monthly average of global radiation on a horizontal
surfaces');
HO=input('Monthly average extraterrestrial daily radiation ');
p=0.2 %solar reflectivity
l=input('the latitude position of the place');
o=l*pi/180 %latitude position
n=0
for i=1:12
    n(i)=15*(2*i-1);
d(i)=23.45*sin(360*(284+n(i))/365); %declination for the mean day of
month
end
k = H./HO;
HD = H-1.13*H.*k;%diffuse beam component of the radiation on a tilted
surface
for i=1:12
    for b = 1:90

w=min(acos(-tan(o)*tan(d(i)*pi/180)),acos(-tan(o-(b*pi/180))*tan(d(i)
*pi/180)));

rb=(cos(o-(b*pi/180))*cos(d(i)*pi/180)*sin(w)+w*sin(o-(b*pi/180))*sin
(d(i)*pi/180))/(cos(o)*cos(d(i)*pi/180)*sin(w)+w*sin(o)*sin(d(i)*pi/1
80));
    HB=(H(i)-HD(i))*rb;%direct beam component of the radiation on a
tilted surface
    HR=H(i)*p*(1-cos(b*pi/180))/2;%reflected beam component of the
radiation on a tilted surface
    rd=(1+cos(b*pi/180))/2;
    HS=rd*HD(i);
    HT(i,b)= HB+HS+HR;%monthly average daily total radiation on the
tilted surface

    end
end
tiltangle = [10:10:90];
plot(tiltangle,HT(1,10:10:90),'-*');
hold on
plot(tiltangle,HT(2,10:10:90),'-*');
```

```
hold on
plot(tiltangle,HT(3,10:10:90),'-*');
hold on
plot(tiltangle,HT(4,10:10:90),'-*');
hold on
plot(tiltangle,HT(5,10:10:90),'-*');
hold on
plot(tiltangle,HT(6,10:10:90),'-*');
hold on
plot(tiltangle,HT(7,10:10:90),'-*');
hold on
plot(tiltangle,HT(8,10:10:90),'-x');
hold on
plot(tiltangle,HT(9,10:10:90),'-x');
hold on
plot(tiltangle,HT(10,10:10:90),'-x');
hold on
plot(tiltangle,HT(11,10:10:90),'-x');
hold on
plot(tiltangle,HT(12,10:10:90),'-x');
hold on
title('Monthly average total solar radiation in location')
xlabel('Tilt angle')
ylabel('Irradiation')
legend('Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sep','Oct','N
ov','Dec')
```

MATLAB Code for Anisotropic medium

```
clear all;
close all;
clc;
H=input('the monthly average of global radiation on a horizontal
surfaces');
HO=input('Monthly average extraterrestrial daily radiation ');
p=0.2 %solar reflectivity
l=input('the latitude position of the place');
o=l*pi/180 %latitude position
n=0
for i=1:12
    n(i)=15*(2*i-1);
d(i)=23.45*sin(360*(284+n(i))/365); %declination for the mean day of
month
end
k = H./HO;
HD = H-1.13*H.*k;%diffuse beam component of the radiation on a tilted
surface
for i=1:12
    for b = 1:90

w=min(acos(-tan(o)*tan(d(i)*pi/180)),acos(-tan(o-(b*pi/180))*tan(d(i)
*pi/180)));

rb=(cos(o-(b*pi/180))*cos(d(i)*pi/180)*sin(w)+w*sin(o-(b*pi/180))*sin
(d(i)*pi/180))/(cos(o)*cos(d(i)*pi/180)*sin(w)+w*sin(o)*sin(d(i)*pi/1
80));
    HB=(H(i)-HD(i))*rb;
    HR=H(i)*p*(1-cos(b*pi/180))/2;
    rd=(((1+cos(b*pi/180))/2)*(1+HB/HO(i)))+(HB/HO(i)*rb);

    HS=rd*HD(i);
    HT(i,b)= HB+HS+HR;
    end
end
tiltangle = [10:10:90];
plot(tiltangle,HT(1,10:10:90),'-*');
hold on
plot(tiltangle,HT(2,10:10:90),'-*');
hold on
plot(tiltangle,HT(3,10:10:90),'-*');
hold on
```

```
plot(tiltangle,HT(4,10:10:90),'-*');
hold on
plot(tiltangle,HT(5,10:10:90),'-*');
hold on
plot(tiltangle,HT(6,10:10:90),'-*');
hold on
plot(tiltangle,HT(7,10:10:90),'-*');
hold on
plot(tiltangle,HT(8,10:10:90),'-x');
hold on
plot(tiltangle,HT(9,10:10:90),'-x');
hold on
plot(tiltangle,HT(10,10:10:90),'-x');
hold on
plot(tiltangle,HT(11,10:10:90),'-x');
hold on
plot(tiltangle,HT(12,10:10:90),'-x');
hold on
title('Monthly average total solar radiation in location')
xlabel('Tilt angle')
ylabel('Irradiation')
legend('Jan','Feb','Mar','Apr','May','Jun','Jul','Aug','Sep','Oct','N
ov','Dec')
```

MATLAB Code for the area to be acquired by the pv cells

```
clc;
clear all;
close all;
E=input('the energy needed from the system ');
R=input('solar cell efficiency');
PR=input('performance ratio');
s1=xlsread('Book1.xlsx',1,'E2:E7202','basic');
A1 = size(s1);
for i=1:A1(1)
if s1(i,1)~=0
 ar1(i) = E/(R*PR*s1(i,1));
end
end
Avgarea1 = mean(ar1);
disp(Avgarea1)% maximum area required to be covered with solar cell
in month of March
s2=xlsread('Book2.xlsx',1,'E2:E7202','basic');
A2 = size(s2);
for j=1:A2(1)
if s2(j,1)~=0
 ar2(j) = E/(R*PR*s2(j,1));
end
end
Avgarea2 = mean(ar2);
disp(Avgarea2)% maximum area required to be covered with solar cell
in month of December
s3=xlsread('Book3.xlsx',1,'E2:E7202','basic');
A3 = size(s3);
for k=1:A3(1)
if s3(k,1)~=0
 ar3(k) = E/(R*PR*s3(k,1));
end
end
Avgarea3 = mean(ar3);
disp(Avgarea3)% maximum area required to be covered with solar cell
in month of August
s4=xlsread('Book4.xlsx',1,'E2:E7202','basic');
A4 = size(s4);
for l=1:A4(1)
```

```
if s4(l,1)~=0
 ar4(l) = E/(R*PR*s4(l,1));
end
end
Avgarea4= mean(ar4);
disp(Avgarea4)% maximum area required to be covered with solar cell
in month of May
```

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