Simulation of solar irradiation assessment for power generation

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Abstract: Solar Energy forms the perennial source to all living processes existing on Earth, directly or indirectly owing to its widespread usage to support the primary energy producers of the eco-system. The solar energy has been an important driver to all activities, supporting the civilizations as it has been used in different applications ranging from, drying of hide to sophisticated application of powering a satellite. The world today has found relief, through use of eco-friendly sources, of which solar energy has been primary form. The study has identified typical solar system design for household application through computational tool. The solar power module performance and variation in incident solar intensity on both horizontal and inclined surfaces are compared with load variation. The energy gain by integrating equations for Hubballi city was evolved, along with its comparison with locations like Delhi and Hamburg (Germany). It was observed that existing fixed SPV device was inadequate to meet the anticipated energy demand. The four different types of solar tracking modes were investigated using Empirical equations on MATLAB computational tool as a measure to enhance energy gain at the location. It was observed that operating in sun-tracking mode, SPV module programmed on basis of the objective function to minimize incidence angle, yielded higher solar energy throughout the year.

Keywords: Solar irradiance, Sun path diagram, collector Tracking, Life cycle costing

1. Introduction

The current global energy demand has been reported to be meager compared to quantum of total solar energy incident on Earth. The simple and elegant way to harness solar energy has been the Solar Photovoltaic (SPV) technology that employs PV devices (solar cells) to directly convert incident solar radiation into electricity. This method of direct energy conversion has been eco-friendly owing to its features of avoiding noise, pollution or moving parts, making it robust, reliable and long lasting [1].

The SPV conversion involves photon particles transferring electromagnetic energy, as they hit solar cell. The physics of the conversion involves the generation of photo-electrons in response to incident solar energy that falls on the p-n junction of cell material. These photo-electrons constitute the electric current once the cell terminals are connected to external loads like electric lamp, storage battery,
heating elements or any appropriate electrical device. A regular arrangement of these cells forms a solar panel and such multiple panels can be paired to form a solar array. To energize electrons from conductor in panel the photons should be incident normally. The PV module power depends on intensity of sunlight, which in turn depends on collector incidence angle of sun beam. The precise monitoring and measurement of solar radiation becomes necessary input for design of solar panels and for estimating their performance at different operating conditions.

Solar Tracking Systems are devices designed in such a manner that they maximize the solar irradiation received by the PV array by continuously aiming to orient them in the direction of incident solar radiation. It consists of a mechanism, driving motors and a tracking controller. Hence these systems form an integral part of modern solar power generating system for obtaining maximum radiation.

For establishing a solar power system, the main hurdles faced are regarding the economics. The most important PV economic parameters are the total costs of installing a PV system, electricity price, Feed-In tariffs and the energy payback time - EPBT. Investments into renewable energies, particular into PV and wind technologies are another economics related area.

2. Literature Review

Laseinde [2] have reported that efficiency of solar power generation system can be improved by using low cost microcontroller and tracking system. The maximum power point tracking algorithm is designed and developed using multiple-axis servo-motor feedback tracking system, which increased the efficiency of the solar panel array by 23.95%. It is highly important to track the sun at a high degree of accuracy to improve solar irradiation absorption. The developed algorithm has the advantage of space savings compared to adding more solar panels to improve energy generated. Mills [3] investigated efficiency of coal-fired power plant by using a Hybrid system. Efficiency of coal-fired power plant can be improved either in two ways, combining solar energy with coal-fired power generation, and co-firing natural gas in coal-fired plants. Both the ways increase flexibility of power plant and also reduces emissions, even solar is limited to geographical locations and other affordable supply of natural gas is needed. The coal solar hybrids may be interdependent or completely independent.

Abbas [4] investigated models to measure hourly, daily and monthly intensity to find most suitable model for a given location the hourly outputs predicted by available models are compared with the field measurements of the given location. In this article all basic earth-sun angles are described along with specific procedure for different models. Among isotropic models for estimating diffuse radiation on inclined surfaces, the two models that are found to be the most accurate are the Liu-Jordan and Koronakis models. While among anisotropic models, the Perez, Temps-Coulson, Klucher and Bugler models are found to be the most accurate. Ricci [5] have come up with a new hybrid of wind-solar street light system with an increased power and flexibility in use. It had multiple Savonius vertical axis wind turbine and solar panel at top. The adopted cylindrical geometry has shown a maximum power factor of 0.21. Dedicated safety equipment has been designed to prevent turbine over-speed by automatic stop in extreme wind condition. Various designs of wind turbines with different frontal area shape and dimensions are tested for varying weather conditions. Further work is being done about the dedicated hybrid power control of Savonius and PV, in order to optimize the MPPT. Gao [7] have reported on predicting performance of concentrating PV modules for different concentration ratios and operating temperatures. The efficiency and power of PV modules increase as the optical concentration ratio increases at the same operating temperature and also decrease with the temperature at the same optical concentration ratio. Water cooling can reduce the operating temperature of PV modules effectively and get satisfactory efficiency. For the solar concentrator aperture area of 1 m², the PV module is 0.4 m² when CR =2.5 and its average power output is nearly 120 W for natural air cooling [6].

Chen [7] investigated PV/T collector for solar utilization. It can produce electricity and heat at the same time with heat extraction from the back of PV module, which will cool down the PV module resulting in the increase in conversion efficiency. The integration of a PV/T collector with the building
structure like shading device will reduce cost; otherwise, some alternative PV materials should be
developed. Cuce [8] have reported on performance of silicon cells improved by passive means of
cooling. Efficiency and maximum power output of PV cells with and without fins are determined for
different illumination intensity and ambient temperatures. Maximum cooling is observed for intensity
level of 600 W/m². Performance of PV cells both with and without fins increases with decreasing
ambient temperature. It is observed from experimental results that the dominant effect of shunt
resistance on the current–voltage characteristic of the PV cell without fins decreases with increasing
intensity levels. Rahman [9] have reported on characteristics of standalone PV systems with the aid of
implementation in mat lab/Simulink for modeling. The battery charging can be controlled by the
charge controller by reducing the duty cycle to prevent the battery from overcharging. Also, the output
result of the inverter can meet the 220 Vac load demand with the sine wave signal and lower
harmonics. Overall, the system shows feasibility in practice.
Mukherjee [10] investigated on carbon production during silicon wafers manufacturing followed by
calculation of amount and their impact. The single crystal silicon cells, which are the starting material
for solar energy, are produced in exchange of greenhouse gas, the carbon dioxide. This article
highlights an estimation of solar energy production and carbon credit (CC) earning by the photovoltaic
cells of mono-crystalline silicon in a definite module, largely used in West Bengal, India. Maleki [11]
reports on diesel generator and renewable energy sources for off grid loads. The optimization
technique finds the optimum number of system components by which the system can satisfy the
demanded load at the most cost effective way. Simulation results indicate that the conventional diesel
generator alone system is more cost-effective than the other systems. Ulgen [12] have reported on
estimation of solar radiation parameters for the city of Izmir in the western part of Turkey. The ratio
of monthly average hourly diffuse radiation to monthly average hourly global radiation (I₅ / I₉) was
correlated with monthly average hourly clearness index (Kₙ) in form of polynomial relationships. It
gives more information about atmospheric characteristics of solar stations in addition to degree of
solar energy potential of stations and their surrounding areas. Experimental data were measured in the
Solar-Meteorological Station of Solar Energy Institute in Ege University over a 5-year period from
1994 to 1998. Baljit [13] have reported on solar collector performance variation on using Dual-fluid
system along with application Fresnel lenses (refractive and reflective). Indoor experiments were
carried out to determine the performance of a concentrating PV-T solar collector with an FL and CPC
as concentrators. Four modes of operations were analyzed, and the performance of each mode was
investigated. Parameters such as the air and water mass flow rates, solar radiation intensity and PV
plate temperature were manipulated to determine the responding performance of the PV-T solar
collector.
Ong [14] investigated on using a combination of a solar heat pipe collector with thermoelectric
modules for simultaneous power generation and hot water heating. Heat pipes (HPs) are very effective
and passive heat transfer devices that are capable of transferring large amounts of heat through long
distances with small temperature differences between the heat source and the heat sink. Investigations
were carried out as the evacuated HP solar collector, TE modules and heat sinks are readily and
commercially available. Such systems offer small, mobile, transportable and off-grid power and
heating systems. Zhang [15] have reported on annual performances of domestic solar water heating
system and Photovoltaic/Thermal combination system of Shangai city. The results show that when
only solar energy is used, the effective day number of SWH system is more than PV/T system under
the same case every month; for the PV/T system, heat loss at the nighttime dissipates most of the
absorbed solar energy under the continuous heating mode considering the nighttime heat loss case;
initial water temperature determines system electric efficiency. On the whole, PV/T system offers
competitive performance only under the auxiliary heating mode, no matter from the points of primary
efficiency and static payback period. Harrison [16] investigated energy performance gap between the
predicted and measured output of photovoltaic systems using dynamic simulation modeling software.
To help achieve the targets set out in the Climate Change Act, building service consultants often use
EDSL Tas, dynamic modeling software, to simulate PV systems and integrate the energy output results
into the overall energy performance of a building. A performance gap of 8.6% was found between the predicted and output of PV systems using dynamic simulation modeling software, EDSL Tas. Gao [17] investigated Economic performance of solar PV cooling system, solar absorption cooling system and conventional vapor compression cooling system using annual cost method. For the PV cooling system, ‘full power to grid’ PV grid-connected mode and ‘self-generated, left power to grid’ PV grid-connected mode are discussed.

3. Simulation Studies

3.1 PV system design followed by load estimation

Solar PV systems can be used for a variety of applications. They are mainly used for electrical power generation for industrial or domestic purposes. Solar power produced was used for driving AC appliances like pump, T.V, lights, refrigerator and computers as listed in Table 1.

Considering any application which needed powering these devices referred as Load, a computational tool is created which assists the user or investor to analyse possible features of the solar power module to be created. This acts as design tool for solar power applications and also gives an estimate of daily energy requirement. Considering a typical household application, this requires inputs like power rating of AC appliances to be used, its working hours per day and number of devices [18].

| Components | Power(W) | Hr/day | Number | Energy(Wh) |
|------------|----------|--------|--------|------------|
| Fan        | 60       | 9      | 1      | 540        |
| CFL        | 9        | 8      | 2      | 144        |
| T.V        | 150      | 2      | 1      | 300        |
| Refrigerator | 150   | 7      | 1      | 1050       |
| Computer   | 250      | 3      | 1      | 750        |

The high-power domestic appliances like water pumping system requires details provided in Table 2 as the tool inputs to evaluate the essential power to lift water from the ground.

| Enter depth | 8 m |
| Enter water requirement | 25 m³/day |
| Enter frictional losses | 5 per cent |
| Enter pump efficiency | 0.5 |
| Density of liquid | 1000 kg/m³ |

Here the PV system is designed for worst case scenario, which will ensure that the system is reliable, also a regulated standalone PV system is used which includes other devices in between panel and load, like an inverter for AC loads or converter for DC loads, Battery bank for working in off-sunshine hours and also in case of Autonomy required and an electronic controller circuit which includes MPPT circuit and charge controller for smooth operation and to draw maximum power from panel. Hence these input features of devices are required, which also includes type of battery and panel to be used.

| Inverter efficiency | 0.93 |
| System voltage | 24 V |
| Battery specifications |   |
The tool uses the specifications provided in Table 3, to evaluate number of batteries and panels required of particular capacity. The wattage used in series and parallel along with daily energy requirement is computed.

### 3.2 Optimization of Sun tracking modes

Sun tracking mechanism is used to maximize the solar irradiation received by the PV array by continuously aiming to orient them in the direction of incident solar radiation. Hence modern solar PV systems also include sun tracking mechanism in built in them, so this also falls under the design process.

Summation of full day solar inclined radiation of all months gives total radiation obtained for the entire year for different panels working under different modes of axis tracking. Then by comparison between these results gives the optimum mode to be applied for tracking.

#### 3.2.1 Study on solar intensity variation according to load

Now by considering the same previous house-hold application where the load requirement changes throughout the day, from morning till evening depending upon number of machines or appliances being active during a time interval. The solar radiation intensity on inclined and horizontal surfaces is calculated and plotted against time by a computational tool.

The basic design calculations related to solar energy are essential in sizing of the system components as highlighted through equations

**Extra-terrestrial intensity:**

\[ I_{ext} = I_{sc}[1 + 0.033 \cos(360n/365)] \text{ (W/m}^2) \text{ } --(1) \]

where \( I_{sc} = \) Solar constant \((1367 \text{ W/m}^2)\)

**Local Solar time=Local time±4 (L_{st}=L_{loc}) + E**

\[ E = 9.87 \sin(2B) - 7.53 \cos(B) - 1.5 \sin(B) \]

\[ B = \frac{360}{364}(n - 81) \]

where \( L_{st} = \) Standard meridian of India, \( L_{loc} = \) Longitude of location

**Solar angles**

- **Declination angle** \( (\delta) = 23.45 \times \sin[(360/365) \times (284 + n)] \) --(3)
- **Hour angle** \( (\omega) = (\text{Solar time}-12) \times 15^o \) --(4)
- **Slope(\beta), Latitude angle(\phi), Surface azimuth angle(\gamma)**

**Incidence angle**

\( (\Theta) = \cos^{-1}(\cos(\phi) \cos(\delta) \cos(\gamma) + \sin(\phi) \sin(\delta) \sin(\gamma) - \sin(\theta) \cos(\phi) \sin(\delta) \sin(\gamma)) \)

**Zenith angle** \( (\Theta_z) = \cos^{-1}(\cos(\phi) \cos(\delta) \cos(\gamma) + \sin(\phi) \sin(\delta) \sin(\gamma)) \)

**Hour angle at sunset** \( (\omega_s) = \cos^{-1}(-\tan(\Theta) / \sin(\delta)) \)

**Number of sunshine hours** = \( 2/15 \times \omega_s \)

#### 3.2.2 Sun path diagram
At every location the path of sun differs, hence for sun tracking the path followed by sun during the sunshine hours is of prime importance. The behavior of sun at any location can be obtained by sun path diagram. The sun path diagram is a graph in which solar azimuth angle is plotted against Altitude angle. It consists of various curves in a single graph. Curves are of 2 types: - Time curves (6 am to 6 pm) and Month curves (January to December) for a particular date. Here a computational tool is developed which calculates solar azimuth angle and Altitude angle for different time zones from morning till evening (6 am-6 pm) and for different months (Jan-Dec) on 30/8/2019 at Hubballi location and relates them by plotting sun path diagram for estimating behavior of sun.

3.3 Simulation study on solar radiation and cell performance by MAT LAB tool.
Here the solar radiation energy is calculated and simulated using MAT LAB software by method found by Researchers for the same inputs of previous study. Here the total radiation energy incident for the entire day for horizontal and inclined surface is estimated along with hourly global radiation. Also the inclined solar intensity is calculated and plotted for different slope angles.
In order to study variation of solar cell efficiency with incident solar radiation this MATLAB tool calculates efficiency as a function of cell temperature and incident radiation.
Inputs like specifications of solar panel and ambient temperature are required.

| Table 4 Input cell features |
|-----------------------------|
| Solar cell power rating     | 15 W |
| $V_{mp}$                    | 18 V |
| $I_{mp}$                    | 0.83 A |
| Area                        | 0.06 m$^2$ |
| Ambient temperature         | 30 °C |

Variation of solar cell efficiency with incident solar intensity is investigated using the parameters listed in Table 4 as per the manufacturer manual.

3.4 Economics of solar PV systems
Now as solar modules are one-time investment projects, they are meant to have a relatively larger life then other power producing devices like Diesel generator and gas turbines. Designing solar power modules for a particular application time value of money must be considered, also for any system, life cycle cost must be considered rather than only its initial investment. Life cycle cost is the sum of all recurring and one-time (non-recurring) costs over the full life span or a specified period of a good, service, structure, or system. In order to make predictions whether a solar power system should be accepted or rejected for a given application, some of its important future conditions should be predetermined. Hence designing any system requires knowledge about its characteristics like life of system, its initial cost, its important component replacement cost, recurring maintenance and consumption cost, rate of interest, its resell value and profit from system. Here for designing, a suitable computational tool is created where these inputs of device are fed and required system characteristics are obtained. Output includes life cycle cost, unit cost of electricity generated, Net present value etc.
Considering a solar power system

| Table 5 Input features of a system. |
|-------------------------------------|
| Useful Life (n)                     | 20 Yrs |
| Initial cost ($C_o$)                | 12000 (Rs) |
| Maintenance cost ($C_m$)            | 200 (Rs) |
| (One-time replacement)              |        |
| Cost ($C_r$)                        | 3000 (Rs) |
### Table 6 Output results

| Factor (f)      | 7.96 |
|-----------------|------|
| Life cycle cost | 14326.2 (Rs) |
| Capital recovery cost (CR) | 1799 (Rs) |
| (operating cost annual) |       |
| Unit cost of electricity | 1.232 (Rs) |

Where factor refers to \( f = \frac{(1 + i)^n - 1}{i(1 + i)^n} \) \( \rightarrow(9) \)

\[
LCC = C_o + (C_m \times f) + C_r \left[ \frac{1}{(1 + i)^n} \right] - S \left[ \frac{1}{(1 + i)^n} \right] \rightarrow(10)
\]

\[
CR = LCC \times \left( \frac{1}{f} \right) \rightarrow(11)
\]

\[
Unit \ cost \ of \ electricity \ generated = \left( \frac{CR}{365 \times P} \right) \rightarrow(12)
\]

### 4. Results and Discussions

#### 4.1 PV system design followed by load estimation

As studied a typical household application was considered for design and estimation of daily energy requirement, further calculations was done using this computational tool.

### Table 7 PV System parameters

| Description                          | Value     |
|--------------------------------------|-----------|
| Energy Supplied to inverter          | 4224.194 Wh |
| Total Ah of battery required         | 176.0081 Ah |
| No. of batteries required Series     | 2         |
| Parallel                            | 2.5~3     |
| Total                               | 5         |
| IF autonomy                         |           |
| Total Ah                            | 528.0242 Ah |
| Number of batteries                 | 15        |
| PV panel                            |           |
| PV Energy Output                    | 5521.822 Wh |
| Type of panel(W)                    | 75        |
| Voltage                             | 15        |
| Current                             | 5         |
| Number of panels required Series    | 1.6~2     |
| Parallel                            | 7.66~8    |
| Daily energy requirement            | 19878.56 kJ/day |
4.2 Optimization of sun tracking modes

The following four modes of tracking were adopted in the study and were identified as mode 1, mode 2, mode 3 and mode 4 as indicated in the following,

- Rotation around Horizontal E-W axis, two tracking modes can be applied for this
  Slope=zenith angle. (Sun altitude angle tracking) –mode 1
  Minimizing angle of incidence (Maximum beam irradiance) - mode 2
- Rotation around Horizontal N-S axis, similarly modes like
  Slope=hour angle (Constant speed tracking) –mode 3
  Maximum beam irradiance – mode 4

Comparison between different sun tracking modes was done using a computational tool by Empirical approach based on their solar energy capturing capacity. Blue-Altitude angle tracking, Red-Minimizing angle of incidence, Green-Constant speed tracking and Purple-Maximum beam irradiance.

![Figure 1: Monthly Variation of radiation for different tracking modes](image)

Summation of full day inclined radiation of all months and then multiplied by 30 days gives total radiation obtained for the entire year for different panels working under different tracking modes. It can be observed that by implementing tracking mode 2 which works under objective of Minimizing angle of incidence can capture maximum solar energy throughout the year.

![Figure 2: Yearly solar energy captured by different panels under different tracking modes](image)

4.3 Study On Solar Intensity Variation According To Load
Considering the same previous house-hold application, the variation in incident solar intensity was compared with load variation throughout the day by using both general and Empirical approach.

The incident solar intensity on horizontal and inclined surfaces was calculated and plotted against time along with load variation throughout day by the computational tool.

![Graph of Solar Intensity and Load Variation](image)

**Figure 3:** Variation of incident solar radiation and load with time

The polynomial equations for the graph plotted is given by:

Horizontal: \( y = -0.005x^6 + 0.3715x^5 - 10.789x^4 + 152.79x^3 - 1109.7x^2 + 4144.1x - 6659.7 \) \( -- \) (13)

Inclined: \( y = -0.0049x^6 + 0.3676x^5 - 10.68x^4 + 151.43x^3 - 1101.3x^2 + 4107.6x - 6608.4 \) \( -- \) (14)

Load: \( y = 0.0054x^6 - 0.4233x^5 + 14.09x^4 - 254.21x^3 + 2559.5x^2 - 13158x + 26603 \) \( -- \) (15)

This computational tool integrates the curves (area under the curve) and gives an estimate of daily energy captured by horizontal and inclined surface along with daily load requirement.

For a study conducted on 30/8/2019 for panel inclined 27° and facing towards south at Hubballi location energy generated was 19713.57 and 31084.05 kJ/m²-day respectively for Horizontal and Inclined surfaces when connected load was 19871.86 kJ/day.

It can be observed that incident solar energy for inclined surface is larger than load requirement per day hence this design can be accepted; also this empirical method is appropriate for intensity calculations.

![Graph of Solar Intensity and Load Variation](image)

**Figure 4:** Variation of incident solar radiation and load with time

Similarly the equations are given by:

Inclined: \( y = 0.0036x^6 - 0.2718x^5 + 8.7021x^4 - 150.79x^3 + 1450.3x^2 - 6966.3x + 12766 \)

Horizontal: \( y = 0.0019x^6 - 0.1442x^5 + 4.7196x^4 - 84.982x^3 + 843.17x^2 - 4001.1x + 6827.9 \)
Load: \[ y = 0.0054x^6 - 0.4233x^5 + 14.09x^4 - 254.21x^3 + 2559.5x^2 - 13158x + 26603 \]

It can be observed that incident solar energy is larger than load requirement per day hence this design can be accepted; also this general method is appropriate for intensity calculations.

4.4 Sun-path diagram

The figure 5 refers to sun path diagram plotted by a computational tool at Hubballi location for estimating sun behaviour.

![Figure 5: Sun path diagram for location (latitude =15.3647°)](image)

This kind of computational analysis is a necessary part of solar power generation system design. So if we assume a government project for establishing a solar power generating plant in India. The right location selection is of main concern, hence using this computational tool one can estimate the intensity, also analyze variations in parameters and estimate relations between them with help of graphs. Also, study sun path for different dates and months at that location.

4.5 Economical study of solar PV systems

A computational tool was developed for estimating economic aspects of a solar PV system. Inputs like life of system, Initial investment cost, Maintenance cost, rate of interest etc., are given to obtain LCC, CR and Unit cost of electricity generated. Hence before investing into any project these parameters should be known and proper study should be done.
The study shows that with increase in energy requirement per day, unit cost of electricity production decreases because the solar modules are designed for maximum and emergency load handling conditions hence low energy requirement refers to inefficient use of solar power being generated.

4.6 Simulation of solar intensity variation with time, slope, Surface azimuth angle and location.

The calculation of intensity of solar radiation depends mainly on 5 factors Location, Date, Time, Inclination of Panel and Surface Azimuth Angle. Considering any real-life application to estimate the intensity these parameters act as inputs for the computational tool being developed, thistool acts as a mathematical Model and corresponding values of Extraterrestrial Intensity, Angle of Declination, Hour angle, Hour angle at sunset, Number of sunshine hours, Angle of incidence, Zenith angle, Altitude angle,Air mass ratio etc., are obtained.

Analyzing for a solar power system located in Hubballi location (15.3647° north latitude), panel having slope 27°, facing towards south, calculated on 30/8/2019 at 1:30 pm.
Figure 7. Variation in solar radiation intensity- A: With time for horizontal and inclined surface, B: With time if surface is facing 45° towards west, C: With slope, D: with surface azimuth angle and E: With respect to different latitudes on earth from North pole to South Pole.

From Fig. 7 (A and B) it can be observed that the solar irradiation on Horizontal and inclined surfaces are nearly equal for panel facing towards south and the intensity increases from morning till noon and is maximum at Noon (hour angle=0) and decreases towards evening, this is because that at solar noon (air mass=1). From Fig 7 (C) the Solar intensity is observed to be maximum when solar panel is inclined 0° or nearly equal to latitude angle and the intensity decreases with increasing slope, this is due to change in magnitude of effective area (Normal area) facing towards sun. The Fig. 7 (D) shows that solar radiation intensity increases as the solar module starts facing towards west from south and then gradually its intensity decreases this is due to variation in effective magnitude of area normal to sun.

From Fig. 7 (E) solar radiation intensity tends to increase towards the equator and decreases towards the poles and is due to the fact that near the poles the solar radiation has to travel larger distance resulting in increased diffraction and loss of solar intensity. Further for estimating accurate values of solar intensity many models have been proposed so far, these calculated results have to be compared with experimental results using a solar illuminator and experimental room.

5. Conclusions

The following conclusions were drawn based on solar radiation measurement, economics, and optimization of sun tracking modes, sun-path diagram, load estimation and comparison analysis. Sun tracking works with the objective of minimizing angle of incidence in order to capture maximum solar energy throughout the year. This principle was adopted for servo motors and controller circuit that resulted in maximizing energy yield with maximum efficiency of Solar PV system.

The variation of load and solar intensity with time was formulated through computational tool by using generalized and empirical approach. The study indicated that PV system design was adequate to meet the full day load requirement at Hubballi location. However the same was not evident for Delhi and Hamburg (Germany). This clearly signified use of both general and empirical approach for calculation. The simulation using MATLAB for panel facing towards south on 30/8/2019 at Hubballi location it was observed that the efficiency of solar cell decreased with increase in solar radiation intensity due to relative rise in cell temperature.

The economic study of solar PV systems through computational tool indicated, that with increase in energy requirement per day, unit cost of electricity production decreased because the solar modules are designed for maximum and emergency load conditions.

References

[1] https://www.pveducation.org/pvcdrom/introduction/solar-energy
[2] Laseinde T and Ramere D 2019 Low-cost automatic multi-axis solar tracking system for performance improvement in vertical support solar panels using Arduino board Int J Low-Carbon Tech 14(1) 76-82
[3] Mills S 2018 Combining solar power with coal-fired power plants or co-firing natural gas Clean Energy 2(1) 1-9
[4] Mousavi M Hizam S A and Gomes C 2017 Estimation of hourly daily and monthly global solar radiation on inclined surfaces: Models re-visited Energy 10(1) 134
[5] Ricci R et al 2015 An innovative wind–solar hybrid street light: development and early testing of a prototype Int J Low-Carbon Tech 10(4) 420-429
[6] Gao Y et al 2010 A parametric study of characteristics of concentrating PV modules Int J Low-Carbon Tech 5(2) 57-62.
[7] Chen H and Riffat S B 2011 Development of photovoltaic thermal technology in recent years: a review Int J Low-Carbon Tech 6(1) 1-13
[8] Cuce E et al 2011 Effects of passive cooling on performance of silicon photovoltaic cells Int J Low-Carbon Tech 6(4) 299-308
[9] Rahman A 2014 Modeling of a maximum power point tracker for a stand-alone photovoltaic system using MATLAB/Simulink J Low-Carbon Tech 9(3) 195-201.
[10] Mukherjee S and Ghosh P B 2014 Estimation of carbon credit and direct carbon footprint by solar photovoltaic cells in West Bengal, India. J Low-Carbon Tech 9(1) 52-55
[11] Maleki A 2018 Modeling and optimum design of an off-grid PV/WT/FC/diesel hybrid system considering different fuel prices J Low-Carbon Tech 13(2) 140-147
[12] Ulgen K and Hepbasli A 2002 Comparison of solar radiation correlations for Izmir Turkey J Energy Res 26(5) 413-430
[13] Baljit S et al 2020 Performance study of a dual-fluid photovoltaic thermal collector with reflection and refraction solar concentrators. J Low-Carbon Tech 15(1) 25-39
[14] Ong K. S 2016 Review of solar, heat pipe and thermoelectric hybrid systems for power generation and heating J Low-Carbon Tech 11(4) 460-465
[15] Zhang T et al 2017 Annual performance comparison between solar water heating system and solar photovoltaic/thermal system-a case study in Shanghai city J Low-Carbon Tech 12(4) 420-429
[16] Harrison S and Jiang L 2018 An investigation into the energy performance gap between the predicted and measured output of photovoltaic systems using dynamic simulation modelling software- a case study J Low-Carbon Tech 13(1) 23-29
[17] Gao Y et al 2018 Comparison of the solar PV cooling system and other cooling J Low-Carbon Tech 13(4) 353-363
[18] Solanki C S 2015 Solar Photovoltaics: Fundamentals Technologies and Applications 2nd Edn PHI Learning 200-280