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Analysis of Solar Power Output with Optimum Tilt Angles and MPPT Arrangements

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ABSTRACT

The photovoltaic panel performance is mainly influenced by its tilt angle, orientation, climatic conditions and geographic location of solar collector. From literature authors analyzed solar power output with optimum tilt angles and orientation. Some authors used MPPT arrangement for better performance. The main objective of this project is to achieve best output from solar system by maintaining optimum tilt angles, orientation and MPPT arrangements. The analysis is optimal choice of azimuth orientation and tilt angle for the solar collector in order to capture maximum solar irradiation on inclined solar collector In addition to that a MPPT technique is also used to grab maximum power from solar panel. The analysis is done at Rayachoty, India.

A gain of 7.86%, 6.7%respectively is achieved by adjusting the optimum tilt angles monthly and seasonal wise, along with an MPPT technique compared with the yearly optimum tilt angle at latitude(β=L). Solar collectors maintaining at monthly tilt angle facing south orientation results in a loss of 1.3% compared with collector facing both north and south orientations. This indicates the orientation of panel is as important as its tilt angle.

Keywords:-Solar irradiation, optimum tilt angle, azimuth orientation, MPPT arrangement.

1. INTRODUCTION

Solar energy is abundant source of energy, the amount of energy we need is actually 1/1000 part of total energy available on earth from sun. The major culprit of global warming is emission of CO_2 and different harmful gases in to atmosphere. So, to meet the energy demand without pollution, it is the major option to capture maximum solar irradiation. Solar energy available on a solar collector is a complex of various factors including local climate, optimum tilt angle, orientation and ground reflection properties.

By maintaining optimum tilt angles and orientation we can grab and utilize maximum solar energy. To maintain optimum tilt angles there are 2 types of tracking system 1. Manual tracking system and 2. Automatic tracking system. Automatic tracking system is much expensive, requires energy for operation, and more maintenance is required as well as this won't be suitable for rooftops and solar heating systems. So manual tracking is suggested in this project.

The measurement of solar irradiation data is in the form of global and diffuse radiation on horizontal surface. The amount of solar irradiation available on the tilted solar collector is a function of direct beam,
Diffused beam and ground reflected radiations. The monthly mean daily solar irradiation historical data on horizontal surface is collected from Photovoltaic Geographical Information System (PVGIS) a joint research center of EUROPIAN COMMISSION, provided over duration of 2001-2012.

In order to capture maximum solar energy flat plate collectors need to maintain optimum tilt angles, so it must required to calculator optimum tilt angles. By using dual axis tracking system it is possible to achieve 40% more solar energy [10]. It is approximated that a flat plate collector moved to face the sun twice a day we can achieve nearly 95% of solar energy collected by automatic tracking system.

Prashantini sunderian[9] carried out analysis to determine priority of orientation of solar collectors are equally important as tilt angles. M.Benghanem[8] gave a method to calculate optimum tilt angles and total irradiation available on tilted solar collector. Rusheng tang[10] gave simple mathematical procedure to estimate optimum tilt angles of collectors based on monthly horizontal irradiation.

From literature authors analyzed solar power output with optimum tilt angles and orientation. Some authors used MPPT arrangement for better performance; here we are proposing optimum tilt angles, orientation along with MPPT arrangement to achieve more additional energy and better performance.

2. METHEDOLOGY

The estimation of solar energy generated from tilted solar collector is determined based on solar geometry and the work flow analysis will be as shown in Fig. 1.

Solar geometry:

The axis of earth is approximately tilted by 23.45 with respect to earth orbit around the sun. The angle between the line that points to the sun from equator and line straight out from equator is called declination angle. It varies from 23.45 to -23.45 over the year this is related to having different seasons.

$$\delta = 23.45 * \sin\frac{(360 * (284 + n))}{365}$$

Where n= day sequence in year i.e.; n=1 is first January. During equinox del=0, 23.45 at Northern summer solstice and -23.45 during southern summer solstice.

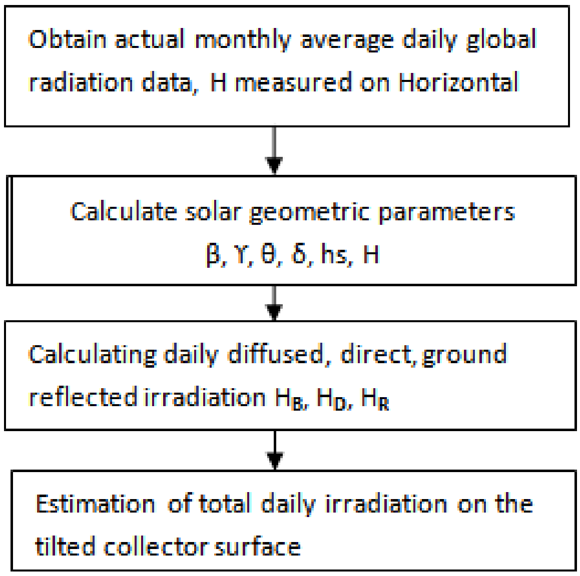

Fig. 1: process flow of solar irradiation measurement

Hour angle (h): the Angular position of sun to East or west of local meridian per hour earth rotates 15 after solar noon it is positive and negative before solar noon.

$$h = (\text{local time} - 12) * 15^0$$

Sunset hour angle (hs):

$$hs = \cos^{-1}(-\tan L * \tan\delta)$$

Where L is location latitude in degrees

Zenith angle (Z): the angle between the line that points to the sun and vertical, it will be 90 at sun rise and sunset.

$$Z = \cos^{-1}((\sin L * \sin\delta) + (\cos L * \cos\delta * \cos h))$$

Solar altitude angle (A): the angle between the line that's points to sun and horizontal, it is compliment to zenith angel.

$$A = 90 - Z$$

Incidence angle (θ): the angle between straight out from panel and the line that points to the sun.

$$\theta = \cos^{-1}(a - b + c + d)$$

$$a = \sin\delta * \sin L * \sin\beta$$

$$b = \sin\delta * L * \sin\beta * \cos\Upsilon$$

$$c = \cos\delta * \cos L * \cos\beta * \cos h$$

$$d = \cos\delta * \sin L * \sin\beta * \cos\Upsilon * \cos h$$

Υ=0; modules oriented towards south, Υ=180 modules oriented towards north.
According to Hottel and woertz model optimum tilt angle is given by

$$\beta = \tan^{-1}\frac{(\sin L * \cos\delta * \cos\Upsilon * \cos h) - (\cos L * \sin\delta * \cos\Upsilon) + (\cos\delta * \sin\Upsilon * \sin h)}{\cos Z}$$

3. IRRADIANCE ON THE TILTED SOLAR COLLECTOR SURFACE

The solar irradiation reaching the earth directly without being scattered is called direct beam irradiation. Some of sun light is scattered in to space and some of it get back on to the earth surface which is called diffused radiation. Some of scattered light in to space get rescattered on to earth surface at the areas where snow covers the land. The total amount of solar irradiation on the horizontal earth surface is called global irradiance which is a sum of direct and diffuse irradiance. The solar collector will be tilted with respect to horizontal, so the total irradiation on tilted module surface is a sum of direct beam, diffused beam and ground reflected irradiance.

$$H_T=H_B+H_D+H_R$$

Several authors have been proposed different models for analyzing total irradiance on inclined surface by the available horizontal surface data. The only variation lies in analyzing diffused beam radiation which can be analyzed in two ways namely isotropic and anisotropic models. The direct irradiation on inclined surface is given by

$$H_B = Hb * Rb \qquad Hb = Hg - Hd$$

Where Hg, Hb and Hd are the monthly mean daily global direct beam and diffuse radiation on a horizontal surface and Rb is the ratio of average daily beam irradiation on a tilted surface to the horizontal surface given by

$$Rb = \frac{(\cos(L-\beta) * \cos\delta * \sin hs) + (Hs * \sin(L-\beta) * \sin\delta)}{(\cos L * \cos\delta * \sin hs) + (Hs * \sin L * \sin\delta)}$$

Where Hs is the sunset hour angle in radians.
The ground reflected radiance is given by

$$H_R = Hg * \rho * \left(\frac{1-\cos\beta}{2}\right)$$

Where ρ *is* diffused reflectance depends on the type of floor and its reflection index, mostly according to rooftops the floor will be concrete based so reflection index is 0.2.

3.1 Analysis of diffused irradiance

1. **Isotropic**: It is assuming that the sky is completely clear over the sky dome
2. **Anisotropic**: It is assuming that anisotropy of diffused radiation over circumstances solar region and rest is isotropic ally distributed over sky.

H_D=Hd* Rd

Where Rd is the ratio of average daily diffuse radiation on a tilted surface to the horizontal surface which is given by

$$Rd = \left(\left(\frac{H_b}{H_0}\right) * Rb\right) + \left(\left(1 + \frac{H_b}{H_0}\right) * \left(\frac{(1+\cos\beta)}{2}\right) * \left(1 + \sqrt{\frac{H_b}{Hg}} * \sin^3\frac{\beta}{2}\right)\right)$$

Where H_0 is monthly extra terrestrial radiation on horizontal surface

$$H_0=\frac{N}{\pi}(86400 * Io * \cos L * \cos\delta * (\sin hs - hs * \cos hs)$$

Where N=Days of a given month.

$$I_0= 1373 * \left(1 + 0.033 * \cos\frac{(360*n)}{365}\right)$$

n= number of days counted from the first day of January.

Total solar irradiation on tilted solar collector is given by

$$HT= (Hg-Hd) * Rb+ Hg * \rho * \left(\frac{1-\cos\beta}{2}\right) + Hd* Rd$$

4.MAXIMUM POWER POINT TRACKING ALGORITHM

The solar collector typically converts 30-40% of solar energy in to electrical energy. So in order to improve efficiency of solar collectors maximum power point tracking algorithm is used. The most basic type of MPP algorithm is Perturb and Observe method.

The solar collector power is measured using a sensor and change in the power is observed whether it is positive or negative. If the change in power is positive we are moving towards MPP point else moving away from MPP point so sign of voltage perturbation should be reversed. Simulink model of Perturb and Observe MPPT model is taken from [11].

5.IMPLEMENTATION OF MPP USING BOOST CONVERTER

The voltage and current are measured from solar collector and given as input to the MPP technique which results in duty cycle. This duty cycle is given to the PWM generator to give gating pulses to the MOSFET in boost converter. Because of MPPT and boost converter voltage will be boosted and current will be reduced which in turn final power increment. The solar system setup along with MPPT is given in the Fig. 2

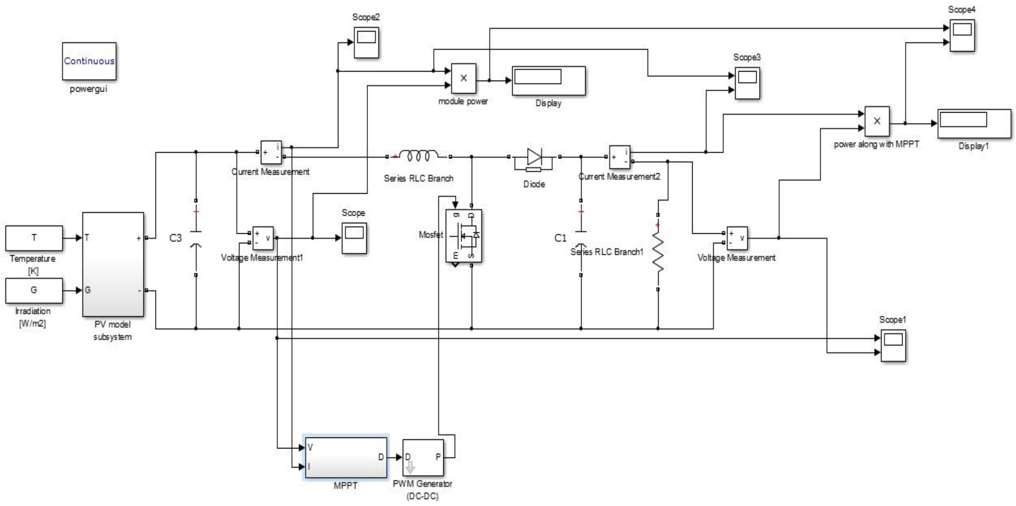

Fig. 2: Simulink model of solar system along with MPPT arrangement

6.RESULTS AND DISCUSSION

For Rayachoty, historical data for this analysis is available from 2001-20012 at Photovoltaic Geographical Information System (PVGIS) a joint research center of EUROPIAN COMMISSION website. The present database includes global irradiance (Hg), direct normal irradiance (Hb), and diffuse irradiance (Hd).

Rayachoty station data

The fig.3 shows monthly average daily global solar radiation Hg, direct beam radiation Hb, and diffuse radiation Hd on horizontal surface in the city of Rayachoty in India. The average value of Hg during summer is 6.07kwh/m^2/day, and its average winter value is 5.69kwh/m^2/day. Total solar irradiation available on tilted surface is computed for different tilt angles such as monthly, seasonal and yearly tilt angles for Rayachoty area using programming in MATLAB is developed using mathematical relations. The ground albedo (solar reflectivity) is assumed as 0.2 according to literature.

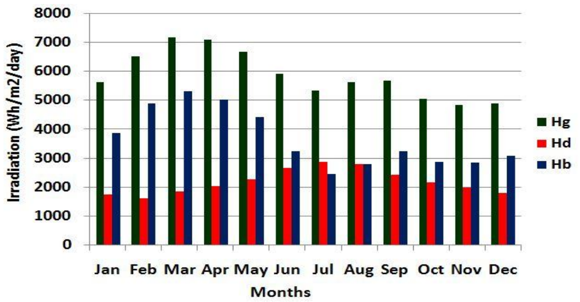

Fig. 3: Monthly average daily global irradiation (H_g), diffuse irradiation (H_d) and beam irradiation (H_b) on a horizontal surface

Fig.4 represents total solar irradiation on tilted surface using monthly, seasonal and yearly optimum tilt angles. The optimum tilt angle of flat plate collector during January is 35^o and total monthly solar irradiation on tilted surface is 7407wh/m^2/month. The optimum tilt angle in June is -9.01^o and total irradiation on tilted surface is 6082wh/m^2/month. The optimum tilt angle in December is 37^o and total irradiation on tilted surface is 6191wh/m^2/month. Maintain orientation is as important as optimum tilt angle. During summer tilt angle shows negative sign which represents the orientation should be toward north which gives an additional energy of 1.1%. as the location moves toward equator orientation effect will be increased

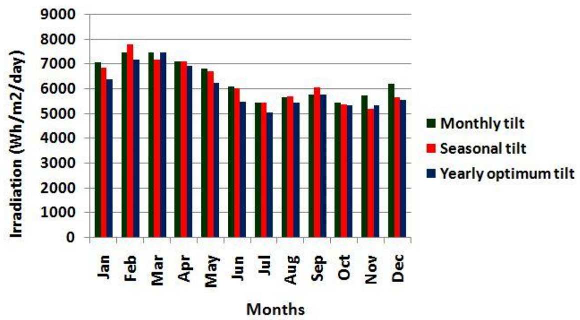

Fig. 4: Total monthly solar radiation for optimum, seasonally and yearly fixed tilt angles.

Fig.4 shows total monthly daily solar irradiation collected for optimum tilt angles. When monthly optimum tilt is used the annual collectible solar energy is 6332wh/m^2/day, with seasonal tilts annual collectible energy is 6273wh/m^2/day and by maintaining yearly optimum tilt annual collectible energy is 5994wh/m^2/day.

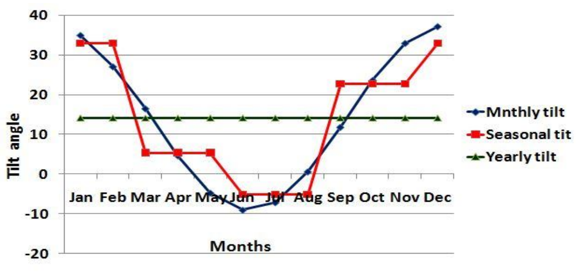

Fig. 5: Monthly, seasonal and yearly fixed optimum tilt angle variation according to months

Fig.5 represents tilt angles for month, seasonal and year wise the seasonal average is calculated by taking average of tilt angles for each season and same is implemented 4 times a year. In winter the tilt angle of collector should be 33^o during spring tilt is 5.4^o, in summer tilt is -5^o and during autumn tilt is 23^o.the yearly average tilt is calculated by taking average of all months or it also can be maintained at latitude angle which is 14^o.

The solar irradiation varies throughout a day so hourly analysis for a year days would be complex. Therefore daily average irradiation is divided in to 7 equal irradiation hours and the hourly irradiation is given as input to simulation part.

Month	Monthly Optimum tilt angle (°)	Optimum solar radiation Wh/m2/day	Yearly optimum tilt angle (°)	Optimum solar radiation Wh/m2/day
Mar	16	7453	14	7437
Apr	5	7075		6909
May	-4	6783		6220
Jun	-9	6082		5453
Jul	-7	5438		5027
Aug	0	5625		5421
Sep	12	5743		5729
Oct	23	5413		5331
Nov	33	5703		5329
Dec	37	6191		5542
Jan	35	7047		6369
Feb	27	7457		7140

Fig. 6a: Monthly versus yearly optimal tilt angles effects on total radiation reaching the aperture of collector surface.

Month	Season	Seasonal Optimum Tilt angle (°)	Optimum Solar radiation Wh/m2/day	Yearly optimum tilt angle (°)	Optimum solar radiation Wh/m2/day
Mar	Spring	5	7168	14	7347
Apr			7078		6909
May			6680		6220
Jun	Summer	-5	5998		5453
Jul			5410		5027
Aug			5688		5421
Sep	Autumn	23	6046		5729
Oct			5367		5331
Nov			5160		5329
Dec	Winter	33	5818		5542
Jan			6817		6369
Feb			7788		7140

Fig .6B: Seasonal versus yearly optimal tilt angles' effects on total radiation reaching the aperture of collector surface.

Fig.7A represents power of solar setup during January month from solar setup with seasonal optimum tilt and both optimum tilt and MPPT arrangements. The hourly average of solar irradiation during January is 973Wh/m2 which is given as input to solar set up along with MPPT which results in power of 954W/h and 980W/h with and without MPPT arrangement respectively. So by maintaining seasonal tilt angles during January month per day we can achieve 6.6KWh and 6.86KWh with and without MPPT for a 1KW solar system there by 207KWh, and 213KWh per month respectively. By maintaining monthly optimum tilt during January we can achieve 213KWh and 220KWh with and without MPPT respectively. By maintaining yearly optimum tilt during January we can achieve 194KWh and 198KWh with and without MPPT respectively.

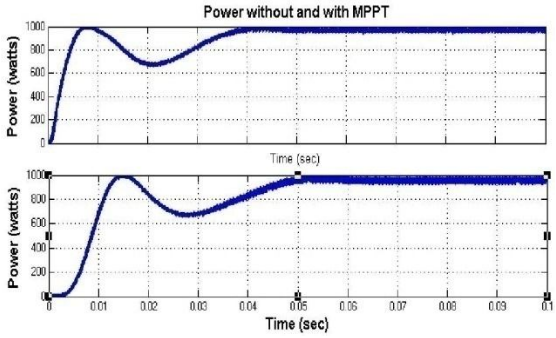

Fig. 7A: Solar system power without and with MPPT arrangements

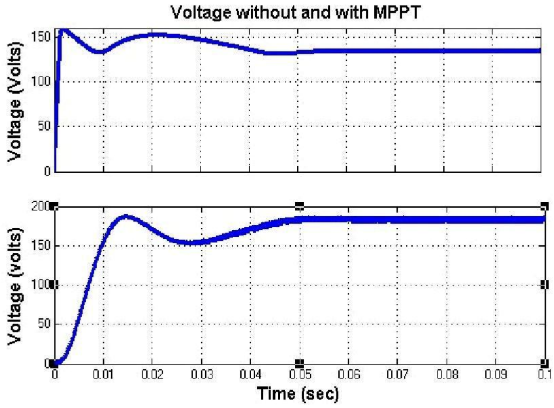

Fig. 7B: Solar system voltage without and with MPPT arrangements

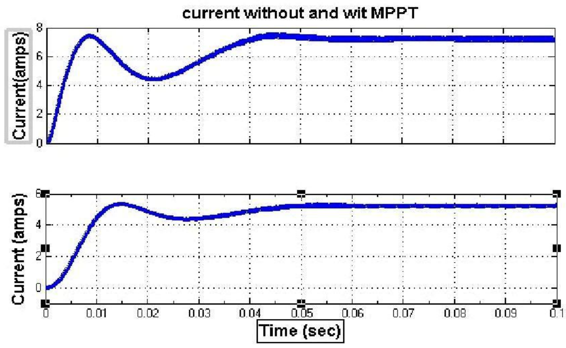

Fig. 7C: Solar system current without and with MPPT arrangements

Fig.8 represents tabular form of number of KWh/month achieved using monthly, seasonal and fixed optimum tilt angles and MPPT arrangements. For a 1KW system by maintaining fixed/ yearly optimum tilt we can achieve 2137KWH/month, by adding MPPT arrangement it is 2187KWh/month which is an energy increment of 2.2%. At the same way by seasonal optimum tilt angles we can achieve 2281KWh/month with optimum tilt and MPPT arrangements which is an energy increment of 6.7% and by monthly optimum tilt and MPPT we can achieve 2305KWh/month which is an increment of 7.8%.

Month	Annual tilt kwh/month	Seasonal tilt kwh/month	Monthly tilt kwh/month
Jan	194	213	220
Feb	195	222	212
Mar	227	224	234
Apr	203	214	214
May	189	208	212
Jun	160	180	182
Jul	152	167	168
Aug	164	176	174

Sep	168	181	172
Oct	161	168	153
Nov	156	153	171
Dec	168	175	193
Total	2137	2281	2305

Fig. 8: Number of kwh generated by 1kw solar system using optimum tilt angles and with both optimum tilt , MPPT arrangements.

7.CONCLUSION

Solar system with seasonal optimum tilt angles and MPPT arrangement is achieving the best results. As the difference between monthly and seasonal tilt angles is 1%. So it is better to change the optimum tilt once in 3 months that is seasonal optimum tilt angles along with MPPT arrangement which gives144KWh/annum of additional energy for a 1KW solar system i.e.; an increment of 6.7% additional energy compared to the existing system. The orientation of solar collector also plays an important role as tilt angle of collector which gives a loss of 1.1% if we fix panel towards south, which will result in increased/decreased loss according to location. To achieve higher efficiencies the mounting structure should be designed in such a way that the angle can be easily changeable at least on a seasonal basis if not monthly.

FUTURE SCOPE

Single and Dual axis trackers are not applicable at all solar applications which include additional cost and requires energy for operation. Design and develop the plug and play solar rooftop power system. The power pack shall be customer friendly and easy to install and maintain. This work mainly focuses on three areas of optimization; module spacing and tilt, azimuth orientation, inverter and power optimizer with shade tolerance. The system shall be designed using PVSYST model. The electrical model shall be developed for each design and verification of the performance shall be using MATLAB/SIMULINK tools. The system cost shall be estimated for all designs. Finally the LCOE shall be estimated with power generation prediction and estimated cost. The best optimum technique shall be used to be best LCOE without sacrificing quality.

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APPENDIX

NOMENCLATURE

δ Declination angle in degrees
β Tilt angle
h Hour angle in degrees
hs Sunset hour angle in degrees
Hs Sunset hour angle in radians
L Latitude in degrees
Z Zenith angle in degrees
A Altitude angle in degrees
θ Incidence angle
Υ Surface azimuth angle
ρ Diffused reflectance
N Days of the given month
n Number of days counted from the first day of January.
H_T Total irradiance on tilted surface during a day
H_B Direct beam irradiance on tilted surface during a day
H_D Diffused beam irradiance on tilted surface during a day
H_R Ground reflected irradiance on tilted panel during a day
Hb Direct beam irradiance on horizontal surface during a day
Hd Diffuse beam irradiance on horizontal surface during a day
Hg Global irradiance on horizontal surface during a day
Ho extra terrestrial radiation on horizontal surface

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