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ORIGINAL RESEARCH ARTICLE

PERFORMANCE EVALUATION OF TRACKING AND NON-TRACKING PV SYSTEMS IN SCOTLAND, UK

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ABSTRACT

Solar energy is an important component of renewable energy resources. Solar tracking system is a suitable option that could be used in capturing both direct (beam) and diffuse radiation. To investigate the performance of tracking and non-tracking PV systems, solar angles were estimated based on solar geometry and combined with global and direct radiation measurement covering a year. Results showed that using horizontal fixed panels or tracking the sun about single axis was worst to boost the energy collection of the panels, while tracking the sun about two axes or using fixed but optimally tilted panels was found to be better and efficient. With an annual electricity of 67.3 and 66.3 kWh/h respectively and an improvement of 3.65 and 2.12%. This implies that fixed tilted panel will be suitable to be employed in the region with lower irradiance as Edinburgh.

1.0 Introduction

Solar energy is an important component of renewable energy resources. Edinburgh is a location that has variation in sunshine hours with high latitude; hence to capture solar radiation in the application of solar photovoltaic (PV) technology it is necessary to apply a technology that optimizes the solar resources in the location. Solar tracking system is a suitable option that could be used in capturing both direct (beam) and diffuse radiation. This will enhance performance at low cost. A solar Tracking system is a device which direct solar panels or modules toward the sun. These devices change their orientation throughout the day to follow the suns path to maximize energy capture. The work under study will be achieved by modelling the resource data (monthly and daily irradiation record) for higher power output during winter months, with the use of the tilt-angle solar PV tracker (solar power world, 2013).

Solar tracking increases the energy received by the photovoltaic modules which in turn increases the annual and daily power output, but its application will be more expensive and more complex than fixed mount. The solar tracking system will be cost effective in cases where there is sufficient output power throughout the year. The tracking system can be defined as a device which manoeuvres with respect to the movement of the sun. The device can decrease the angle of incidence of the radiation beam on its surface by rotating on its axis which in turn increases the direct radiation acting on its surface. Solar Tracking device can be classified according to its rotation as a single axis or two (dual) axis tracking. Single axis tracking device follows the direction of the sun either across east to west in the sky or up and down while two axis tracking device follows the sun from east to west and it tilts the modules with respect to movement of the sun. (solar power world,2013). Both devices are being investigated in this study, they are said to operate with electrical/thermal power gain of about 20-40% higher than fixed panel (Ryan, 2010). There is not any trading importance for both direct and diffuse radiation, because Edinburgh lies in higher latitude it's always cloudy and rainy.

Standard photovoltaic are used in this study because they are not expensive, and simple to use. They have the added advantage of using both component of irradiation that is diffuse and direct radiation. When tracking is introduced it decreases incident angle to the direct radiation and increases energy production. Photovoltaic modules received maximum radiation when the sun strikes on it at right angle. When tilted to the sun, the collection of energy by the module becomes lower, and therefore optimal installation of fixed or single-axis devices depends on latitude of the site. The collected energy not only depends on the panel's angle to the sun, which depends on latitude, day of year and time of day, but also on local weather conditions, clouds. It is therefore important to use local radiation information to assess the expected amount of energy collected in a year (Duffie and Beckman,2013).

Areas with higher radiation data tend to have 30% increase with single axis tracking while 20% increase was observed in areas with lower radiation data when compared to fixed photovoltaic module. Shadow geometry in azimuth tracking was used in his photovoltaic plant design (Lorenzo et al, 2002). Percentage increase in mean surface irradiance due to tracking for 18 temperate sites was reported (Nann, 1990) and 34% average increase in irradiance resulted by using single axis instead of fixed panels with mean irradiance of 29 to 37% while 39% increase in average with two axis tracking is capable of increasing the mean irradiance from 33 to 42% than fixed panel. Therefore, transferring from single to dual will result to irradiance mean increase of about 3 to 7%.

The main purpose of this study is to model and simulate the behaviour, define and compare the performance of a horizontally fixed photovoltaic panel, a single-axis tracking PV Panel and a two- axis tracking PV panel system. It also intends to evaluate the performance of tracking and non-tracking PV systems in Scotland choosing Edinburgh as the location based on hourly global horizontal radiation data. The outcome would enable renewable energy planners to determine which of the solar technologies is most suitable to be implemented in Edinburgh. Successful installation of such a renewable technology would assist in meeting the growing energy demands of the country and in the reduction of environmental problems associated with the use of fossil fuel such as Green House Gases (GHG) whilst promoting the use of renewable energy.

In order to reduce the electricity cost generated, a configuration of three tracking modes namely seasonal, one axis N-S tracking and diurnal tracking are incorporated into the system. More than 120%of electrical energy was achieved by fixed panels with an azimuth tracking in Damascus, Syria (Al-Mohamad, 2004). Another theoretical analysis (Chang, 2009b) on gain of ISNA (Inclined South North single Axis) based on extra-terrestrial radiation for different latitudes and period of time for areas having latitude lower than 65 with tracking panels showed the ratio of collectible annual radiation than fixed panel to be approximately 1.5, this is said to increase gradually for latitudes with a higher value of about 1.8 in Arctic zone. In Taiwan, (Chang, 2009c) discovered a 3.1% increase in annual energy capture for a month by using tilted angle photovoltaic panel over the single axis tracking.

Horizontal east west axis tracking panels were said to be lower than that of inclined south north single axis (ISNA) tracking panel when radiation was collected annually (Chang, 2009b). Applying single axis tracking system to fixed panels (Chang, 2009a) observed that using single axis tracking in Taiwan for assessing photovoltaic performance; an improvement of 19% was achieved. Chang (2009c) also predicted that single axis tracking with an optimized inclination rotational axis is said to experience about 50% higher irradiance than fixed panel but at latitude lower than 65°.

Identical panels in Germany were tested side by side and higher Energy of about 118% and 130% was obtained with one axis azimuth tracking and dual axis tracking panels, respectively, than fixed slope panels (Helwa et al., 2000). For some days, with north south tracking system showed a gain of 30 to 45% higher in power output than fixed photovoltaic module. In the same period 50% gain in solar energy was found by orienting horizontal module to two axes tracking in a cloudy day (Kelly et al., 2009).

A study carried out by Lubitz (2011) shows that tilting an azimuth tracker between two and twelve times per year manually produces better gain in irradiation than fixed, south facing panel. Lubitz (2011) also found that at optimum tilt angle, converting due south fixed panels with azimuth single axis tracking will yield higher gain. An investigation on optical performance of inclined south north single axis tracking photovoltaic modules, estimated mathematically the annual collectible radiation on fixed and tracked modules and found out a tracking system is more efficient than fixed panel (Li et al., 2010).

2. Material and Methods

2.1 Solar Angles

In order to be able to track the PV panel one must know the exact direction of the sun ray. This can be obtained by sun path: the equatorial or global system and the azimuthal or local system. Azimuthal system makes use of altitude (α) and azimuth angle γ)as shown in Figure 1, while Equatorial system uses declination (δ) and hour angle (w) as shown in Figure 2.

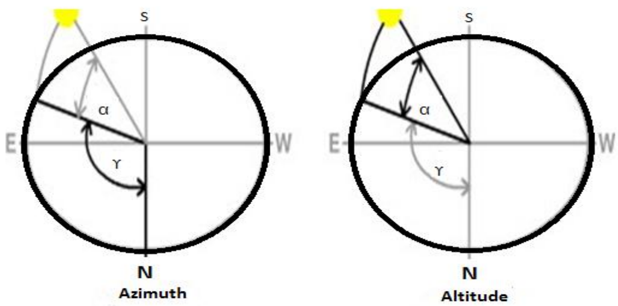

Figure1: Sun position in the sky is typically given as an azimuth and altitude angle. (Solar Position,1994-2012).

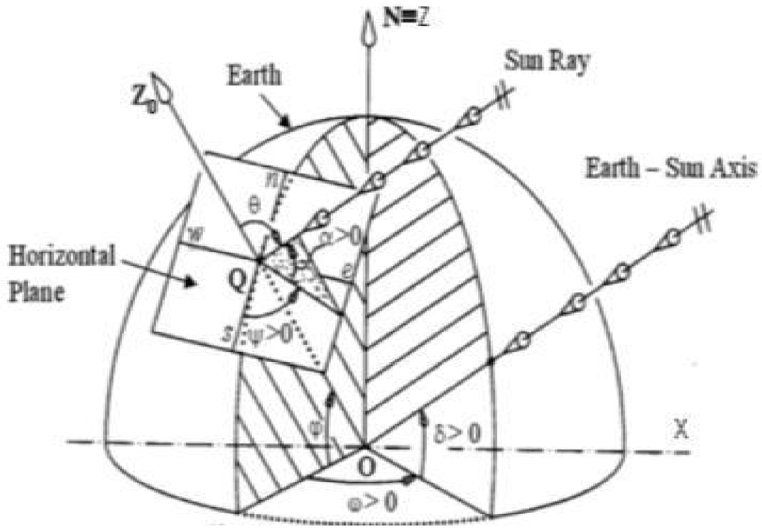

Figure 2: Solar Angles (φ,), Declination (δ), Hour Angle (ω,), Altitude (α), Azimuth (γ), and Zenith (Z).

The formulas below where source from (Duffie and Beckman, 2013)

The azimuth angle, γ, can be expressed as;

(γ) = Cos-1(Sin α * Sin φ – Sin δ/Cos α * Cos φ) (1)

The altitude or (elevation) angle, α can also be expressed as;

α= Sin-1 (Sin δSin ϴ+ Cos δ Cos ϴCos (HRA))

And α = 90-ϴ (2)

The equatorial system has the following expression; Declination :(Duffie and Beckman, 2013)

δ = 23.45 ◦ Sin 360 ◦ (n – 80) /36 (3)

Hour Angle; w: = 15 ◦ (12 – T) (4)

The constant angles defining the orientation and location of the tilted plane:

ϒ, Solar Azimuthally angle. Solar azimuth angle (γ) is defined as the horizontal angle which is measured from south in the Northern hemisphere to the horizontal projection of the sun rays (Duffie and Beckman, 2004).

n is the time of year

δ, Declination (δ) angle is the angle between the line joining the sun and the earth and its projection on the equatorial plane. Declination angle is zero at the venal (20/21 March) and autumnal (22/23 September) positions.

W, Hour angle w is the angle between the meridians passing through the sun and the meridian of the site. Hour angle is zero at solar noon and increases toward the east. (Markvart, 1996).

Φ, Latitude φ is defined as the number of degrees north or south of the equator. Or 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, rotating axis of the earth intersect the surface of the earth at 90° latitude (north pole) and −90° latitude (south pole). Each location on the earth surface can be found by intersection of longitude and latitude angle.

Solar altitude angle refers to how high in the sky the sun is. It is described in terms of solar zenith angle which is the vertical angle between the sun rays and a line perpendicular to the horizontal plane through the point (Θz = 90 - α).Equation (3) and (4) are used in equatorial system, whereas (1) and (2) are used in azimuthal system. An important formula which indicates the hour angle, at which the sun rises and set, was depending on the latitude and season (Agee et al., 2007);

$$W_{sr,ss} = + \text{ or } - \text{Cos}^{-1}(-\tan \varphi \tan \delta). \quad (5)$$

In most renewable energy projects, it is very important to know how long it will take for the investment to pay for itself. This is why payback period will be calculated. With the following advantages: A longer payback period indicates capital is tied up. Focus on early payback can enhance liquidity. Investment risk can be assessed through payback method.

$$\text{Payback Period} = \frac{\text{Installation cost}}{\text{Savings cost} - \text{Maintenance cost}}$$

2.2 Methodology

The methodology developed to complete the project is based on the following:

Latitude, longitude, time zone, local time (hours and year). The location was used for the computation of solar angles at different hours of the day for each month. The hourly global radiation and the daily 'synoptic' direct and global radiation for Edinburgh for the year 2010-2011 were obtained from the United Kingdom Met. Office through the British Atmospheric Data Centre (Midas, 2012) and is expressed in kWh/m2. For fixed horizontal photovoltaic panel the tilt angle is zero. Incidence angle Θwas calculated using the equation below.

$$\text{Cos } \Theta = \text{Sin } \alpha \quad (6).$$

where:

Θ= incidence angle α = elevation angle

An excel spreadsheet was used to calculate incidence angles for varying elevation angles.

For tilted surfaces facing south the angle of incidence was calculated using the equation below:

$$\text{Cos } \Theta = \text{Sin } \alpha \text{ Cos } \beta - \text{Cos } \alpha \text{ Sin } \beta \text{ Cos } A \quad (7)$$

where:

α = Elevation angle (degrees) β = Tilt or slope (degrees), γ = Azimuth angle (degrees). An excel spreadsheet was used to calculate incidence angles for varying elevation angles of tilted surfaces facing south.

From SYNOPTIC Radiation, the daily direct radiation and daily global radiation for each month at a specific date of the year was deduced respectively. The ratio of the direct to the global radiation is shown in Figure 3. This shows that the direct radiation is only a few percent of the global radiation in the summer but was much higher in some winter months, typically around 20% between November and February, with an unusually sunny December in Edinburgh.

To Split hourly global into direct radiation and diffuse radiation at different hours of the day for each month the following equations were used to calculate direct radiation and diffuse radiation respectively.

$$\text{Direct} = \text{Global Radiation} * \text{Ratio} \quad \text{Diffuse} = \text{Global Radiation} *(1-\text{Ratio}) \quad (8)$$

Global Radiation was obtained from MET Office data.

Knowledge of view factor is important in estimating the solar radiation incident on the surface of a collector. And View factor was calculated for fixed horizontal PV system using the formula below.

$$\text{View Factor} = \text{Cos (Incidence angle)} \quad (9)$$

View factor for tilted surfaces was calculated using the formula below

$$\text{View Factor} = \text{COS (Incidence angle)} \quad (10)$$

The radiation captured by the collector or received radiation was calculated using the equation below;

Received Radiation = View factor * Direct Radiation Diffuse radiation.

Performance curve was determined from the generic example in Twidell and Weir (pg., 222 I-V characteristic). This is because PV modules create a flow of current that's described as direct current (DC) because the electrons move in just one direction. As sunlight strikes the PV cells, the electrons move off the cells and through a load (any piece of electrical equipment) before heading back to the cells, all while staying in a straight line.

The power was calculated using the equation below, as

$$P = IV \quad (11)$$

where:

I=Current (Ampere) and V=Voltage (Volt). A straight-line graph was obtained with a slope of 0.068 ± 0.0004

3. Result and Discussions

3.1 Fixed horizontal Panel

As the view factor for fixed horizontal panel is shown in Figure 3. The view factor for two-axis tracking is always equal to one; both single axis and fixed panel has a view factor of cosine of incidence angle, summer month (May to Sept. 2012) has a higher view factor than winter month (Nov. to Jan. 2012) as seen in the graph, with the resulting electricity generated as shown in Figure 4

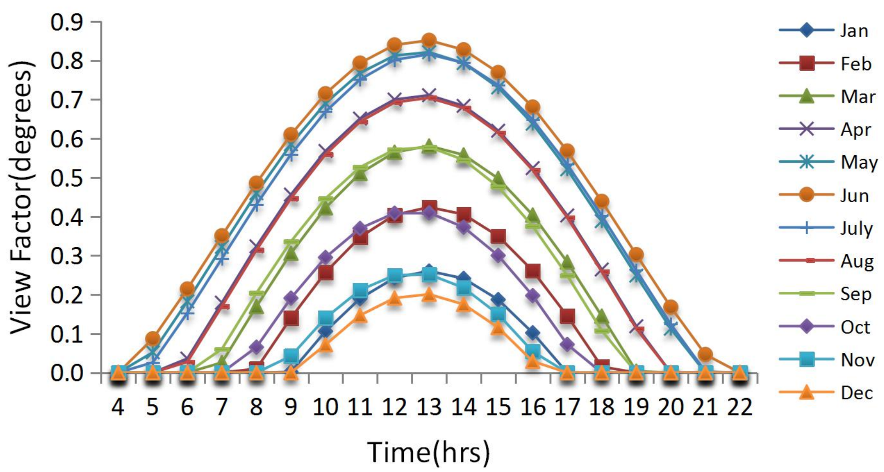

Figure 3: View factor for fixed horizontal panel

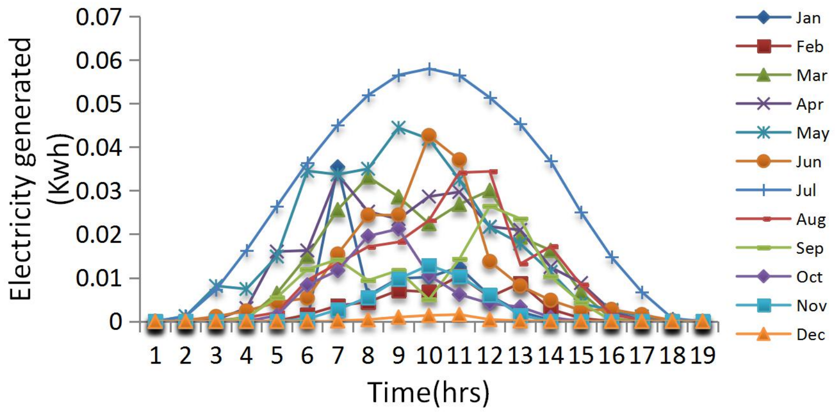

Figure 4: Daily electricity generated from fixed horizontal panel (kWh)

3.2 View factor for other Panels

Optimum tilt PV panels makes almost identical in summer and winter month but single horizontal axis tracking panel did not achieved that whereas two axes tracking always has a view factor of one as shown in Figure 5.

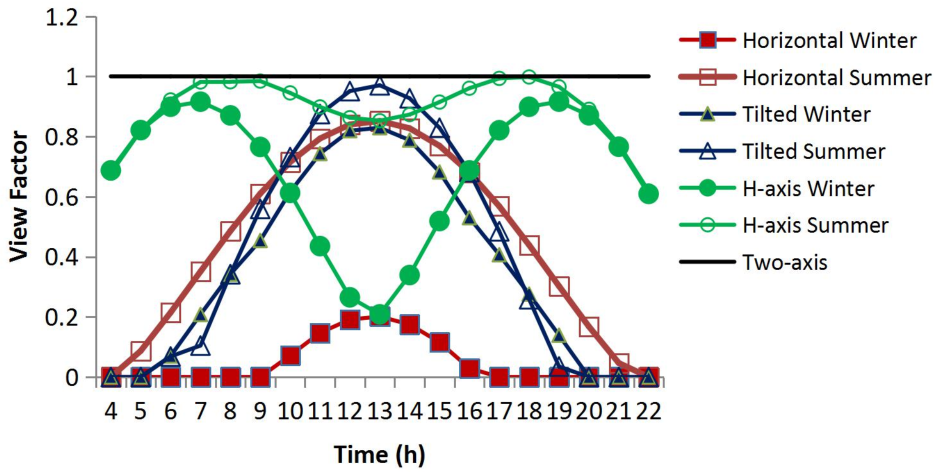

Figure 5: Graph of view factor from the five systems

3.3 Electricity Production

Results obtained by simulation in this work are shown in Tables 1 and 2. It is seen that two axis sun tracking system generate 54.03% more electricity than the fixed tilt, single axis tracking and horizontal fixed PV panel, with a clear weather HT = 7.95 Kwh/m^2 day in July 24, 2011 which is much higher than single axis tracking and horizontal fixed PV panel which generates about the same amount of electricity annually.

The simulation result shows that the highest daily electricity generated from horizontal fixed PV panel is 53.612% on July 24, 2011, with a total daily received radiation HT = 7.88412 Kwh/m^2 (warmest month with an average temperature of over 20 °C) and 31.2423% on May 21,2011, with total daily received radiation HT = 4.59445 Kwh/m^2 (partly cloudy). In general, the power generation of horizontal fixed PV panel usually increases much more on clear weather. But in some partly cloudy days, the increase in power generation will still be obvious which may be due to the variation of diffuse radiation from ground, sky or cloud. The monthly result also shows that the increase in power generation from the system is around 16.61972 Kwh and 9.685111 Kwh respectively which is from a period of July and May with an annual output of

64.94633 Kwh/h. which can represent the typical summer weather in Edinburgh but also there are many daily performance in August, September and June which also represent the weather in summer.

With respect to single axis tracking the simulation results indicates that the electricity generated will be higher or larger in areas with abundant solar energy resource (that is high HT). Then the present daily generated power result (51.3849%) which was made in Edinburgh with low solar energy resource with an annual output of 65.01102 Kwh. 3.65% Improvement was also obtained by two axis sun tracking system and an improvement of 2.12% from fixed tilt PV panel

Table 1: Annual Electricity Generation for the Five Systems

System	Horizontal Fixed panel	Fixed Tilted Panel	Horizontal single axis tracking	Vertical single axis tracking	Two axis tracking
Annual Electricity	64.9	66.3	65.0	63.2	67.3

Table 2: Monthly Daily Electricity for five PV systems, Kwh.

Month	Horizontal Fixed	Fixed Tilted	Horizontal single axis	Vertical single axis tracking	Two axis tracking
Jan	2.55	2.76	2.62	2.51	2.83
Feb	1.44	1.59	1.53	1.32	1.66
Mar	7.17	7.28	7.26	6.98	7.36
Apr	7.28	7.34	7.37	7.16	7.43
May	9.68	9.70	9.76	9.51	9.79
Jun	5.73	5.75	5.64	5.49	5.81
Jul	16.61	16.63	15.92	16.36	16.74
Aug	5.99	6.06	6.07	5.75	6.13
Sep	4.12	4.22	4.25	4.00	4.32
Oct	2.70	2.86	2.78	2.62	2.93
Nov	1.47	1.67	1.54	1.37	1.75
Dec	0.15	0.40	0.22	0.17	0.49

3.4 Cost Benefit Analysis / Pay Back Periods for the Systems

The following price per KW was assumed for Non- Tracking System Calculations.

Installation cost of non-tracking is (£500.00 per 1kW of 1 m^2 area) (PV panel guide, 2011).

Cost of maintenance £30.00 per year.

Savings £77.00 per year calculated from percentage improvement (using an electricity price of 13.95p per kWh) using the formula below;

Therefore; Payback Period = 10 years

Assumptions;

The following price per KW was assumed for Tracking System Calculations

Installation cost for tracking is (£4,000 per 1kW of 1 m^2 area) of 1 m^2 area (Energy saving trust, 2012, Eco experts, 2007).

Cost of maintenance £50.00 per year.

Savings £78.00 per year it is also calculated from the improvement using same electricity price as the non-tracking system.

Payback Period = 14 years 2

4. Conclusions

These results indicated that two axis sun tracking was an effective technique to boost the radiation collected by solar panel which always points the panel directly to the sun. The only difference in performance of the photovoltaic system in summer and winter is the module temperature which is said to be lower in winter. The result shows that single axis sun tracking will not be of important to the location (Edinburgh). The present simulation result shows that tracking PV panel will only be useful in areas with high solar energy resource and the cost is much more expensive as compared to conventional PV panel.

It is concluded that fixed tilted panel will be suitable to the people in Edinburgh because two axis tracking manoeuvres with respect to the movement of the sun, horizontal fixed panel can't capture enough energy therefore, fixed tilt will be the best for the location (Edinburgh) according to my simulation result. As shown in figure 4 and 5 respectively.

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