MAXIMIZING THE OUTPUT POWER HARVEST OF A PV PANEL: A CRITICAL REVIEW

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Abstract-
The quick exhausting of traditional energy sources and the present consistently expanding energy request with regards to ecological issues have supported concentrated research on solar energy innovation. Apprehending most extreme energy from the sun by utilizing solar PV technology is impenetrable. A few features that influence the solar energy yield of this technology comprise the material of the photovoltaic, solar irradiances topographical area, the orientation of the panel, the angle of sun and surrounding climate. This present work reviews the ideologies and contrivances of solar PV tracking systems to decide the greatest solar panel tilt-angle, both isotopic and ant isotopic solar models and uses of numerous procedures for outlining solar panel tilt- angle by means of dissimilar optimization techniques. The work displays that sun-tracking systems are quite expensive than the opposing fixed mounted variety. This is mostly due to having motor-powered and moving portions. More also, having all these moving and mechanical parts means that there will be some amount of regular inspection, adjustments or even replacements required which leads way to another disadvantage. For greatest energy harvest, the optimum tilt angle for solar PV systems must be resolved definitely for every territory as it is basic for most extreme power generation by the system.

Keywords: Optimal-tilt angle, Photovoltaic, Solar Energy.

1. Introduction
Solar energy has turned into a promising elective source because of its preferences such as plenitude, contamination free and inexhaustibility. A portion of the key preferences are immediate utilization of absorbed heat received from sun, nonappearance of mechanical components, low repairs cost, high dependability, effective lengthy life and direct transformation of light to power through a basic solid state technology [1-20]. Along these lines, the issue of power transmission by cables could be wiped out by the utilization of sun based cells at the site where the power is required. Harvesting energy from the sun utilizing sun-powered PV (photovoltaic) methods remain a prominent verdict of sustainable power source innovation around the world. Regardless of the dive in petroleum derivative costs [4-6], Studies on the PV solar systems have gotten much thought, for the most part, on numerous worldwide applications [21-40]. The instantaneous solar radiation on a level collector plate surface is a component of the situation of the Sun in the sky, which changes continually. Figure 1 demonstrates the introduction and incline of PV sun oriented board are very much characterized by the tilt edge of PV sun based
board concerning the level surface (β), the azimuth edge (γ), which means the introduction of the sun powered authority regarding due south. The pinnacle edge (α) is the point between the line to the Sun and polar axis. The solar radiation accumulation at the solar PV will be best when the sun's beams are at 90 degree to the solar PV board's surface (α).

![Diagrammatic illustration of the solar, orientation and tilt angles](image)

Figure 1: Diagrammatic illustration of the solar, orientation and tilt angles

There are some articles [41-46] that show that the irradiance solar PV power system hinge on dual features, azimuth angle and tilt angle. In this study, major approaches to increase the output power yield generated from PV technology are reviewed in the paper.

2. Solar tracker applications

The solar tracking technology assumes an essential work in various solar PV technology uses where its advantages not just be present in the power and effectiveness improvements and increment contrasted with the fixed systems, yet in addition in the monetary investigations of the vast scale solar PV technology applications [47, 48]. The utmost active solar energy harvest can be attained by the use of Sun-tracking systems. A solar tracker is an electromechanical device that orients a load toward the Sun [49] as shown in Figure 2. Loads are usually Fresnel reflectors, solar panels, the mirrors of a heliostat or parabolic troughs, [50, 51]. Sun based trackers are a high-productivity substitute for customary, mounting units and static sun oriented racking. Sensibly than proceeding in one settled point all during that time sun based trackers direct themselves to screen the sun's situation through the sky, capturing a more noteworthy extent of sunlight based vitality that can be changed into electrical energy.
Solar tracking systems can be partitioned into two primary groups dependent on the procedures that govern the solar PV system [53-56]. Passive and active tracking systems are the two basic groups of trackers. Passive tracking systems utilize a low breaking point compacted gas liquid that starts from sun-based thermal while the active tracking system uses DC motors and mechanical drives to coordinate the board toward the sun [55, 57-62].

2.1 Passive tracker system

Passive tracking systems apply a low-slung breaking point compacted gas vapor that is headed to the other side or the other (by sun-powered thermal making gas weight) to make the tracker move because of an irregularity [53-56]. As this is a non-accuracy introduction it is inadmissible for specific kinds of concentrating photovoltaic authorities yet works fine for regular PV board types. The comprehensive vapor be able to drive the denser gas to the shaded ampoule and transport the weightiness to that on the side of the solar PV module, in this way making a gas weight that creates the motion [63]. Figure. 3(a) & (b) demonstrate the working procedure of passive solar tracker.

Figure. 2: Figure 2. 1: PV solar tracker [52]
Figure 3: Working principle of passive solar tracker [63]

Some studies have been done on the passive trackers. Table 1 provides a quick summary of studies done on a passive solar tracking system. The core benefit of the passive method is its competence to trajectory the sun from to and fro devoid of applying gears drive, electric motors, controllers or any mechanical drives.

| Techniques                  | Descriptions                                                                 | Merits                                      | Demerits                                   |
|-----------------------------|------------------------------------------------------------------------------|---------------------------------------------|--------------------------------------------|
| Noval passive [66]          | Single axis  
The mechanical parts was implemented  
Matched with a static system | Very economical  
The overall efficiency was amplified by 23.3% | Simply disrupt by the atmospheric conditions |
| Somework Track Rack [67]    | Single axis  
The mechanical parts was implemented  
Matched with a static system | Easy installation  
Very economical  
The overall efficiency was amplified by 25% | Simply disrupt by the atmospheric conditions |
| Solar Pumping System [68-70]| Single axis  
The mechanical parts was implemented  
Matched with a static system | The overall power was amplified by 16% 
The overall solar radiation was amplified by 14% | Simply disrupt by the atmospheric conditions |
| Somework Principle [71]     | Single axis  
The mechanical parts was implemented  
Matched with a static system  
Three different gases were used | More accurate  
The overall efficiency was amplified by 23.5% | Very costly |

A reasonably stress-free installation procedure, actual results, a low-slung cost of maintenance and nonappearance of peripheral power supplies are the benefit of passive tracking system over active tracking system [56, 62]. Globally, Passive solar trackers are still presently used in several residences. Nevertheless, passive solar trackers possess many teething troubles that affect their overall performance as illustrated in Table 1.

2.2 Active solar tracker

Otieno et al. [64] partitioned active solar trackers into three classifications: dual axis trackers, single axis trackers and chronological trackers. Shaltout et al. [65] characterized active solar trackers into four classifications, in particular, spin cell, single axis tracking, triangular solar panel and double-axis tracking technology as appeared in Figure 4.
The triangular solar trackers utilize two solar photovoltaic modules looking inverse to each other, and the two modules can get equivalent measures of daylight radiation. The single axis tracking technology is the easiest and least expensive tracking system; notwithstanding, its viability is low in light of the fact that the solar PV module can be coordinated vertically or horizontally as it were.

Table 1: Summary of studies on an active solar tracker

| Techniques        | Descriptions                                                                 | Merits                                      | Demerits                                      |
|-------------------|------------------------------------------------------------------------------|---------------------------------------------|-----------------------------------------------|
| Photo Sensor      | Sensor-driven structure                                                       | Changes direction every ten minutes interval| Ineffective                                  |
| [39,72-73]        | The mechanical parts was implemented                                         |                                             | High error rate                               |
|                   | Used a controller motor                                                      |                                             |                                               |
|                   | Compared with other models                                                   |                                             |                                               |
| Temperature sensor | Sensor-driven system                                                          | Cheap                                       | No practical data available                   |
| [75-78]           | The mechanical parts was implemented                                         | Easily rotates                              |                                               |
|                   | Electric direct current motors was used                                       |                                             |                                               |
|                   | Simulation Implemented                                                       |                                             |                                               |
|                   | Used a controller motor                                                      |                                             |                                               |
|                   | Compared with other models                                                   |                                             |                                               |
| Arduino ATmega32s | Recipe Sensor Based Microprocessor Driven Double -axis tracking system       | Low-cost                                    | Not effective in a cloudy and dark sky        |
| +LDRS [79,80]     | Software implemented                                                         | Increase the power gain                      | Energy ineffective                           |
|                   |                                                                              | Increase the generated power                |                                               |

Figure 3: Samples of active trackers
Loschi et al. [83, 84] ordered dynamic sun based tracking frameworks into four classifications dependent on the innovations used to change the direction of rotation of the photovoltaic modules. These classifications are centered on microprocessor, auxiliary-bifacial-cell-based, date-and-time-based and control as electro-optical-based or a combination of these categories. Microprocessor and electric-optical sensor trackers can control the photovoltaic modules based on a response mechanism. For photovoltaic frameworks, trackers are utilized to limit the point of occurrence between the approaching daylight and a photovoltaic board [85-87]. This builds the measure of vitality created from a settled measure of introduced control producing limit. In standard photovoltaic applications. There is numeral of works demonstrating that following frameworks empower noteworthy measure of sun based vitality contrasted with fixed frameworks [88, 89]. Abdallah [90] found that trackers beacons increment general everyday vitality reap to around 43.87% as related with a settled framework. A far-reaching audit of energy pick up of various trackers was set up by Mousazadeh et al. [91] in their paper creators detailed an increase in gathered sunlight based vitality by the utilization of GPS beacons in the scope of 10–100% at risk on assorted land conditions and timeframes. Chang [92] discovered significant upgrades of 18.7%, 28.5% and 51.4% from the watched, anticipated and additional earthly radiations separately by methods for a solitary pivot following framework. Tomson [93, 94] portrayed an expanding of occasional energy yield of around 10–20% by the utilization of the two-positional following framework that spots gatherers in the sunrise and in the mid-evening.

The performance of single single axis tracker was tried and established to have added up to 24% in the yield of solar PV system [74]. The double axis tracker solar PV gives 30% more vitality pick up than fixed solar PV [90-96]. Execution of settled and sun tracker PV frameworks was researched by Rustemli et al. [95, 96] and established that 29% more energy pick up for sun tracking framework. Kivrak et al. [97] did the test to check the execution fluctuation between a double pivot following PV board and a settled tilt PV board are thought about for quite a long time of May and June and it was stated that the vitality age for the following framework rises almost 64% as identified with that of settled PV structure. Abdallah [90, 98] laid out that there was an expansion in the electrical power

| Open Loop [81, 82] | DC stepper motors was used Electric direct current motors was used | The high cost of maintenance | Can work in bad weather It is effective in Dull sky Supplementary Energy developed matched to fixed panel Suitable for mobile tracking It may be installed in at all locality It does not need user guide | Verified in scarce sunny days The variances amid premeditated and measured azimuth and zenith are 3.6% and 43% Cannot assess depraved climate conditions Implemented on a prototype [84] |
|-------------------|-------------------------------------------------|-----------------------------|-----------------------------------------------------------------|------------------------------------------------------------------|
| Open –Closed Loop Driver System Double -axis tracking system Electric direct current motors was used The mechanical parts was implemented Related with other models Use a GPS system Simulation study | Open –Closed Loop Driver System Double -axis tracking system Electric direct current motors was used The mechanical parts was implemented Related with other models Use a GPS system Simulation study | Open –Closed Loop Driver System Double -axis tracking system Electric direct current motors was used The mechanical parts was implemented Related with other models Use a GPS system Simulation study | Open –Closed Loop Driver System Double -axis tracking system Electric direct current motors was used The mechanical parts was implemented Related with other models Use a GPS system Simulation study | Open –Closed Loop Driver System Double -axis tracking system Electric direct current motors was used The mechanical parts was implemented Related with other models Use a GPS system Simulation study |
pick up to 43.87% for the two tomahawks, 37.53% for east-west, 34.43% for vertical, and 15.69% for north-south following, separately, when contrasted with that of settled surface slanted toward the south in Jordan and Amman. An analysis performed by Morcos [99, 100] demonstrated that, changing gatherers' azimuth and tilt edges day by day to their ideal qualities in the geological area Egypt came about into the pickup of 29.2% altogether sunlight based radiation contrasted that of settled authority and the tilt-point equivalent to its geographic scope. The impact of double pivot sun-powered following on vitality pick up of solar PV board tested and tried by M. Kacira et al. [101]. The examiners found that on a specific day in Sanliurfa, Turkey, with a two-hub sun-powered trackers, there was 29.3% pick up altogether sun oriented radiation which came about into day by day normal pick up of 34.6% in control delivered. Sanzidur Rahman et al. [102] effectively composed and tried double hub sun trackers. The energy picks up of 52.78% for solar trackers contrasted with that of settled PV board was found by the creator. Yao et al. [103] played out the investigation by utilizing double axis sun based trackers. It was noticed that the normal energy productivity of the ordinary following PV, expanded by 23.6% and there was a steady increment of 31.8% in the PV vitality effectiveness. Yilmaz et al. [104] depicted that Two-axis tracker structure is more productive than a focused structure with a yearly increase of more than 31.67%. Strategy for measuring of a fixed solar PV is displayed by Rezk et al. [105] and built up a framework for sun following. Augmentation of 59.34% in the sunlight based radiation striking on PV board when utilizing double tomahawks following framework was found by Khan et al. [106] built and tried sun based following framework with reflecting mirror by utilizing stepper engine and Arduino microcontroller to expand the PV board productivity [106-108]. It was noticed that, the most extreme proficiency of PV board with followed and non-followed is 12.86%, 10.14% separately. Single-axis and dual-axis tracking system propose a diverse order of involvedness and proficiency, however the entirely solar tracking system stick to this rudiments [67-72,109-110].

3. **Tilt-angle application**

This segment grants a summary on the utmost operative expertise and approaches employed in the modern studies to show case the simulations, mathematical models, design parameters and applications of a tilt-angle in various applications. The alternative method is to upturn the amount of harvested energy to a position that the PV panel is at an optimum angle monthly or seasonally.

| Authors                      | Location | Year       | Optimum Tilt Angle with respect to Latitude | References |
|------------------------------|----------|------------|---------------------------------------------|------------|
| Stanciu C. and Stanciu D     | Romania  | 2014,2016  | $\beta = \phi - \delta_{opt}$              | [111, 112] |
| Uba and Sarsah               | Ghana    | 2013       | $\beta = \phi + 17_{opt}$                  | [113]      |
| Author(s)                        | Location      | Year | Equation                                                                 | Reference |
|---------------------------------|---------------|------|--------------------------------------------------------------------------|-----------|
| Bakirci                         | Turkey        | 2012 | $\beta = 34.783 - 1.4317\delta - 0.0081\delta + 0.0002\delta_{opt}$     | [8]       |
| Rowlands et al                  | Canada        | 2011 | $\beta = \varphi_{opt}$                                                 | [114]     |
| Benghanem                       | Saudi Arabia  | 2011 | Yearly, $\beta = \varphi_{opt}$                                          | [115]     |
| Moghadam et al.                 | Iran          | 2011 | $\beta = 0.917\varphi_{opt}$                                            | [116]     |
| Calabrôa                        | USA Europe    | 2009 | $\beta = \varphi - (26, 27, 28 \, opt)$                                 | [117]     |
|                                 |               |      | Where $\varphi$ varies from 36° to 46°                                   |           |
| Ahmad and Tiwari                | India         | 2009 | Summer; $\beta = \varphi - 60 \, opt$                                    | [118]     |
|                                 |               |      | Winter; $\beta = \varphi + 90 \, opt$                                    |           |
| Gunerhan and Hepbasli           | Turkey        | 2007 | Summer or Winter; $\beta = \varphi \pm 15 \, opt$                       | [119]     |
|                                 |               |      | March and September; $\beta = \varphi_{opt}$                             |           |
| Duffie and Beckman              | USA           | 1974 | $\beta = (\varphi + 15^\circ) \pm 15^\circ \, opt$                      | [120]     |
| Elminir et al.                  | Helwan, Egypt | 2006 | $\beta = \varphi \pm 15^\circ_{opt}$                                    | [121]     |
| Shariah et al.                  | Jordan        | 2002 | $\beta = \varphi - 3 \, opt$                                            | [122]     |
| Ibrahim                         | Cyprus        | 1995 | Summer; $\beta = \varphi - 21 \, opt$                                    | [123]     |
|                                 |               |      | Winter; $\beta = \varphi + 13 \, opt$                                    |           |
| Gopinathan                      | South Africa  | 1991 | $\beta = \varphi_{opt}$                                                 | [124]     |
| Author          | Country       | Year  | Tilt Angle Equation | Reference |
|-----------------|---------------|-------|---------------------|-----------|
| El-Kassaby      | Egypt         | 1988  | $\beta = \varphi + 3.5^\circ \text{opt}$ | [125]     |
| Lewis           | UK            | 1987  | $\beta = \varphi \pm 8^\circ$ | [126]     |
| Lunde           | USA           | 1980  | $\beta = \varphi \pm 15^\circ \text{opt}$ | [127]     |
| Iqbal           | Canada        | 1979  | $\beta = \varphi + ( -10 \rightarrow 15 ) \text{opt}$ | [128]     |
| Garg and Gupta  | USA           | 1978  | $\beta = \varphi \pm 5^\circ \text{opt}$ | [129]     |
| Kern and Harris | South Africa  | 1975  | $\beta = \varphi + 10 \text{opt}$ | [130]     |
| Löf and Tybout  | USA           | 1973  | $\beta = \varphi + ( 10 \rightarrow 30 ) \text{opt}$ | [131]     |
| Yellott         | USA           | 1973  | $\beta = \varphi \pm 20 \text{opt}$ | [132]     |
| Heywood         | England       | 1971  | $\beta = \varphi - 10 \text{opt}$ | [133]     |
| Chinnery        | South Africa  | 1967  | $\beta = \varphi + 10 \text{opt}$ | [134]     |
| Hottel          | USA           | 1954  | $\beta = \varphi + 20 \text{opt}$ | [135]     |

The greater part of past studies in this field researched on the month to a month tilt angle of the PV solar panel collectors and the outcomes demonstrated that the tilt angle relies upon the latitude of the location. The incline angle is characterized by the angle of tilt of the collectors with respect to horizontal and different mathematical models has been proposed as shown in Table 3. The positive sign is referring to the winter while the negative sign refers to the summer season. The solar energy improvement is calculated based on a tilt angle had a relative error below 1.5%. Nijegorodov [136] et al. offered 12 formulas for computing the monthly optimum tilt angle which is used in succeeding studies for authentication of other scholars' results as presented in Table 4.
### Table 4: Monthly Tilt-angle Equation as presented by Nijegorodov [87]

| Month     | Equation                        |
|-----------|---------------------------------|
| January   | $\beta_{\text{opt.(m)}} = 0.9901\Phi + 24.631$ |
| February  | $\beta_{\text{opt.(m)}} = 0.6613\Phi + 26.283$ |
| March     | $\beta_{\text{opt.(m)}} = 1.2657\Phi - 8.6368$ |
| April     | $\beta_{\text{opt.(m)}} = 0.89\Phi - 11.878$  |
| May       | $\beta_{\text{opt.(m)}} = 0.381\Phi - 9.3689$  |
| June      | $\beta_{\text{opt.(m)}} = 0.0235\Phi - 2.9196$ |
| July      | $\beta_{\text{opt.(m)}} = 0.138\Phi - 4.2233$  |
| August    | $\beta_{\text{opt.(m)}} = 0.3931\Phi - 0.4064$  |
| September | $\beta_{\text{opt.(m)}} = 0.1767\Phi + 23.08$  |
| October   | $\beta_{\text{opt.(m)}} = 0.6592\Phi + 23.08$  |
| November  | $\beta_{\text{opt.(m)}} = 0.9975\Phi + 23.192$ |
| December  | $\beta_{\text{opt.(m)}} = 0.9236\Phi + 29.184$ |

There are a number of studies and investigates that were completed keeping in mind the end goal to locate the best execution of a close planetary system, others in an examination between various areas, the ideal tilt point and introduction (azimuth) of PV frameworks, PV solar panels and some other application in specific regions around the globe as follows: Botswana [137], Abu Dhabi, UAE [138], eight provinces of Turkey [139-142], Greece [143], United States of America (USA) [143-145], North America [146], India [147], Canada [148], Egypt [125], Jordan [149], Taiwan [150], Basra, Iraq [151], 30 cities in China [152], Syria [153], Malaysian territory [154, 155], Dhaka, Bangladesh [156], Japan [157], Cyprus [158], Spain [159], Ghana [160], Romania [161], Brunei Darussalam [162], South Africa [124, 130, 134, 163-164] and Nigeria [165-171].
4. **Conclusion**

The main purpose of this work was to present various researches done to increase the output power yield of a PV solar panel such as diverse types of solar tracking systems based on their technologies and driving methods and also numerous optimal tilt-angle models. There is no reservation about the respectable performance of sun tracker based PV solar system. However, Sun-tracking systems are quite expensive than the opposing fixed mounted variety. This is mostly due to having motor-powered and moving portions. More also, having all these moving and mechanical parts means that there will be some amount of regular inspection, adjustments or even replacements required Which leads way to another disadvantage. Finally, much work has been done on solar optimization modeling but a little study was done on experimental validation of solar PV optimization modeling.

5. **Recommendation**

I hereby recommends that greater researches need to done on experimental validation of solar PV optimization modeling.

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