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Recent advancements and challenges in Solar Tracking Systems (STS): A review

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ABSTRACT

The conversion of solar energy into electricity is a viable response to address most of world's energy problems. Among the parameters affecting the performance of both photovoltaic (PV) cells and concentrating solar power (CSP) systems include their orientation and tilt angle with respect to the sun. Solar trackers (ST) are ideal devises for efficiency improvement. This paper aims to review the most commonly used ST and identify the systems that offer benefits such as greater efficiency, greater tracking accuracy, easy installation and cost effectiveness.

There are mainly two types of ST viz. single and double axis ST. The optimization of these devices requires cumbersome specifications to avoid potential tracking errors that often lead to their poor performance. These specifications cannot be fulfilled by simple tracking methods due to different sources of tracking errors such as the misalignment of the tracking fixture, the level of pollution of the area, the shading of the sensors, the types of control schemes involved, the auxiliary units of the system, the lack of maintenance as well as the imperfection and power mismatch of connecting grids.

The study reveals that double axis ST in form of polar-axis and azimuth/elevation featuring the solar movement models and the dynamic closed loop feedback control are the most effective and generally give more than a 40% improvement in energy return compared to fixed PV panels. Moreover, large systems significantly reduce the costs and save on materials. The energy consumed by the moving fixtures is mostly low (2–5% of the collected energy) but this could be higher if no optimization is performed. Lastly, all the hardware and software energy saving parameters must be optimized right from the early stages of the development of the system to prevent materials wastage and the energy over-consumption by the tracking units.

1. Introduction

Solar energy holds incredible promises for renewable energy to meet the world's already high and constantly increasing energy demand [1,2]. The conversion of solar energy into electricity is performed by both flat PV and concentrating solar power (CSP) systems. The output power generated by these devices depends on the quantity of solar energy they collect [3]. In recent years, novel technologies have been developed to increase the amount of solar energy collected by these systems using both direct and indirect techniques. Some of these techniques include but is not limited to the applications of ST and the optimization of the tilt angle to allow them to collect most of the available solar radiation [4,5]. However, these techniques still present a number of limitations [6], that only ST may overcome if optimized and controlled accurately [7]. Ideal ST allow PV panels and CSP systems to precisely point to the position of the sun and compensate for changes in daily altitude angle and seasonal latitude offset as well as changes occurring in azimuth angle of the sun.

The sluggish movement of the sun needs a stable and non-oscillatory control system that can also match this sluggish movement of the sun. In the case of ST, the main focus should be put on the configuration of the tracking axes [8,9], the optimization of their moving fixtures [10] and a proper configuration of the control systems [11] should higher efficiency be deemed necessary. Each of these parts presents certain characteristics, advantages and disadvantages [8] which can be easily manipulated to increase the overall amount of energy collected by the tracker. Currently, solar trackers are classified into two main groups based on their movements: single axis trackers (rotating around one axis) [12–16] and double axis trackers (rotating around two axes) [17–20]. Other studies [21,22] have however, highlighted others types of trackers with much more complicated structures although these ones are not as popular as single and double axis trackers are.

Furthermore, the recent progress in production of PV panels and

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Nomenclature

STS(s)	Solar/Sun tracking system(s)
ST	Solar Tracker(s)
MPPT	Maximum power point tracking
MPP	maximum power point
PV	Photovoltaic
MATLAB	Matrix Laboratory
TCPC	tracking compound parabolic concentrating
FMSC	fixed mirror solar collector
ATFMSC	Automatic tracking fixed mirror solar collector
SUPP	solar updraft power point
HSAT	Horizontal single axis solar tracker
VSAT	Vertical single axis tracker
TSAT	Tilted single axis tracker
HTSAT	Horizontal tilted single axis tracker
PLC	Programmable logic controller
LDR	Light dependent resistor
PC	Personal computer
DC	Direct current
AC	Alternating current
PID	Proportional integral derivative
PI	Proportional integral
NSR	Normal solar radiation
DSR	Diffuse solar radiation
BTNR	Bifacial tracking no reflector
BTPR	Bifacial tracking panels and reflector
GCR	Ground cover ratio.
PTC	Parabolic Trough Collector
Rp	Performance ratio
F	Correctional Factor
δ	Declination angle (Rad)
ω	Clock Angle or Hour Angle (Minutes)
α_s	Solar Elevation Angle (Rad)
γ_s	Solar Azimuth Angle (Rad)
θ_z	Zenith Angle Or Inclination Angle (Rad)
θ	Angle of incidence of the solar beam radiation (Rad)
β	Inclination angle (Rad)
H	Instantaneous Solar Radiation (W m^{-2})
H_n	Maximum Solar Radiation (W m^{-2})
H_b	Direct Solar Radiation (W m^{-2})
R_b	The solar radiation ratio
H_{dp}	The diffuse Solar Radiation (W m^{-2})
H_d	The diffuse Solar Radiation (W m^{-2})
K_y	Clearness Index or Cloudiness index
H_{gr}	Reflected radiation (W m^{-2})
H_T	The total amount of solar radiation (W m^{-2})

CSP systems, sophisticated computer technologies as well as the reliable control systems have opened more research opportunities aiming to optimize the design and operating algorithms of ST. Currently, these devices are achieving remarkable increasing efficiencies [7,23–25] both on clear and cloudy days [8,26] and are also becoming more environmentally friendly [27,28] and economically viable [29,30], thanks to these technical advances. In more general terms, ST provide energy gains between 0 – 100% compared to equal size fixed PV systems optimally directed towards the sun [26,31–33] depending on the season, time and location [34]. Research [34] suggests that there is an extensive amount of work with different solar tracking algorithms as an attempt to improve their efficiencies and obtain a much more optimized system.

In most of the cases, single axis ST easily increase their energy produced by 12–20% when compared to fixed flat PV systems [23]. Interestingly, an energy increase up to 30% can still be achieved if the tracker is more optimized [18,35]. Moreover, while many may still doubt the performance of single axis trackers, Huang and Sun [36] demonstrated that they can also achieve tremendous energy gain collecting up to 56% more if special design and control system are integrated. In case of double axis trackers, a yearly energy gain of 20.4% was collected [37] and in a similar study [38] 43.9% yearly energy gain was collected when compared to optimally inclined panels. Meanwhile, Şenpinar and Cebeci [39] achieved 13.25% energy gain higher than that of an equal size fixed PV system while investigating the performance and economic benefits vs. environmental conditions of a double axis ST. A number of other researchers successfully compared the performance of both single and double axis trackers and reported 3–5% energy gain of the double axis trackers when compared to single axis trackers [9]. The above remarks indicate that ST are versatile, thus, several design and control methods may be utilized to achieve their ultimate goals viz. to allow PV panels to maximize the amount of solar energy collected [34,40].

The literature [30,35,41] suggests that double axis trackers are more efficient and can also be cost-effective if bigger systems are implemented. Other studies [8,26,39] alleged that the positioning of double axis trackers is not so easily affected by environmental conditions. Although some may argue that ST could eventually disappear due to their complexity and running costs [42,43]; research [26] reveals that the technology is actually used worldwide and more research are currently underway seeking to address the issues and limitations related to their technology and cost effectiveness among others. Consistent with the above authors, Huang et al. [43] reiterated that there is no doubt about the fact that double axis trackers produce more electricity than single axis trackers. However, they further argued that their implementation is only justified if the amount of electrical energy produced compensates for the costs of the equipment, energy consumed by the moving parts as well as the maintenance and running costs. As such, design optimization should be given priority to address most of these above mentioned constraints, shortcomings and concerns.

In order to minimize the costs of these systems and achieve the best levels of solar energy collection, some suggestions and recommendations were made and documented in the literature. Regarding the technical issues, Huang and Sun [30] suggest that PV modules should be connected in series or in parallel on the same tracker and that the equipment used should be customized to save money. Alexandru and Tatu [41] recommend the use of PV string control technique to minimize the costs and cut the running energy by more than 20%. Their technique suggest the simultaneous transmission of the daily movements to all the modules of the string through a multi-parallelogram mechanism and a single motor. For economic reasons, Dakkak and Babeli [35] equally propose the use of larger PV systems since the same tracking units can handle both bigger and smaller systems. Moreover, as temperature is one of the parameters affecting the performance of the PV systems [26,44–47], materials resisting excessive heat should be given priority if these systems are to be installed in deserts or other high temperature regions. There are some literature [48–50] showing the relationship between temperature and performance of the PV systems and that can give more information on how to compensate for temperature through the material selection. Excessive heat reduces the efficiency of crystalline silicon panels [48] causing a drop of 0.5% in efficiency for every single °C temperature rise [49]. The efficiency loss in thin-film panels is however, always less and estimated to about half that of crystalline silicon panels [50].

This paper presents a systematic review of the operational principles and advantages of the major types of ST presented in the literature over the past two decades. The main objective is to identify the types of