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Performance and economic comparison of fixed and tracking photovoltaic systems in Jordan

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ABSTRACT

This study aims at comparing the experimental performance and economic parameters of fixed and double–axis open–loop tracking PV grid–connected systems installed at the Hashemite University, Zarqa, Jordan. Both systems, having a nameplate capacity of 7.98 kWp each, monitored for one full year from February 9, 2014 to February 8, 2015. The performance analysis was conducted in terms of final yield and conversion efficiency, while the economic analysis investigates the payback period and internal rate of return, in addition to the electricity cost. The actual performance results show that the annual production of the tracking system is 31.29% higher than that of the fixed system. The annual conversion efficiency of the fixed system is 13.83%, while it is 13.85% for the tracking system. Although the temperature of modules is higher for the tracking system, this close match is contributed to the accumulation of dust on the fixed system, whereas the motion of the tracking system cleans out dust continuously. While the double-axis tracking system generates more energy than does the fixed system, the feasibility study over 20 years shows that the fixed PV system is more feasible in Jordan. The economic analysis of payback period, internal rate of return and electricity cost disclose that these parameters are in support of investment in fixed PV systems.

1. Introduction

Photovoltaics (PV) systems have become a prevalent electricity supplier, changing the way the world is powered, as part of the renewable energy mixture. Global PV installations saw record years between 2013 and 2016, with at least 38.4 GW of newly added capacity in 2013. In 2014, there was a slowdown in the overall increase in newly added system, with an estimated installed capacity of 40 GW. The year 2015 saw a 25% increase in installation, with an estimated newly added capacity of at least 48.1 GW. More than 50% increase in installation was added in 2016, with at least 75 GW newly added capacity. This has brought the global cumulative installed capacity to at least of 303 GW by the end of 2016 [1–3], with the world leaders in total installed capacity are China (78.1 GW), Japan (42.8 GW), Germany (41.2 GW), and USA (40.3 GW) [2,3]. In the period extending to 2018, PV installations are expected to grow in China and South–East Asia in general, followed by Latin America, the Middle East and North Africa (MENA) countries and India.

The extra gain from PV *tracking systems* compared to the PV *fixed systems* has a great deal of attention from researchers. Nevertheless, this does not necessarily imply a greater benefit coming from more generation selling, because the investment, operation and maintenance costs increase as well. A large number of studies were conducted comparing both types of systems based on their geographical location, types of tracking mechanisms, type of PV modules, a variety of operating conditions and parameters and economic feasibility. Hence, this paper aims at providing a review of recent studies related to PV tracking systems in the world with regards to: 1) latest reviews, 2) geographical location studies, 3) performance and methodologies, and 4) feasibility of tracking systems compared to fixed systems. In addition, this paper provides a case study focusing on Jordan, a sunbelt country with great potential of utilizing PV, in terms of experimental performance and economic feasibility of PV tracking systems.

1.1. Latest reviews on PV tracking systems

Several review articles that summarize development and directions of research on PV tracking systems are published in the last decade

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Nomenclature

RE	Renewable Energy
PV	Photovoltaics
REEEL	Renewable Energy and Energy Efficiency Law
PPA	Power Purchase Agreement
IPP	Independent Power Producers
Y_f	Final Yield
E_{out}	Net Output Energy
NP	DC Nameplate Power of the PV System
η	System Conversion Efficiency
A_c	PV Cells Total Area
I_G	Total Global Incident Irradiance
n_p	Total Number of Modules in the System
PBP	Payback Period
IRR	Internal Rate of Return
OMC	Operating and Maintenance Cost
T	Electricity Tariff
AEP	Annual Energy Production
ASE	Annual Sold Energy
AB	Annual Balance
AUP	Annual Uniform Payment
P	Capital Cost
Subscript F	A Quantity Related to Fixed PV System
Subscript T	A Quantity Related to Tracking PV System

[4–8]. A recent review on photovoltaic systems [4] discussed the technical challenges related with the rising number of distributed generation resources connected to the grid. The authors suggested using tracker system to maximize output power during times of low solar irradiance and high unpredictability. More importantly and directly related to the main scope of this work, they advised that the cost of implementing solar tracking systems could rapidly outweigh the gains due to, for instance, the introduction of moving parts, operations, maintenance costs, service that is more frequent, downtime, and outages. They also refer to a comparison between single–axis tracking and fixed PV systems where the annual operation and maintenance cost of the single tracking system is more than 200% compared to that of fixed system, in addition to longer payback period of 9 years.

A review study on the effect of sun tracking was presented in [5]. It shows that gain rate is approximately between 15% and 45% throughout the year depending on the location and type of PV modules. In addition, it states that double–axis tracking systems give 10–20% more electrical energy generation when compared to single–axis tracking systems. These two findings result in the conclusion that sun trackers should be used with PV modules [5]. Another review [6] presented the case based on the tracking mechanisms, size of the system, geographical conditions, and several time durations. It demonstrated that tracking is not recommended for small systems. Furthermore, it argued that the most efficient tracking systems are polar–axis and azimuth/elevation types.

Passive and active methods of solar PV tracking systems are reviewed in [7]. Passive trackers utilize solar heat to cause an imbalance and move the system, whereas active trackers, which are more commonly used, employ motors, gear mechanisms and control to operate trackers. The review concludes that dual–axis active trackers maximize the efficiency of the PV system and the extra gain is approximately 30% compared to fixed PV systems. Advantages and disadvantages of different types of tracking systems are discussed thoroughly in [8]. It shows that dual–axis tracking is the most efficient compared to other tracking systems in terms of energy production. Moreover, the single–axis tracking system is the most feasible in terms of cost and flexibility.

1.2. Geographical location tracking studies

The performance of PV systems depends significantly on the geographical location of these systems, and tracking systems follow the same trend [4–6]. Several research groups conducted studies on performance of trackers in different parts of the world; including Jordan [9–11], Egypt and Germany [12], Tunisia [13], Saudi Arabia [14], the Mediterranean coastal part of Algeria [15,16], Malaysia [17,18], Turkey [19–21], USA [22,23], Ghana [24], Spain [25], Brazil [26], Europe and Africa in [27], Europe [28], and Nigeria [29]. The studies ranged in their methodology between experimental, analytical, or simulation of tracking system.

Multi–axis sun–tracking systems at different modes of operation (N–S and E–W) are evaluated experimentally in Jordan for 22 days (from June 10, 2004 to July 2, 2004) [9]. It found that the overall increase is about 30–45% in the output power for the N–S axis tracking system compared to the fixed and E–W tracking PV system. In other studies in Jordan [10,11], single– and dual–axis, open–loop PV trackers were constructed and controlled by a programmable logic controller. For a 4–day experiment, an increase in the collected energy of 24.5% and 41% were obtained for single– and dual–axis trackers, respectively, compared with the fixed surface. However, these results were not conclusive for Jordan due to the short period of collecting performance data for the PV systems. In addition, the economic feasibility of utilizing tracking in this study was not considered.

In [12], an analytical model was developed to predict the performance of a PV panel as a function of tracking the sun and the operating conditions, and validated in Egypt conditions. Then, based on the model and available data from Egyptian and German Meteorological Authorities, they simulated the PV performance for the 15th of July in hot and cold conditions in Egypt and Germany, respectively. They found that the gain does not exceed 8% in hot areas and is approximately 39% in cold areas. Another study in Tunisia [13], the authors simulated the performance of fixed, and single and double axes tracking PV systems. They found that the system should generate an extra 10.34% and 15% in the summer and winter solstice days, respectively, in single–axis system compared to the fixed system with an annual extra gain of 5.76%. In addition, the same study reported that the simulation results show that the double–axis tracking system generates extra energy of 30% and 44% in the winter and summer solstice days, respectively, compared to the fixed PV system.

PV modules were exposed to outdoor atmospheric condition for several months in the Eastern province of Saudi Arabia [14]. It was found that solar tracking can reduce dust accumulation effect by 50% at off–peak time. The performance data of seven PV systems was collected and analyzed over short periods (18 days) at different seasons [15] and over a full one year [16] in Bouzareah (Mediterranean coastal city in Algeria). The systems were dual-axis tracker, vertical axis single rotating axis with yearly optimum slope tracker, vertical axis single rotating axis with seasonal optimum slope tracker, single rotating axis inclined at yearly optimum slope tracker, single rotating axis inclined at seasonal optimum slope tracker, fixed system inclined at yearly optimum slope and fixed system inclined at seasonal optimum slope. It was found that the trackers are very beneficial during clear days reaching an increase of 58.91% additional electrical energy output when comparing dual–axis tracker to yearly-optimal-slope fixed system. However, in cloudy days, tracking systems produced additional electrical energy output that is less than 5%, when comparing dual–axis to other tracking system, necessitating the need for economic investigation. Moreover, for the partially cloudy days, the clearness index and length of days are the main factor in determining the energy gain.

A study in Malaysia [17] analyzed and compared the performance of different types of PV systems (fixed, dual–axis tracking and