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Simulations for Different PV Solar Tracking Mechanisms under Egyptian Climatic Conditions

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Abstract: -Solar Energy is one of the most important sources of electric energy generation since it is renewable and available everywhere. Photovoltaic panels are used to generate electrical energy from solar energy, but one of the drawbacks of photovoltaic panels is their low-conversion efficiency. One of the ways proposed for increasing the efficiency of the photovoltaic systems is to use solar tracking systems. In this study, different PV solar tracking mechanisms are simulated and a comparative analysis is conducted across different types of tracking systems in Egypt. A software-based using PVSYST software for comparing fixed PV panels, single axis horizontal tracking, single axis vertical tracking and double axis tracking taking into account the system losses. Results showed that using solar tracking increases the energy generated from the PV system in Egypt. This increase depends on the type of tracking used. Double axis tracking proved to be the most efficient type of tracking as the increase in the energy generation reaches more than 33% compared to fixed PV system of the same size and can generate an annual revenue of 1852.88 LE.

Keywords:PV systems, PV tracking, types of tracking

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I. INTRODUCTION

Renewable energy sources such as photovoltaic (PV) play a significant role in the electricity generation and are now crucial due to the electricity shortage and environmental impact of traditional fuels. More than 45% of the energy needed in the world will be generated by PV in the near future (Faranda et al., 2008) [1].An example of the attempts by the Egyptian government to rely more on the solar energy is the solar park in Benban, Aswan. The solar park in Benban will be the world's largest solar park with planned capacity of 1650 MW_p which corresponds to an annual production of 3.8 TWh/year. However, one of the major problems with the PV panels are their low conversion efficiency. Moreover, PV systems are weather-dependent and thus their output power is continuously changing according to weather conditions. Solar tracking technology is one of the most suitable ways of increasing the efficiency of the PV systems. The use of solar tracking systems can increase the power output of the PV system and improve its overall efficiency. The percentage increase in PV energy that resulted from solar tracking in cold regions like Berlin, is about 40 % while in hot regions like Aswan, Egypt the increase is about 10% (SharafEldin et al.,2015) [2]. Thus the aim of this study is to compare different solar tracking mechanisms under Egyptian climatic conditions taking into consideration the different system losses. This paper is divided as follows: Section 2 is a review for previous work. In the third section is the methodology and the simulations procedures. The results are presented in section 4 and the conclusions and the recommendations are presented in section 5.

II. LITERATURE REVIEW

Utilization of the energy generated by the PV panel has been an important topic of research in recent times because of the growing requirement of sustainable resources of energy.(Chin et al.,2011) used MATLAB/Simulink platform to simulate a single axis tracker compared to a fixed panel .The results showed that in case of single axis solar tracker, higher electric current and overall power are produced than that produced by the fixed panel[3]. (Al Garni et al., 2018) used Homer software to simulate and analyze different solar tracking systems. The analysis took place in Mekkah, Saudi Arabia. The results show that the double axis tracking system can produce 34 % more than the fixed PV system while vertical axis tracking produces 20 % more than the fixed PV system [4]. Moreover, (Ali et al., 2016) introduced an optimization in the design of PV panels to suit thechange in the weather conditions and environmental parameters such as solar irradianceand

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temperature in Kirkuk city based on HOMER software. Four case studies for design improvement based on sun tracking are simulated in the paper, i.e.: Simulation without using sun tracking system, using two-axis tracking system, using horizontal-axis tracking system and using vertical-axis tracking system.The optimal design is found to be the double axis tracking as it generates the largest amount of energy compared to all other simulated systems [5]. Thus, this study aims to compare the performance of different solar tracking mechanisms in Egypt using PVSYST software.

III. METHODOLOGY

This section presents the steps for setting up the simulations in the software.The software used for the simulation is PVSYST V6.70. The simulation is performed for different types of solar tracking systems along with the fixed PV system to investigate the yearly and monthly energy yield of each system in Egypt. A load profile is chosen and the PV system is sized based on the energy needsof this load profile and on the geographical site of the system.

3.1 Site definition

The geographical site of the system is chosen to be Cairo, Egypt. A meteorological database is predefined in the software and showed that the monthly average global irradiance in Egypt range from 86 kWh/m^2 to 224 kWh/m^2 and the monthly temperatures range from 14˚C to 35˚C.

3.2 Orientation of PV panels

The next step is to define the orientation of the PV panels of the system. In this study, a comparison is conducted across fixed panels, single axis horizontal tracking, single axis vertical tracking and double axis tracking panels.The tilt angle and the azimuth angle of the PV panels in case of Fixed PV system is chosen to be 30˚and 0˚ respectively. In case of horizontal axis tracking, the tracking panels are defined by a minimum angle of 10˚ and maximum angle of 80˚. While in vertical axis tracking, the panels are defined by tilt angle of 30˚ and the mechanical limitations of the movement of panels are -120˚ and 120˚.

3.3 Load definition

A typical household load profile is chosen where home appliances and their power consumptions are defined for the system. The load consists of 5 LED lamps of 10W power each, 1 TV and 1 PC of combined power of 300 W , 1 AC of 1000 W power, 1 Fridge working throughout the whole day with energy of 1.2 kWh/day and a cloth-washer with energy of 500 Wh/day. The total daily energy needed by the loads is 13.224 kWh/day.Thestandalone PV system is sized based on these loads along with the geographical site.

3.4 Sizing of the standalone PV system

The standalone PV system consists of basic components which are PV panels, batteries to store the energy produced by the panels, solar charge controller to charge these batteries and also to regulate the amount of energy reaching the batteries in order to protect the from being overcharged or undercharged [6]. The standalone PV system is sized based on the energy needs, i.e.: the appliances and their power consumption in addition to the geographical site of the system since the weather conditionsplay a significant role in the power generation of the PV panels.The sizing process starts by choosing the battery size and type which is chosen to be lead-acid 12V 165 Ah BAE Secura battery[7]. 32 of these batteries are used in the system. After defining the battery pack, the PV panels are chosen. The panel generation factor depends on the temperature and the number of sunshine hours in the specified site. The panels used are of Si-monocrystalline type manufactured by Aide solar .The panels are of 240 W nominal power. The current at the maximum power pointis 7.99A, Voltage at maximumpower point is 30.05 V, the short circuitcurrent is 8.533A and the open circuit voltage is 37.50 V[8]. The panel has a temperaturecoefficient of -0.41%/°C and the efficiency of the module is 14.79%. The total number of PV panels used in the simulation are 14 PV panels, 7 modules in series and 2 strings in parallel. A solar charge controller is used to control the charging of the batteries. The size of the charge controller is selected to match the voltage and current of the panels with those of the batteries. The maximum charging current of the controller is 74 A, maximum discharging current is 11.5 A, the voltage of the controller is 48 V with power of 360 W. In this simulation, Maximum Power Point Tracker (MPPT) is used to be able to extract the maximum power from the PV panels.The output power of the PV system continuously varies with change in irradiance and temperature. It is very important to improve the efficiency of charger. MPPT significantly increases the system efficiency. By using it the system operates at the Maximum Power Point (MPP) and produces its maximum power output[9]. . Simulations are then conducted using PVSYST for comparing the different solar tracking mechanisms.

IV. RESULTS

Results showing the energy yield of each system (monthly and yearly) and the losses in each system are presented for each chosen tracking mechanism. The results include: the actual amount of energy generated by the system in each month ($E_{available}$), the missing energy ($E_{missing}$) (if exists) which results from the inability of the PV system to satisfy the energy needs of the load and the amount of excess energy (E_{unused}) (if exists) which is the extra amount of energy the PV system generates that is more than the energy needs of the load in each month., the energy that reaches the user (E_{user}) and the exact amount of energy needed by the load in each month (E_{load}). The system is chosen to be a hybrid one that uses batteries and is also connected to the grid to sell the excess energy from the PV panels[10].

4.1 Fixed PV system

The total energy generated from the PV fixed system is 5.422 MWh with an annual revenue of 358.704 LE as shown in

Table **I**. The system losses accounts to 11.6% due to temperature increase which is lower than that of all tracking mechanisms.The loss due to mismatch is 1.1%, the wiring loss is 2.4% and the unused energy loss is 10.3%.

Table I Monthly energy and cost analysis for fixed PV system

	E_{avail} (MWh)	E_{unused} (MWh)	E_{miss} (MWh)	E_{user} (MWh)	E_{load} (MWh)	Money generated from grid (L.E))	Money Paid to grid (L.E)
January	0.364	0.000	0.067	0.343	0.410	-	56.816
February	0.373	0.000	0.000	0.370	0.370	-	-
March	0.479	0.030	0.000	0.410	0.410	25.44	-
April	0.507	0.093	0.000	0.397	0.397	78.864	-
May	0.523	0.095	0.000	0.410	0.410	80.56	-
June	0.513	0.099	0.000	0.397	0.397	83.952	-
July	0.518	0.090	0.000	0.410	0.410	76.32	-
August	0.508	0.092	0.000	0.410	0.410	78.016	-
September	0.488	0.064	0.000	0.397	0.397	54.272	-
October	0.445	0.031	0.000	0.410	0.410	26.288	-
November	0.362	0.000	0.022	0.375	0.397	-	18.656
December	0.341	0.000	0.082	0.328	0.410	-	69.536
year	5.422	0.594	0.171	4.656	4.827	503.712	145.008

4.2 Single axis horizontal tracking

Table IIdemonstrates the monthly yield energy from the PV system showing theamount of used and excess energy and the price of the electricity that will be bought from or sold to the grid. During the summer months, the energy output of the system is more than that during the winter season because of thetotal number of sunlight hours.Thus, the amount of energy sold during the summer months can reach up to 0.167 MWh per month with a revenue of 141.6 LE.

Table II Monthly energy and cost analysis for single axis horizontal tracking

	$E_{available}$ (MWh)	E_{unused} (MWh)	E_{miss} (MWh)	E_{user} (MWh)	E_{load} (MWh)	Money generated from grid (L.E)	Money Paid to grid (L.E)
January	0.400	0.000	0.038	0.372	0.410	-	32.224
February	0.393	0.020	0.000	0.370	0.370	16.96	-
March	0.492	0.046	0.000	0.410	0.410	39.008	-
April	0.530	0.116	0.000	0.397	0.397	98.368	-
May	0.574	0.147	0.000	0.410	0.410	124.656	-
June	0.581	0.167	0.000	0.397	0.397	141.616	-
July	0.578	0.151	0.000	0.410	0.410	128.048	-
August	0.543	0.124	0.000	0.410	0.410	105.152	-
September	0.501	0.079	0.000	0.397	0.397	66.992	-
October	0.462	0.038	0.000	0.410	0.410	32.224	-
November	0.389	0.004	0.000	0.397	0.397	3.392	-
December	0.377	0.000	0.003	0.376	0.410	-	27.984
year	5.821	0.891	0.071	4.756	4.827	756.36	60.208

4.3 Single axis vertical tracking

Table IIIshows the energy and cost analysis for single axis vertical tracking mechanism. The maximum monthly available energy is 0.724 MWh which occurred during June with an excess energy generation of 0.310 MWh. The yearly energy available 6.669 MWh with an annual revenue of 1411.072 LE. The PV array loss due to temperature is 13% which is higher than that of the horizontal axis tracking.Other types of losses are: the module quality loss which is 0.8%, the array mismatch loss which accounts for 1.1% and the wiring loss which is 2.6%. The unused energy loss is 24.7%, the converter loss efficiency is 6.7% and the storage system battery efficiency loss is 2.7%.

Table III Monthly energy and cost analysis for single axis vertical tracking

	$E_{available}$ (MWh)	E_{unused} (MWh)	E_{miss} (MWh)	E_{user} (MWh)	E_{load} (MWh)	Money generated from grid (L.E)	Money Paid to grid (L.E)
January	0.402	0.000	0.037	0.373	0.410	-	31.376
February	0.417	0.039	0.000	0.370	0.370	33.072	-
March	0.564	0.123	0.000	0.410	0.410	104.304	-
April	0.639	0.224	0.000	0.397	0.397	189.952	-
May	0.693	0.265	0.000	0.410	0.410	224.72	-
June	0.724	0.310	0.000	0.397	0.397	262.88	-
July	0.701	0.272	0.000	0.410	0.410	230.656	-
August	0.657	0.237	0.000	0.410	0.410	200.976	-
September	0.596	0.175	0.000	0.397	0.397	148.4	-
October	0.511	0.084	0.000	0.410	0.410	71.232	-
November	0.394	0.005	0.000	0.397	0.397	4.24	-
December	0.369	0.000	0.033	0.377	0.410	-	27.984
year	6.669	1.735	0.070	4.757	4.827	1470.432	59.36

4.4 Double axis tracking

It can be seen from **Table IV**that the least energy generated from the PV panels is 0.421 MWh during December with an unused energy of 0.024 MWh and missing energy of 0.017 MWh with a revenue of 5.936 LE in winter season. This shows that even during the winter season, the PV panel tracking system can generated enough electricity for the load and sometimes excess energy too. The annual energy generation from the double axis tracking system is 7.212 MWh and annual revenue of 1852.88 LE. The losses in the array due to temperature increase account to 13.6%. And the unused energy loss is 29.1%, the converter efficiency loss is 6.7% and for the storage system, the efficiency loss of the battery is 2.7%.

Table IV Monthly energy and cost analysis for double axis tracking

	$E_{available}$ (MWh)	E_{unused} (MWh)	E_{miss} (MWh)	E_{user} (MWh)	E_{load} (MWh)	**Money generated from grid (L.E)**	**Money Paid to grid (L.E)**
January	0.459	0.012	0.000	0.410	0.410	10.176	-
February	0.457	0.085	0.000	0.370	0.370	72.08	-
March	0.604	0.164	0.000	0.410	0.410	139.072	-
April	0.683	0.268	0.000	0.397	0.397	227.264	-
May	0.735	0.307	0.000	0.410	0.410	260.336	-
June	0.777	0.363	0.000	0.397	0.397	307.824	-
July	0.741	0.313	0.000	0.410	0.410	265.424	-
August	0.698	0.278	0.000	0.410	0.410	235.744	-
September	0.643	0.221	0.000	0.397	0.397	187.408	-
October	0.558	0.131	0.000	0.410	0.410	111.088	-
November	0.437	0.036	0.000	0.397	0.397	30.528	-
December	0.421	0.024	0.017	0.393	0.410	20.352	14.416
year	7.212	2.202	0.017	4.810	4.827	1867.296	14.416

Comparison of the different types of tracking and the fixed PV system shows thatthe use of solar tracking always yields higher energy generation compared to the fixed PV panels. The increase in the output energy depends on the type of tracking. However, the double axis tracking produces the largest amount of energy which represents 33.02% increase over fixed PV system. While in case of single axis horizontal tracking, the increase in output energy is just 7% more than that of the fixed PV system. There are two main disadvantages associated with the double axis tracking are: First, the overheating of the panels as the panels are directly facing the sunlight in a hot climate like Egyptwhich may cause the overheating of the panels and may even burn them. Second, the cost associated with the tracking mechanism which needs to be analyzed to check the feasibility of the system.From the energy perspective, the doubleaxis trackers produce the highest energy output followed by the single axis vertical tracking systems and finally the least efficient tracking type is thehorizontal axis tracking.It is thus not advised to use the single axis horizontal tracking PV system in Egyptas it is noteconomical to use it since it will add extra cost to the system without a significant increasein the energy output.

V. CONCLUSION AND RECOMMENDATION FOR FUTURE WORK

One of the most suitable ways of increasing the efficiency of the PV system is to use solar tracking systems. Using solar tracking increases the energy generated from the PV system by different proportions based on the type of tracking used. A simulation is conducted using PVSYST software to compare different solar tracking mechanisms in Egypt in terms of energy analysis, economic analysis and system losses. Results showed that under Egyptian climate, double axis PV tracking system has the highest energy output compared to other tracking systems and causes an increase in the output energy by 33% compared to a fixed PV system. In all cases, the energy output increases when using tracking system regardless of the type of tracking used.

Although the double axis tracking system is more efficient than single axis tracking from generated electricity point of view, from the cost and flexibility point of view the single axis tracking systems are more efficient. It is recommended for future studies to study the effect of solar tracking on large scale PV systems. Also, it is recommended to study the effect of integrating a cooling system to the PV panels in terms of energy and cost.

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