Experimental and Numerical Comparison between Fixed and Double Axial Photovoltaic Tracking System

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***Abstract*— The electrical performance of any photovoltaic solar cell is described by its current – voltage characteristic curve. Therefore, to improve the photovoltaic performance, a tracking of the sun is used. Thus, the present study represents a comparison between numerical model and experimental results of a fixed and double axial photovoltaic tracking system. The numerical simulations have been carried out correspond to the experimental setup. Therefore, the same dimensions, as well as operating conditions, apply to it, by using both Matlab and Comsol Multiphysics program version 4.2. Besides that, an experimental work is presented depending on the results conjured from the theoretical experience used in COMSOL Multiphysics. The paper reported the electrical performance (I-V characteristics curves, output power and electrical efficiency) of the photovoltaic cell with fixed and double axial tracking. The numerical results revealed that, for fixed PV system the efficiency of the PV modules is increased for both fixed and double axial tracking by about 12.5% and 14 % respectively. In addition, the double axial Sun tracking system module causing an increase in tracking module daily output power up to 23 % compared to that for a fixed module.**

***Index Term*-- component: Photovoltaic systems; Tracking systems; COMSOL Multiphysics; MATLAB ; Solid work.**

TABLE I
NOMENCLATURE

Symbol	Description	Units
c	The speed of light	$3*10^8$m/sec
E_p	The phonon energy	Joules
FF	Fill Factor.	%
G (x)	The optical generation rate	%
h	Planck's constant	$6.626*10^{-34}$J*s
I	Current	A
I_{01}	Dark saturation Current	A
I_{SC}	Short Circuit Current	A
K	Boltzmann constant	$1.38*10^{-23}m^2* kg * s^{-2} * K^{-1}$
Pin	The total optical input power	W
Pout	The maximum power output	W
r(λ)	The reflectance	-
s	The grid-shadowing factor	-
T	Temperature	K
V_{oc}	Open circuit voltage	V
V	Voltage	V
α(λ)	The absorption coefficient	m^{-1}
Γ(λ)	The incident photon flux	-
λ	wavelength	-
η	PV efficiency.	%

I. INTRODUCTION

Solar energy is one of the primary energy sources to replace fossil fuels due to its abundance. Its versatility, abundance and environmentally friendly have made it one of the most promising renewable sources of energy. The goal of achieving high photovoltaic conversion efficiency not only attributes as a scientific achievement and aids specialized application but can also reduce the cost of large-scale solar electrical generators[1].

The low energy conversion efficiency of the PV cells is considered as one of the main problems in using photovoltaic systems. The open-circuit voltage of the PV cells drops, therefore, the power generated and its efficiency will decrease with fixed system significantly, Kordzadeh [2]. He made an experimental work and the results showed that there is an increase in electrical energy over the whole day by 11.3%.

Abdolzadeh and Ameri [3] presented an experimental study to improve the operation of a photovoltaic tracking system by PLC controller of the photovoltaic cells. A 225W double axial tracking photovoltaic system was used in the experimental work. It was found that the tracking system over the photovoltaic cells strongly improved the system efficiency. The total efficiency of the cell increased by 3.26%. In addition, the photovoltaic with tracking system achieved 12.5%.

Another approach based on microcontroller circuit was presented by Sarker et al. [4]. They designed and constructed a two axis (Azimuth and Polar) automatic control solar tracking system and carried out an experimental study to investigate the effect of using two-axis sun tracking systems on the performance of a photovoltaic system (FPVS) under local climate. The designed tracking system consists of the light dependent resistor (LDR) as sun sensor and Microcontroller with built in (ADC) operated control circuits to drive two stepper motor of 0.1 per step. The obtained results revealed that the excess output power of the tracking solar panel with respect to the fixed panel was 9-13.5% at the average solar intensity of 1100 $W.m^2$.

Ali et al. [5] presented an experimental study to improve the efficiency of photovoltaic panels using double axis Sun-tracking system. A microcontroller unit was used to track the Sun radiation smoothly and without any time-lag. The trackers scanned an angle of about 120^o degree from east to west every day, and it stopped tracking and returned to its starting point automatically at the time when the value of the incident solar-radiation decreased to a very small value at sunset.

The results demonstrated that the tracking system improved the PV module output power by more than 20% compared to that for a fixed mounted system and it exceeded it by at least 40% for the period spanning morning and Evening hours. The microcontroller unit as a controller allowed the connection of many PV-modules in series or parallel connection. This technique reduced the costs of tracking systems and represented it as a cost-effective technology.

Herein, a comparison between simulation model and experimental work for fixed and double axial tracking PV system is represented. The present work reports the electrical performance (I-V characteristics curves, output power and electrical efficiency) of the photovoltaic cell with fixed and double axial tracking.

II. PV/T SETUP DESCRIPTION

Double axial PV modules made of a poly-crystalline Si is shown in Figure 1 was simulated using an analytical solution of Passion's equation. The carrier transport in two directions was assumed and the sun irradiance is assumed to be a Gaussian distribution across the twelve shining hours. The tracking was fitted to a constant rate of $0.2^o min^{-1}$. A numerical model based on COMSOL Multiphysics [6] and MATLAB simulation tool for a PV system is introduced as shown in Figure 2.

COMSOL is based on finite element method using a mesh of minimum area of 0.1 mm^2 and maximum area of 1.45 mm^2. The PV panel system consists of 36 cells with dimensions 1.56×0.68 m. The PV panel was made of poly-crystalline Silicon supported by an Aluminum plate of the same dimensions but with 0.04 m thickness supported on a 0.9 m connecting rod, 0.98 m^2 base areas. For optical modeling Maxwell's equations are solved in three dimensions to calculate the absorption coefficient of the silicon (Si) and air mass (AM1.5G) is assumed [7].

AM stands for air mass and 1.5 indicates that the sunlight has been attenuated by passage through the Earth's atmosphere a distance equal to 1.5 times the shortest path (when the sun is directly overhead). G stands for Global illumination where both direct and diffuse components of sunlight are included [8]. The drift diffusion model was considered for the semiconductor modeling of the device, where carrier transport was assumed to be in one direction including both bulk and surface recombination.

III. PV MODELING

The PV system is modeled through two main phases; firstly, modeling the optical behavior of the module by using Comsol in 3D and determine the absorption coefficient of the material. Secondly, modeling of the current-voltage device characteristics curves by MATLAB.

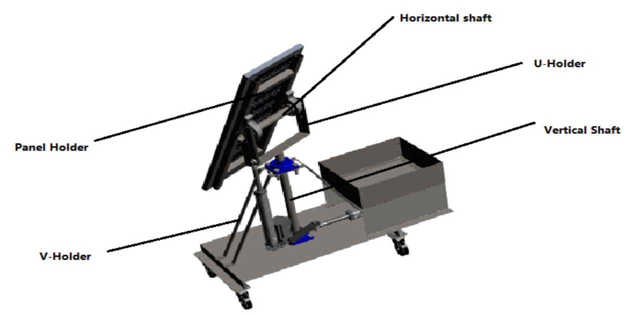

Fig. 1. Tracking PV poly-crystalline system used in Comsol.

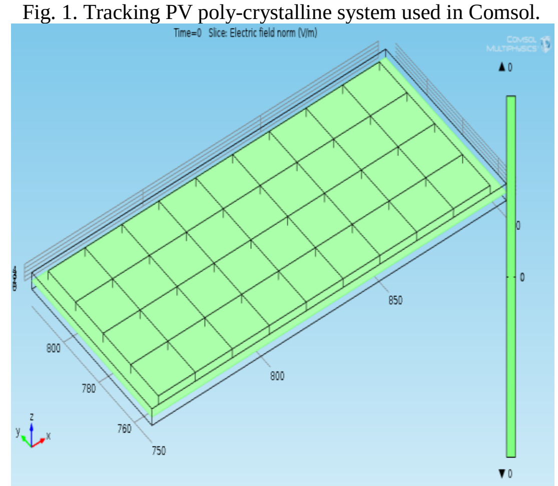

Fig. 2. The PV module used in Comsol.

All electromagnetic radiation, including sunlight, is composed of particles called photons, which carry specific amounts of energy determined by the spectral properties of their source. Photons also exhibit a wavelike character with the wavelength, λ, being related to the photon energy, E_λ, as in the following equation:

$$E_\lambda = \frac{hc}{\lambda} \tag{1}$$

Where: E_λ is the phonon energy; h is the Planck's constant; c is the speed of light and λ is wavelength.

Only photons with sufficient energy to create an electron–hole pair, that is, those with energy greater than the semiconductor band gap (EG), will contribute to the energy conversion process. Thus, the spectral nature of sunlight is an important consideration in the design of efficient solar cells.

In practice, measured absorption coefficients or empirical expressions for the absorption coefficient are used in analysis and modeling. The rate of creation of electron–hole pairs (number of electron–hole pairs per cm^3 per second) as a function of position within a solar cell is:

$$G(x) = (1 - s)\int\left(1 - r(\lambda)\right)\Gamma(\lambda)\alpha(\lambda)e^{-\alpha x}d\lambda \quad (2)$$

Where: G(x) is the optical generation rate; s is the grid-shadowing factor; r(λ) is the reflectance; Γ(λ) is the incident photon flux and α(λ) is the absorption coefficient.
Here, the absorption coefficient has been cast in terms of the light's wavelength through the relationship $h_v = h_c/\lambda$. The photon flux, Γ(λ), is obtained by dividing the incident power density at each wavelength by the photon energy.

Regarding the semiconductor behavior of the device the following equation is a general expression for the current produced by a solar cell.

$$I = I_{sc} - I_{01}\left(eq\frac{V}{KT} - 1\right) - I_{02}\left(eq\frac{V}{2KT} - 1\right) \quad (3)$$

Where: I is the current; I_{sc} is the short circuit current; I_{01} is the dark saturation current; V is the voltage; K is the Boltzmann constant and T is the temperature.

The short circuit current and dark saturation currents are given by rather complex expressions that depend on the solar cell structure, material properties, and the operating conditions. A full understanding of solar cell operation requires detailed examination of these terms. However, much can be learned about solar cell operation by examining the basic form of equation (3).

The electrical efficiency, η, of the solar cell typically under AM1.5G is representing in the following equation:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{V_{oc} * J_{sc} * FF}{P_{in}} \quad (4)$$

Where, P_{out}, electrical power out (at an operating condition of maximum power output); P_{in} is the total optical power in; V_{oc} is the open circuit voltage and FF is the fill factor.

IV. PV EXPERIMENTAL SETUP

A. Design Setup

The experimental set-up was designed to investigate the efficiency of PV panel during operation and Polycrystalline solar module was used in the experiment to generate electricity. The output electric power generated from the modules is fed the charger controller to charger 24 ampere hour solar battery. A general view of the complete experimental set-up is shown in Figure 3.

During the operation, a mechanical tracking system (Polar/Vertical-axis active tracker) [10] was used to modulate the power output from solar panel by regulating the position of the photovoltaic module facing the sun. In other words, this mechanical system makes the zenith angle [11] approaches to zero from sunrise to sunset to ensure that the maximum electrical power is extracted.
The experiment was conducted every 15 minutes from 6:00 am to 6:00 pm. A solar power meter device was used to capture the daily global solar irradiance. In the experiments, PV current, PV voltage and solar irradiance were collected. All the experimental test rig components that used have been calibrated. Readings were collected from September to December2015.
A set of high power resistors is used in the experimental measurements. The current-voltage characteristic curves varying by the load from 1 Ohm to 50 Ohm manually and detecting the current and the voltage using two digital multimeters. These output characteristics are taken under irradiance 801 W/m^2.Thus, a 150 W PV modules to generate maximum output power.

Fig. 3. General view of the experimental system used.

B. Control Design

The control circuit is responsible for identifying the position of the sun relative to the panel hence the Arduino UNO provide signal to H-bridge to rotate the panel through the 4 LDRs sensors. A 12 volt DC is used to operate the actuator and the needed current is around 0.4 ampere so the total power is 4.8 watt from the panel applied into the H-bridge, and switched to operate the actuator output voltage as shown in Figure 4.

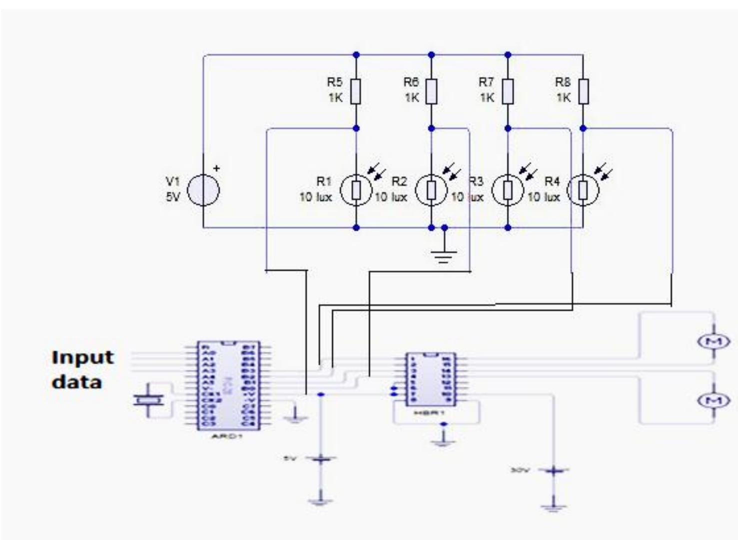

Fig. 4. solar tracking control circuit.

As illustrated in the previous section, Arduino UNO is used to control the motor with a constant step of 0.2 degrees/min (to track the sun movement). Assuming the Sun movement through the day is done by two LDRs from east to west and two LDRs from north to south. This is done through Arduino UNO (Microcontroller) with digital pulses as shown in Figure 5. The circuit setup contains Arduino Uno, power supply, LDR circuit and 4 relays as shown in Figure 6.

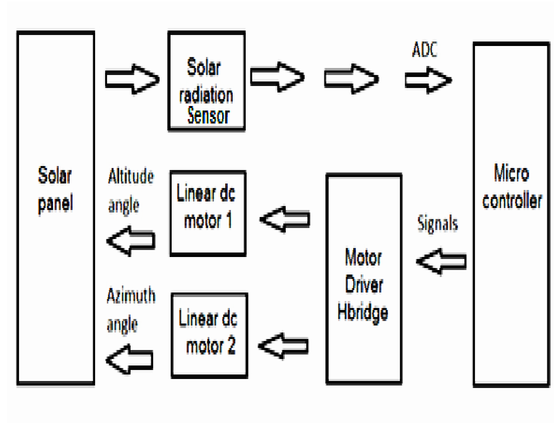

Fig. 5. Operation of solar tracking.

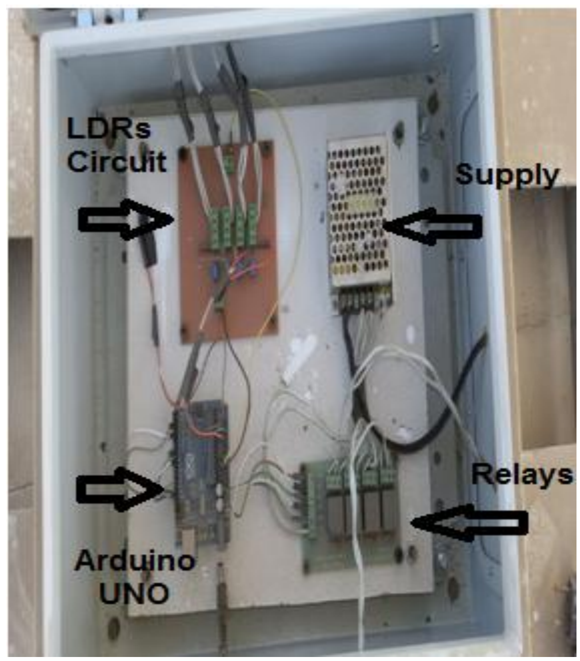

Fig. 6. Circuit setup.

V. RESULTS AND DISCUSSION

A comparison between simulated results and experimental results for fixed and tracking PV modules is reported. The electrical behavior of the PV modules in Comsol is studied through plotting the I-V and P-V characteristic curves with the aid of PV system as shown in Figure7. The Figure shows that, the short circuit current produced from the PV system in simulation work under irradiance 801 W/m^{2}isI_{sc}= 7.8 A, while the open circuit voltage reached V_{oc}= 23.29 Volt with maximum power P_{max}= 148 Watt.

Figure 7 demonstrated that the simulated results can predict the characteristic curves of the PV system with an error of Form the figure it is found that the short circuit current I_{sc}= 6.3 A, the open circuit voltage V_{oc}= 20.38 V, and the maximum power about P_{max}= 144 W. This difference between the simulation and the experimental results is due to the difference in the environmental conditions accomplished with experimental measurements which can't be considered in the simulation model such as temperature and PV module life time.

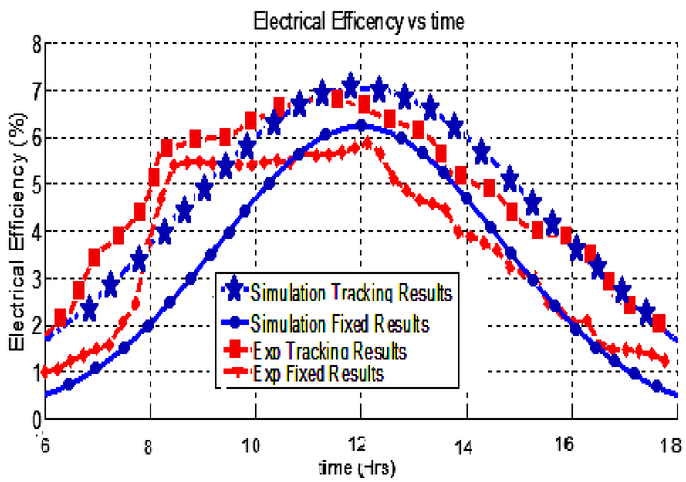

Fig. 7. Simulation and experimental curves for I-V and P-V characteristic curves PV system.

Figure 8 represent the electrical power variation across day with assumption of symmetric variation of irradiance through the twelve hours of morning. From the figure the maximum power obtained from the simulation and experimental results for fixed system on September is 141 and 139 Watt respectively. On the other hand, when using the tracking system there is about 7% enhancement of the power for both simulation and experimental results at the maximum sun irradiance at 12:00 pm.

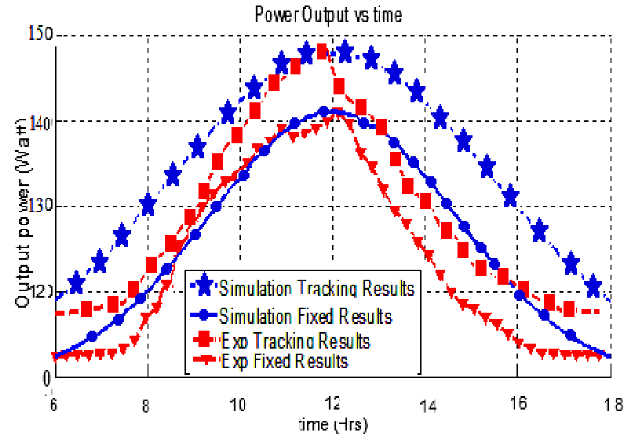

Fig. 8. Comparison between simulation & experimental results for P_{out} with 12 hour's mourning for Fixed & tracking PV system.

Figure 9 represents the electrical efficiency of simulated and experimental results for both fixed and tracking systems. The figure demonstrates a normal accordance between the experimental and numerical results. From the figure it can be seen that, the tracking system gives an improvement of about 2% in the output electrical efficiency with respect to the fixed system.

This enhancement in the P_{out} is reflected on electrical efficiency of the PV modules. In addition, it can be observed that the maximum electrical efficiency for fixed system is 6.1 and 5.9 % for the simulated and experimental results respectively. On the other hand, there is an enhancement of about 2.1% in the maximum electrical efficiency when using the tracking system. Also, the figure shows that the simulated results are fitted well with the experimental results.

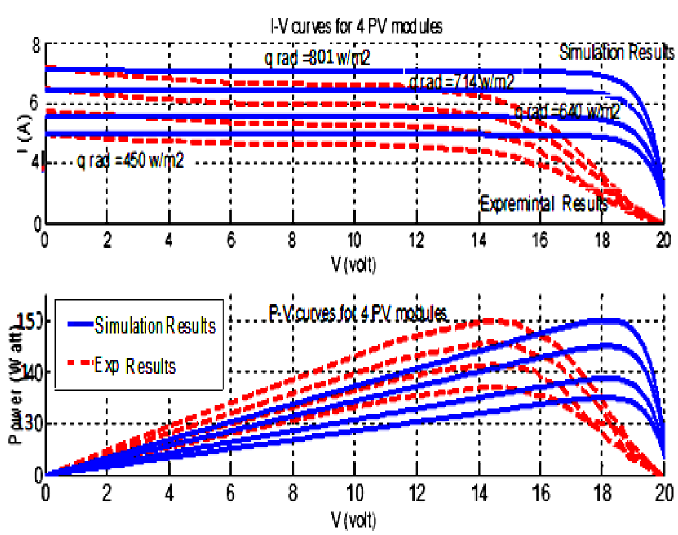

Fig. 9. Comparison between simulation & experimental results for electrical efficiencies with 12 hour's mourning for fixed & tracking PV system on September.

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CONCLUSION

The present paper introduces a comparative study between numerical and experimental results of fixed and doubles axial PV tracking system. The simulation model based on Comsol simulation package (FEM). The paper reported the electrical performance (I-V characteristics curves, output power and electrical efficiency) of the photovoltaic cell with fixed and double axial tracking.

The comparison shows a normal accordance between the simulation and the experimental results. In addition, the paper presents a double axial tracking system where it is possible to enhance the electrical conversion efficiency of the system with acceptable power consumption. From the reported results, the following conclusions were drawn:

For fixed system the electrical efficiency from the simulated results, **η**, reaches 6.1 %, with a fill factor FF = 0.53, open circuit voltage Voc= 20.38 V and the short circuit current Isc = 6.3 A. For experimental results,**η**, **i**s 5.9 %, the FF= 0.45, Voc = 18.38 V, and Isc = 5.8 A.

In the tracking system the electrical efficiency **η** reaches 7.1 %, with a fill factor FF = 0.73, the open circuit voltage Voc= 23.38 V, and the short circuit current I_{sc} = 7.3 A. For experimental results,**η**, **i**s 6.9 %, the FF= 0.69, V_{oc} = 22.18 V, and I_{sc} = 6.9 A. There is an enhancement of about 2.1% in the maximum electrical efficiency when using the tracking system. When using the tracking system there is about 7% enhancement of the power for both simulation and experimental results at the maximum sun irradiance at 12:00 pm.

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