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Investigating Of Proper Photovoltaic Panel Tilt Angle to Be Used As Shading Device in Kuwait

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ABSTRACT
Photovoltaic panels can act as power generator as well as external shading devices with proper tilt angle. In this paper we will study the performance of a Silicon Photovoltaic system with different tilt angle arrangement in Kuwait (latitude 30˚ N). In the study the PV system is installed facing south to collectmaximum solar radiation at noon. The angle is varied from 0^0 to 90^0, during full year at the Solstice (the time at which the day and night come into balance) and Equinox (the end of the day's increase or decrease in day night hours) periods, to achieve optimum tilt angle, higher in magnitude than 30^0 with competitive output power. The results show that the performance and the output power of the PV system with 50˚ tilt angle, is equivalent to the corresponding values at tilt angle equal to Kuwait latitude (30˚) during the whole year.
Keywords: Photovoltaic model, Tilt angle, solar collector, PV system performance, shading, Kuwait.

I. INTRODUCTION

The revolution against generating electrical power using fossil fuel which release hazardous pollutants into the environment, converted the attention towards clean energy devices. The photovoltaic (PV) systems industry improved the efficiency of the model fabrication; while their production cast reduced contributed to the expansion of PV systems globally [1].Photovoltaic (PV) technologies have turned PV applications into one of the most interesting energy alternatives, especially in areas of high quality solar potential [2]. In this context, Kuwaiti governmentshowed noticeable interest during recent years in the Arabian Gulf region as will. According to a German aerospace Center study, Kuwait has among the highest performance indicators in terms of its Direct Normal Irradiance (DNI) - suitable for Concentrating Solar Power- and an equally high Global Horizontal Irradiance (GHI) - useful for photovoltaic systems; these amounts are between 2,100KWh/m^2/year and 1,900 KWh/m^2/year [3]. Building integrated photovoltaic (BIPV) is a PV application close to being capable of delivering electricity at less than the cost of grid electricity to end users in certain peak demand niche market [4]. One important advantage of BIPV systems is that PV models can replace conventional building materials, which lowers the net cost of BIPV systems. PV models besides providing fully integrated electricity generation, serves as part of weather protective building envelope. With a proper BIPV system design, the coolingload can be eliminated, which causes cooling energy consumption reduction leading to total electricity saving.

Using photovoltaic system to reduce the electricity consumption in residential area was explored by a study, which confirmed that a combination of high percentage of sunshine hours and high level of isolation provides a good condition for generating electricity by the PV system in Kuwait. Result of 25 sampled houses, PV panels was installed to generate electricity came out as Presented in Figure 1.

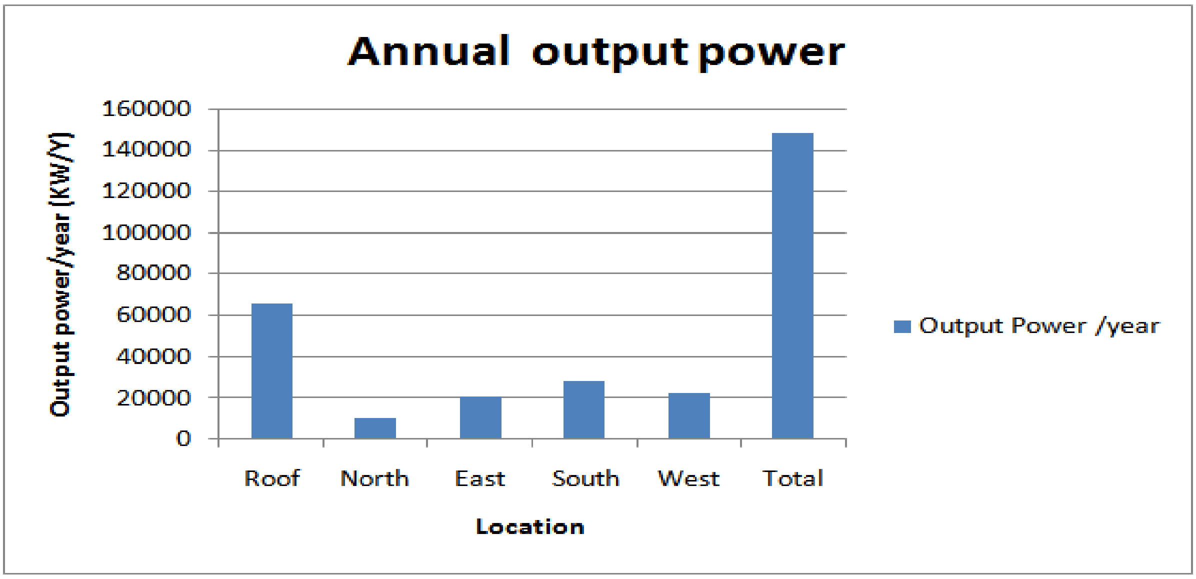
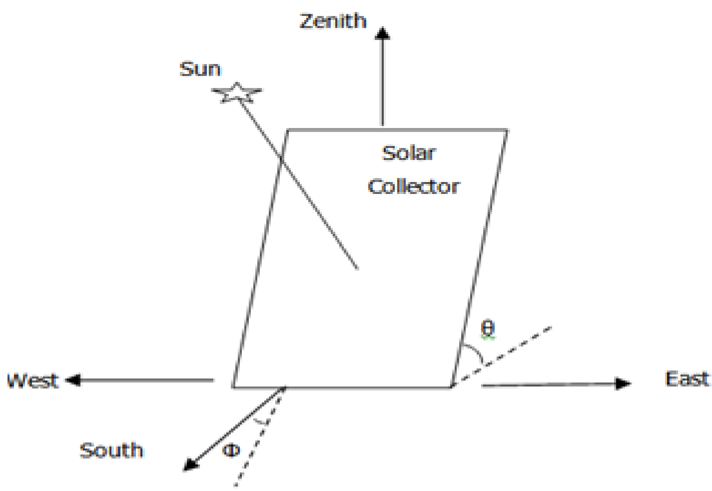


Figure1. Annual output power versus location (side) for sampled house

The result obtained demonstrates the feasibility of green and energy exporting architecture in Kuwait. If only PV panels located on the roof were used for example, as shading envelope with appropriate tilt angles, it is found that the power generated from the roof PV panels can provide 50% of power needed for 52% of the sampled houses. This result confirms the fact that the potential of energy saving will be bigger when BIPV systems are used, as it definitely mitigate at least 25% of the power consumption in the residential area [5]. For the purpose of using PV panels in shading, experimental investigation of the subject was held for two years period. In this context, emphasis is given on examining the effect of varying the panel tilt angle from zero degree to ninety degree searching for the best output power within a tilt angle higher in magnitude than 30° (latitude tilt angle) that can be used in shading.

II. THEORETICAL ANALYSIS

The energy generated of a PV system depends on many factors, such as sun intensity, power conversion efficiency, system location, panel instillation azimuth, tilt angle, weather conditions and so on[3] as shown in Figure 2.The tilt angle indicates how far up from the horizontal a slanted, while the azimuth angle denotes the direction of a celestial object measured clockwise around the observer's horizon from north. So an object due north has an azimuth of 0˚, one due east 90˚, south 180˚ and west 270˚



Θ = Surface tilt angle
Φ = surface azimuth angle

Figure2. Geometry of solar collector

It is known that the yearly optimum tilt angle of panel PV models to collect the maximum yearly incident solar energy is equal to the local latitude. In some applications, it may be difficult to install the PV panel with its optimum tilt angle due to the nature of application or the site in which the application will be used [6].

A number of solar cells basically a p-n diode that converts light energy into electrical energy are connected together in a series and/or parallel. An equivalent-circuit model of a solar cell is shown in Figure3.

The photocurrent I_{ph} generated in the PV cell is proportional to the radiation collected by the cell. The current through the bypass diode I_d varies with the junction voltage V_t and the array reverse saturation current I_o. The parallel resistance R_p is very large; where the series resistance R_s is very small. The diode current I_d, the photo-induced current I_{ph} and the output current I of a single cell can be expressed mathematically as follows: [7]

I
R_S

I_d I_{sh}
I_{ph}
R_P V RL
-

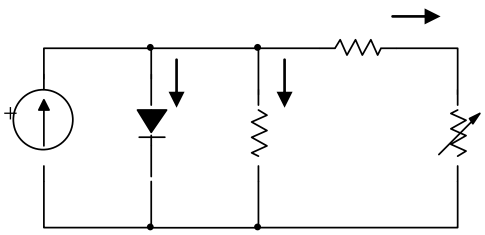


Figure3. PV-cell equivalent circuit

$$I_d = n_p I_o \left[\exp\left\{ k_o \left(\frac{v}{n_s} + IR_s \right) \right\} - 1 \right] \tag{1}$$

$$I_{ph} = \{ I_{scr} + k_i (T - T_r) \} \frac{G}{G_r} \tag{2}$$

$$I_{sh} = \frac{\left(\frac{v}{n_s} + IR_s \right)}{R_p} \tag{3}$$

$$I = I_{ph} - I_d - I_{sh} \tag{4}$$

The references are respectively: n_p is the parallel number of solar-cell panels, n_s the series number of solar-cell panels, I_o the reverse saturation current, R_s the intrinsic resistance of solar array, I_{sh} the (shunt) current of solar-cell panels, k_o the constant coefficient, k_i the short-circuit-current temperature coefficient (=0.0017 A/K), I_{scr} the short-circuit-current of ambience, T the PV-module temperature in (K), T_r the ambient temperature in (K), G the solar irradiation in (W/m^2), G_r reference irradiation (1000 W/m^2).

The output power of a PV module is the product of output current I and terminal voltage V;

$$P = VI = V\left(I_{ph} - I_d - I_{sh} \right) \tag{5}$$

$$P = V \left[n_p \{ I_{scr} + k_i (T - T_r) \} \frac{G}{G_r} - n_p I_o \left[\exp\left\{ k_o \left(\frac{v}{n_s} + IR_s \right) \right\} - 1 \right] - \frac{\left(\frac{v}{n_s} + IR_s \right)}{R_p} \right] \tag{6}$$

III. EXPERIMENTAL SETUP AND PROCEDURE OF THE EXPERIMENT

3.1. Description of the experimental setup

Measurements were conducted through two years period, on the roof ofDepartment of Electronics Engineering Technology, College of Technological studies, Public Authority for Applied Education and Training, Shuwikh, Kuwait. The exact location is determined by the geographical coordination of 29° 22' 11" N and 47° 58' 42"E.Figure 4demonstrates the quality of local solar potential through a year at horizontal plane in Kuwait. The level of solar potential during months June and July are lower than it should be due to the dust phase in the area.

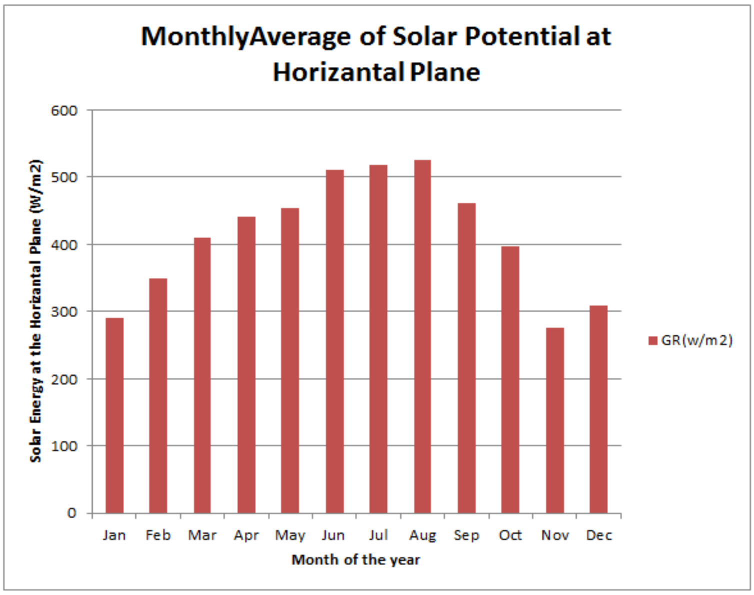


Figure4. Solar potential of Kuwait based on one year solar irradiance measurements

Two monocrystalline PV modules (Model SM55, Siemens) with a rating 55 W maximum power, were used for the experiment. Table 1 shows the electrical parameters for the PV module.
Measurements included current (I), voltage (V), irradiation (G), ambient temperature (T), taken by connecting the system to a data acquisition system (Data traker, DT80) and digital Multimeter (Agilent, model 34405A). Figure.5 illustrates the schematic diagram of the measuring setup.

Table 1
Typical electrical parameters for experimental PV module

Maximum power rating P_{max}	(W)	55
Maximum power current I_{MPP}	(A)	3.15
Maximum power voltage V_{MPP}	(V)	17.4
Short circuit current I_{SC}	(A)	3.45
Open circuit voltage V_{OC}	(V)	21.7
Short circuit temp coefficient	(mA /˚C)	1.2
Open circuit voltage coefficient	(V /˚ C)	- 0.77

Standard test conditions (defined as: irradiation = 1000 W/ m^2; cell temperature = 25˚C; air mass =1.5)

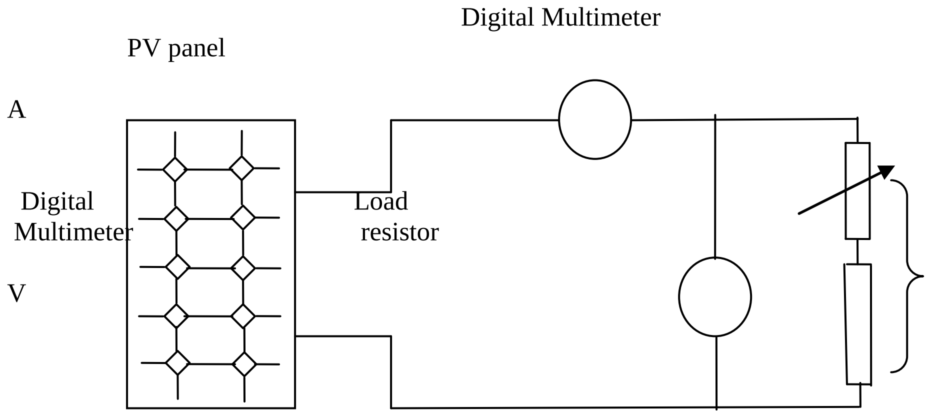


Figure5. Schematic circuit diagram of PV module measurement system

3.2. Description of the experimental procedure

The main concept of the experimental procedure is to compare between the output powers of a PV panel at different tilt angles on a real time basis, during one year. One PV panel was used, and mounted on a frame enables it to rotate 90° from horizontal by 10° step, facing south. Continuous measurements were carried out at noon by varying the tilt angle from 0° (horizontal plane) to 90° (vertical plane) by steps of 10° at the time of the two solstices and the two equinoxes of one year.In the second year two PV panels were used each mounted at a fixed frame, one was tilted at 30°, and the other tilted at 50° from horizontal, facing South. Continuous measurements were carried out during the day from 6 AM to 6 PM with a time interval of one hour. All the data collected were synchronized for data processing.

IV. EXPERIMENTAL RESULTS

4.1. Seasonal optimum tilt angle

The course of a full calendar year was investigated; by examining the effect of tilt angle on maximum total radiation received by a surface of a photovoltaic panel facing South at noon. Figure 6 shows the effect of tilt angle from 0° to 90° from horizontal on PV output power.

Comparing between the output power curves, it is determined that the maximum output power on south facing surface at solar noon can be obtained with the tilt angles of 30˚, 40˚and 50˚at March Equinox (vernal), with the sun elevation of 60˚; 0˚, 10˚ and 20˚ at June, Solstice (northern), with the sun elevation of 84˚from horizontal; with 30˚, 40˚ and 50˚at September, Equinox (autumnal), with the sun elevation of 60˚ from horizontal; 40˚ and 50˚ at December Solstice(winter), with the sun elevation of 36˚ from horizontal.

It is noticed that PV output at tilt angle of 50° is considerably good compared to reference case which is guided corresponding to 30° tilt angle. That led us to continue our measurement for the second year utilizing tilt angle of 50°.

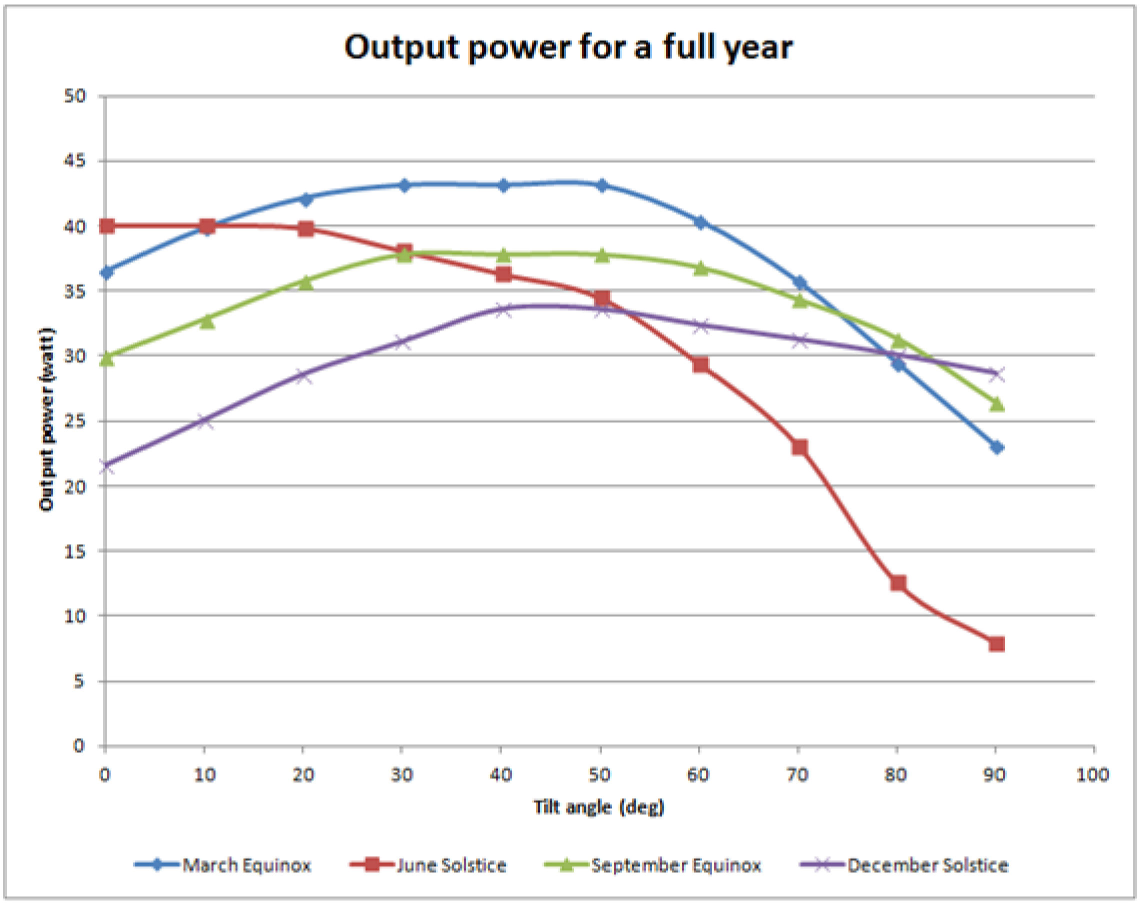
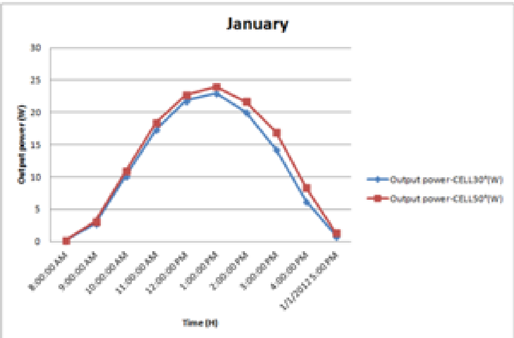


Figure6.Output power versus tilt angle for a full year of a PV panel

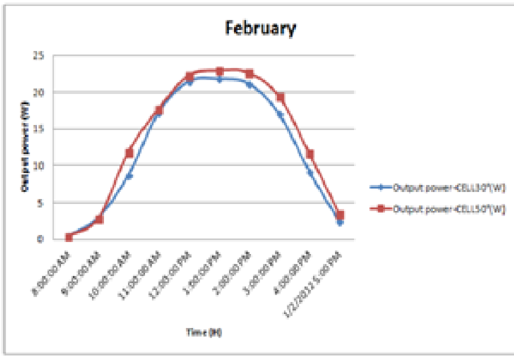
4.2 Comparison between two tilt angles

Second year measurements are carried out to compare between PV output corresponding to tilt angles 30° and 50° which supported to receive maximum radiation on its surface facing South at noon. Looking into the output power curves of Figure 7(a to l), it is determined that the 30˚ tilt angle exceeds in collecting radiation during April, May, June, July and August; as for the 50˚tilt it is superior in January, February, October,November and December.March and September have the same effect on collecting radiation.

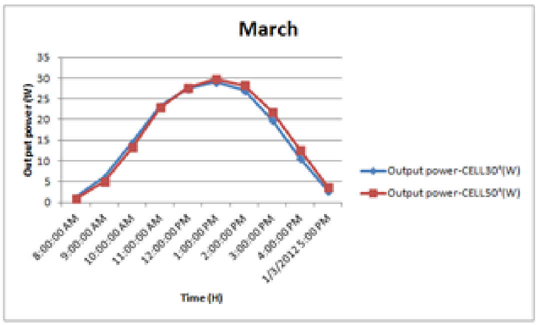
Results let us conclude that PV output is superior at tilt angle 30° for the months April, May, June, July, and August. On the other hand PV output for 50° tilt angle is dominant for the months January, February, October, November, and December.

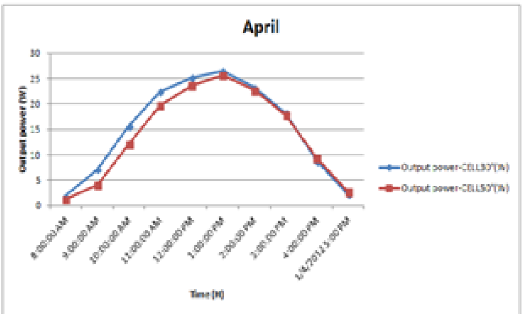


(a)

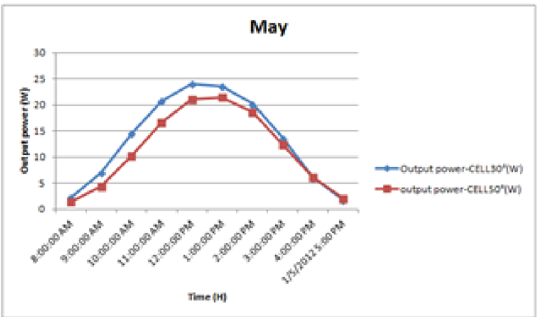


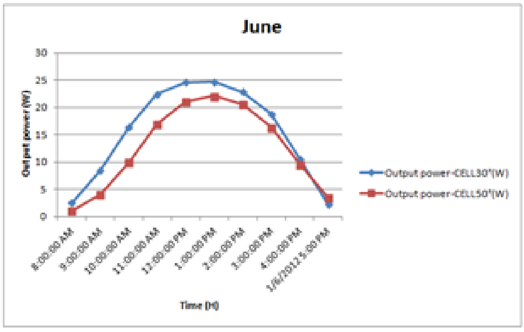
(b)





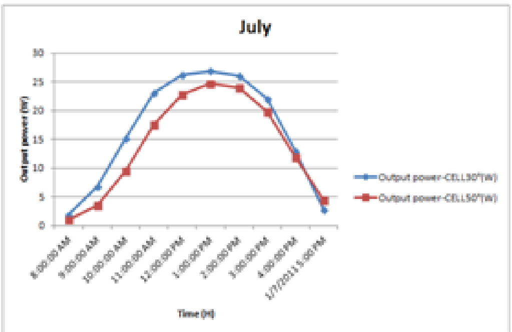
(c) (d)

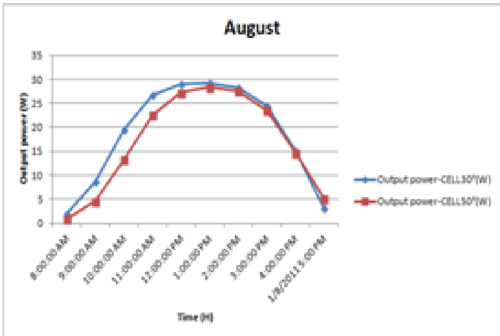




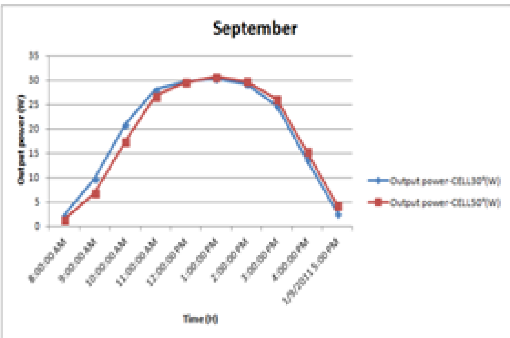
(e) (f)

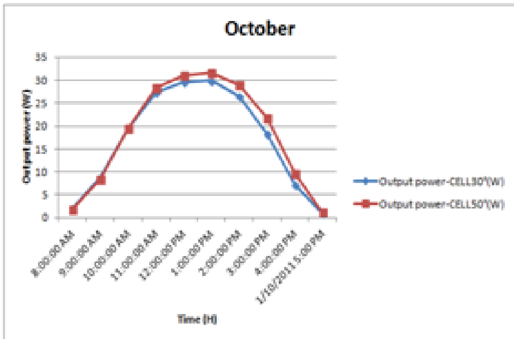
It is determined from that, the 50° tilt angle can replace the 30° tilt angle without any considerable loss of output power.



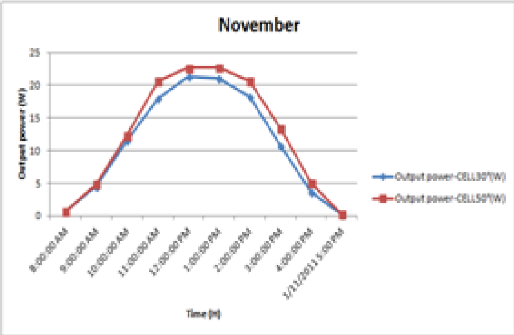


(g) (h)

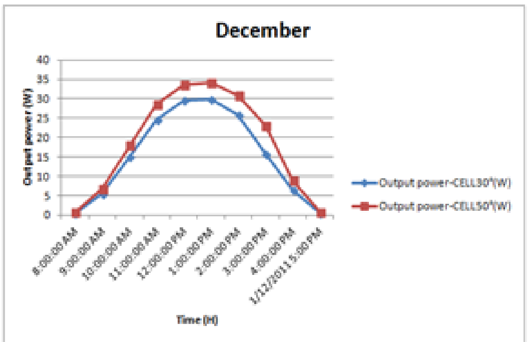




(i) (j)



(k)



(l)

Figure 7. Comparesion of output power for a PV panel tilted at 30° and 50° for a full year

V. CONCLUSIONS

Accordingly, based on the use of Eqs (2) and (6) the maximum output power of PV panel when the sun is perpendicular to the solar panel, that means when the ratio of $G/G_r \approx 1$; practically it is the latitude of the country, in Kuwait it is 30˚N. The sun changes position during the year from 36˚ in December to 84˚ in June in Kuwait, causing an output power change sufficient, but not optimum. Based on current measurements we can conclude that PV modules at tilt angle 50° can give comparable power to the one at tilt angle equal to latitude.

The impact of setting the tilt angle to 50˚ plays a significant role inmaximizing the benefits of a PV panel in saving energy besides generating it, practically the PV panel has significant effect on cooling and load reduction if used as follows:

1- Shading roofs of buildings.
2- Shading windows.
3- Shading car parking roofs.
4- Shading water tank reservoir.

VI. ACKNOWLEDGMENTS

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