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Solar Photovoltaic Trends and Challenges in Kuwait

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Abstract— **The main aim of this paper is to create a model of solar photovoltaic (PV) cell through which the performance of representative solar PV panels tested in specific points of Kuwait is evaluated. This electrical model that describes accurately a solar PV cell is mainly built from the simple junction diode equations. Therefore, the electrical model includes the photo-current as a current source, one single diode junction, and a series resistance as parameters of the model. Moreover, temperature variation as well as solar radiation are two parameters by which its dependencies have been studied.**

This typical model is generated through MATLAB/Simulink® and is then used to test the effect of varying temperature and solar radiation on maximum power generated. Finally the model has been experimentally validated for a typical 30 Watt solar module in connection to an electronically variable load (MOSFET).

Index Terms— **solar radiation, performance, irradiance, experimental validation, I-V curve, maximum power point, Kuwait.**

I. INTRODUCTION

Globally, there have been common problems facing power generation, three of which are the continuously rising oil prices affected by amount of production, environmental risks caused by pollution due to gas emissions, and finally lack of resources due to the depletion of conventional fossil fuel energy resources. As a consequence, the light is getting more focused on friendly energy production such as solar energy and wind energy. These types of energy production and especially the solar energy is attracting industry all over the world and especially the Gulf region that is exposed to sun in the majority of the days all over a year.

In a study done by the World Energy Council, it has been exposed that over the coming ten years, the Gulf Cooperation Council (GCC) is expected to consume an amount of 100 GW in addition to what it consumes now. The same resource mentions that this increase in consumption will cost the GCC around $ 25 billion [1].

The GCC countries are not only naturally gifted by the existence of oil and natural gas, but also with the maximum exposure to sunlight. A regional expert reports that the usual Direct Natural Exposure (DNE) in the Gulf region is about 1800 KW/h every square meter [2]. Therefore, solar energy production is technically feasible in the GCC. Table 1 shows values related to the average solar radiation for solar PV applications that range between 5.1 and 7.0 kWh/m2/day respectively. For solar rough concentrators, direct solar radiation ranges between 5.6 and 6.5kWh/m2/day [3]. In fact, GCC countries are known to be exposed to direct sunlight as well as reduced percentage of clouds and to have very good solar energy potential throughout the year [4].

Table 2 shows the annual and per capita electricity consumption in the GCC for the year 2009 [5]. As clearly demonstrated, Saudi Arabia occupies the first place in term of highest energy consumption among other GCC countries. Moreover, Kuwait numbers reflect the highest GCC per capita energy consumption. In addition, three countries of the GCC have the highest per capita energy consumption around the world. Overall, GCC countries show up to be the main contributors of CO_2 gas emissions by producing between 45% to 50% of the emissions of the entire Arab world. [6].

In addition, this massive energy consumption in GCC regions comes in its majority from residential sector that occupies 47% of the total consumption. As reported in year 2008, this is about twice the worldwide average of 25% [7]. Accordingly, the use of distributed and residential solar PV systems will be an excellent substitute for traditional residential energy production. Moreover, this substitute will be able to reduce transmission and distribution losses. Many solar PV projects are already designed and planned in the GCC area. Lately, Dubai has launched plans to construct 48 km2 solar PV compounds in a plan that comes in two phases and to be executed over the coming 20 years. The 1 GW-facility will consist of both solar PV and concentrated solar thermal energy and it is estimated to cost Dubai government a total of $3.25 billion [8] and will make Dubai as one of the world’s greenest metropolitan areas.

In order that each GCC country meets the equivalent of 20% of its energy consumption using solar PV systems, it has to build equivalent facilities over a land space area in km2 displayed in the fourth column of Table 2, assuming that the solar energy conversion efficiency is 10%.

Sections 2 and 3 of this paper deal with the solar cell modeling using MATLAB/Simulink® followed by the solar cell model simulation. Section 4 includes the process of modeling a typical 60 W solar panel performance as a function of ambient temperature and solar radiation. In Section 5, demonstrates the experimental validation of the proposed model that is conducted for a 30W GE high efficiency solar module. Concluding remarks and future work recommendations are proposed at the end of this paper.

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Table 1. Annual average GCC solar PV resources.

Country	Global Solar Radiation (kWh/m²/day)	Direct Solar Radiation (kWh/m²/day)
Bahrain	6.4	6.5
Kuwait	6.2	6.5
Oman	5.1	6.2
Qatar	5.5	5.6
Saudi Arabia	7.0	6.5
United Arab Emirates	6.5	6.0

Table 2. Annual energy consumption and land requirement for solar PV installations for the GCC countries.

Country	Electric energy consumption (GWh)	Per capita electric energy consumption (kWh)	Land (km²) #1
Bahrain	10,763	9,214	9.215
Kuwait	42,802	17,610	37.828
Oman	12,198	5,724	13.106
Qatar	18,074	14,421	18.006
Saudi Arabia	174,845	6,856	136.865
United Arab Emirates	79,544	11,464	67.055

#1 Solar PV efficiency = 10%.

II. SOLAR PV CELL MODELING

A typical PV cell consists of a silicon P-N junction that releases electrons around a closed electrical circuit at the time it is exposed to light. The equivalent circuit of the PV cell is shown in Fig. 1 [9], with its parameters defined as follows:

- I_L is the photo current generated from the PV cell and is dependent on the solar radiation (G).
- I is the PV cell output current.
- I_d is the bypass diode current and is dependent on the junction voltage and the cell reverse saturation current (Io).
- V is the PV cell output voltage.
- R_{sh} is the shunt resistance with a large ohm value.
- R_s is the series resistance and it has a small value.

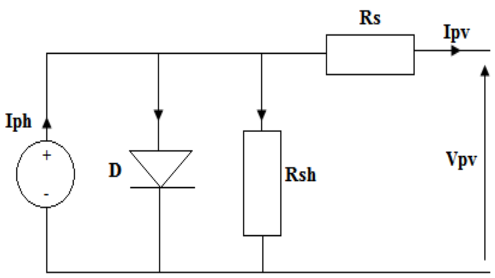


Figure 1. Solar PV cell equivalent circuit.

The below equations represent the relationships among the above parameters that define the solar cell model:

$$I_{oT_1} = I_{SC}(T_1)e^{(-\frac{qV_{oc}(T1)}{nkT_1}+1)} \qquad (1)$$

$$I_o = I_{oT_1}(\frac{T}{T_1})^{3/n} e^{\frac{-qV_g}{nk}(\frac{1}{T}-\frac{1}{T_1})} \qquad (2)$$

$$I_L(T_1) = I_{SC}(T_{1,nom})\frac{G}{G_{nom}} \qquad (3)$$

$$I_L = I_L(T_1)(1+K_o(T-T_1)) \qquad (4)$$

$$I = I_L - I_o(e^{(\frac{q(V+IR_S)}{nKT})}-1) - \frac{(V+IR_S)}{R_{sh}} \qquad (5)$$

Where

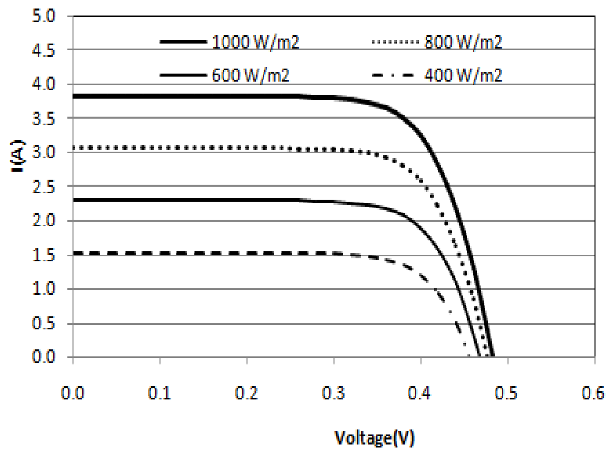
- n is the diode quality factor.
- K_o is the temperature coefficient of the short circuit current.
- T_1 is the reference temperature.
- T is the climate temperature.
- V_g is band gap energy.
- k is the Boltzmann's constant. $k = 1.3806488 \times 10\text{-}^{23}$ m² kg s-² K⁻¹
- q is the electron charge. $q = 1.60217657 \times 10^{-19}$ coulombs
- V_{oc} is the open circuit voltage per cell.
- I_{SC} is the short circuit current per cell.
- G is the ambient radiation. G=1 for 1000 W/m².

III. SOLAR PV CELL MODEL VALIDATION

The effects of ambient temperature, solar radiation, series resistance, shunt resistance and diode reverse saturation current on the solar cell performance are tested in order to validate the solar PV cell model. For these various tests, a MATLAB/Simulink® based model is developed. The model was tested and the results are shown in Figures 2, 3, 4 and 5 respectively. The results are discussed in the following sections.

A. *Effects of Solar Radiation*

The effect of the solar radiation on the solar cell voltage, current, and maximum power point is shown in Fig 2. As projected clearly in this figure, the amount of power delivered from the solar cell increases as the radiation level increases. This happens because as the solar cell is exposed to more radiation, both the voltage and the current in the solar cell increase.



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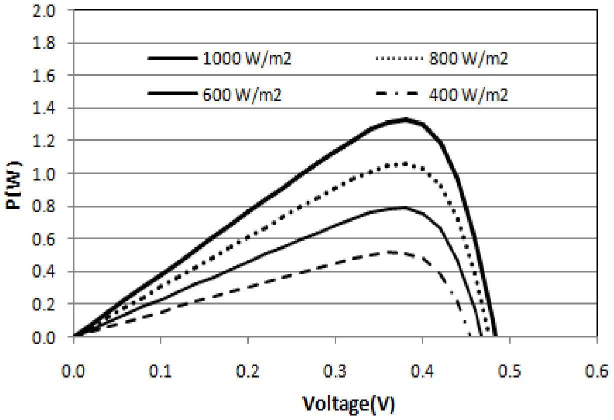
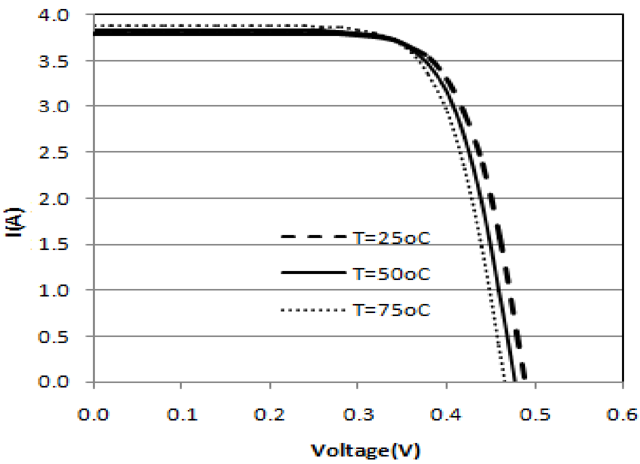


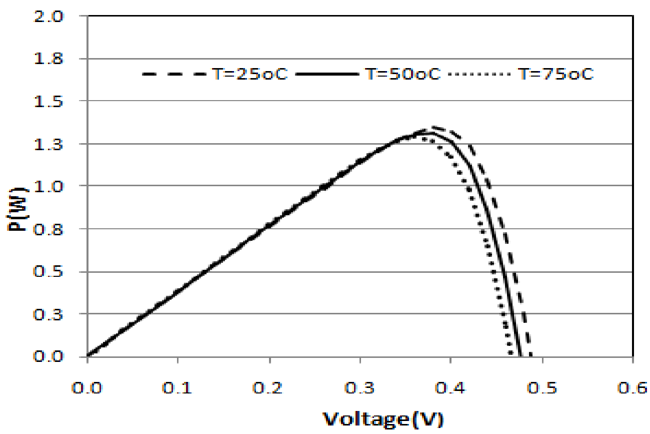
(b)

Figure 2. Effects of the solar radiation on the PV current (a) and the PV power (b).

B. *Effects of Temperature*

The influence of the ambient temperature on the current and maximum power output are shown in Fig 3. The graph shows clearly that the increase in the short circuit current and decrease in the open voltage due to temperature rise result in an overall lower power output.





(a)

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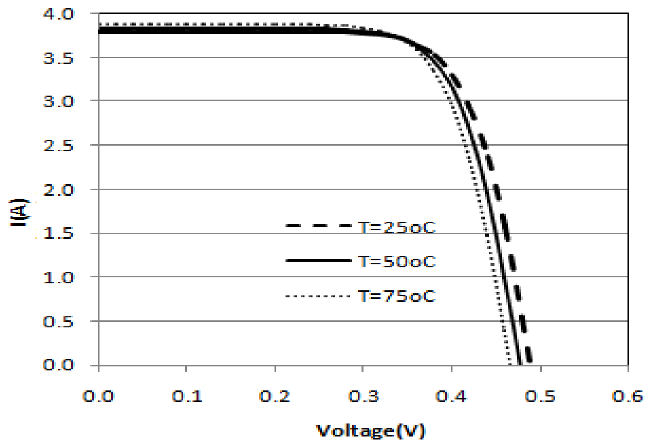
Figure 2. Effects of the solar radiation on the PV current (a) and the PV power (b).

C. *Effects of Temperature*

The influence of the ambient temperature on the current and maximum power output are shown in Fig 3. The graph shows clearly that the increase in the short circuit current and decrease in the open voltage due to temperature rise result in an overall lower power output.



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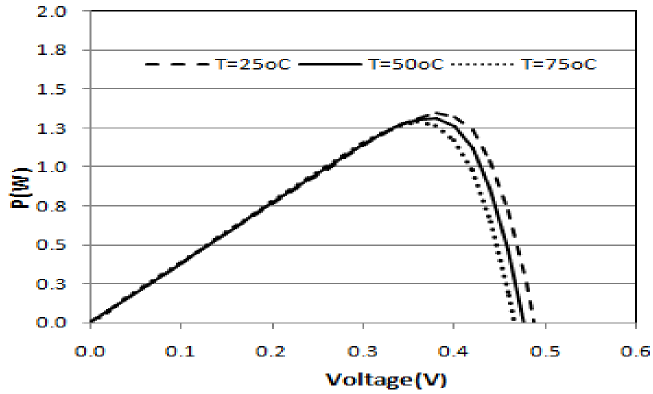
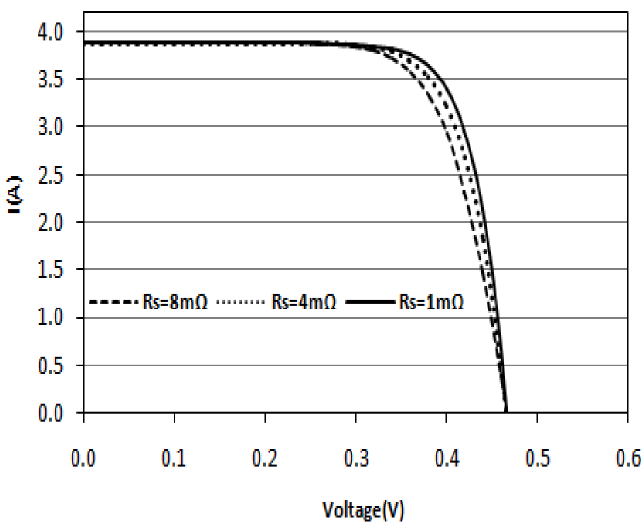


(b)

Figure 3. Effects of the ambient temperature on the current (a) and the power output (b).

D. *Effects of Series Resistance*

The effect of the series resistance R_S on the power performance is shown in Fig. 4. As the value of the series resistance is reduced, this leads to an increase in the power output and the maximum power point as well.



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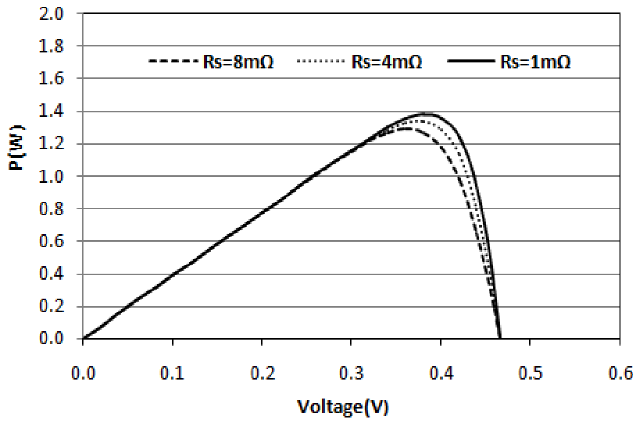

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Figure 4. Effects of the series resistance on the current (a) and the power output (b).

E. Effects of Diode Saturation Current

As seen in Fig 5, reducing the diode saturation current will definitely lead to a higher open circuit voltage and a shift in the maximum power point.

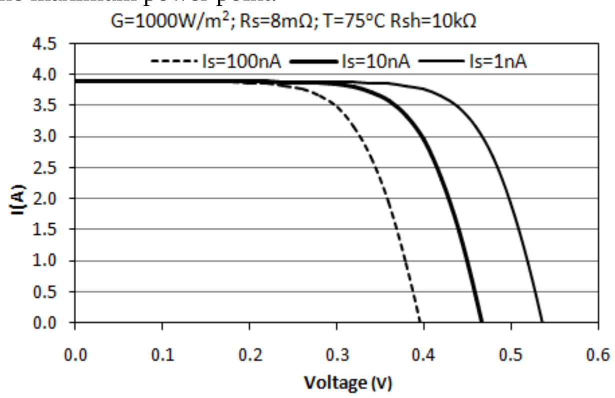
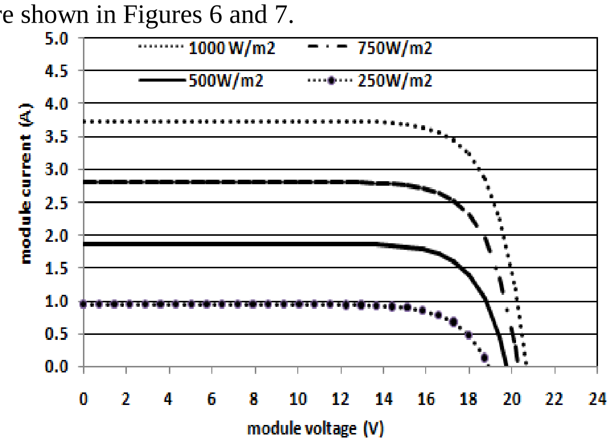


Figure 5. Effects of the diode reverse saturation current on the PV cell output voltage and current.

The results shown in Figures 2, 3, 4 and 5 typically agree with the PV cell characteristics [10].

IV. PV MODULE MATLAB MODEL

The Solarex MSX60 is a typical 60W-PV module. It consists of 36 polycrystalline cells connected in series. Its characteristics are demonstrated in Table 3. Based on these parameters, the MATLAB/Simulink® model was developed and assessed for different solar radiations and ambient temperature values using Solarex MSX60 module. The results are shown in Figures 6 and 7.



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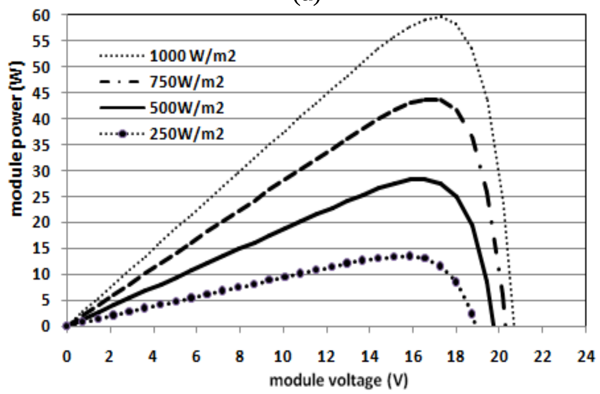

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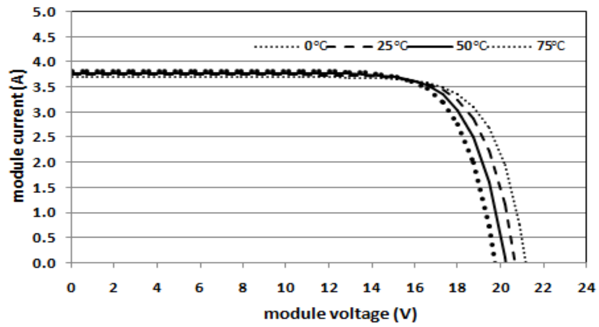
Figure 6. Effects of solar radiation on the current (a) and the power output (b) of Solarex MSX60.



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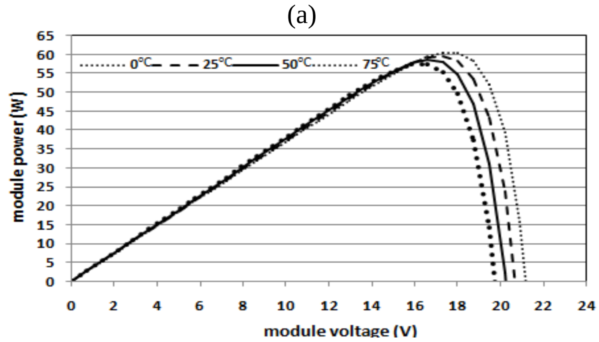

(b)

Figure 7. Effects of the solar radiation on the current (a) and the power output (b) of Solarex MSX60.

Table 3. The key specifications for the Solarex MSX60 PV panel [9]

Temperature	T	25°C
Open circuit voltage	V_{OC}	21.00 V
Short circuit current	I_{SC}	3.74 A
Voltage at maximum power	V_M	17.10 V
Current at maximum power	I_M	3.50 A
Maximum power	P_M	59.90 W

V. EXPERIMENTAL VALDATION OF THE PROPOSED MATLAB/SIMULINK® MODEL

It is known that sun radiation as well as temperature is the main contributors in the performance of a given solar PV system. Other parameters such as wind speed, humidity, and dust accumulation do affect the performance; however, not included in the study. To practically validate the developed Simulink® model, a 30-Watt GE high efficiency monocrystalline PV solar module was put under test and the results obtained were subject to comparison with the simulation results obtained from Simulink®. In the experimental setup, a variable DC load ranging from 0 to 300Ω was connected at the output of the solar module. Hence, the effect of temperature, solar radiation, voltage, and current are studied throughout the experiment. The results for the IV and PV curves are displayed in Figures 8 and 9, respectively. The discrete data points indicate the experimental values and show excellent agreement with model shown in solid line.

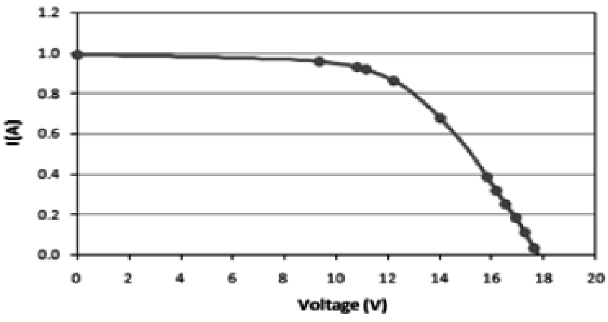

Figure 8. The GE 30 Watt module IV curve. The discrete data points indicate the experimental values

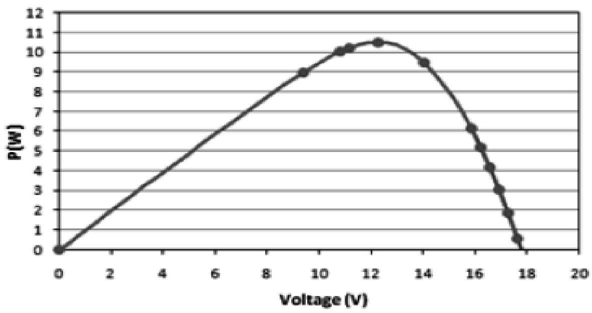

Figure 9. The GE 30 Watt module PV curve. The discrete data points indicate the experimental values

VI. Conclusion

In this paper, typical models for solar photovoltaic cell and module have been developed, demonstrated, and analyzed experimentally for different weather conditions and electronic main parameters. Moreover, the models have been validated by constructing the characteristic curves under different scenarios and the results have been compared to the solar cell and module main characteristics given in the Solarex MSX60 and GE 30 Watt modules' specification sheets.

The main recommendations in the future are to develop a complete model to simulate the electrical behavior of a PV array and subsequently an entire PV system which is very interesting in terms of smart grid integration. This complete model can include all different factors that have been not included due to the limitations in this study.

References

[1] W. E. Alnaser and N. W. Alnaser, "Solar and wind energy potential in GCC countries and some related projects", *J. Renewable Sustainable Energy* 1, 022301 (2009); doi: 10.1063/1.3076058.

[2] R.A. Raouf, "Climate Change Threats ,Opportunities, and the GCC Countries," *The Middle East Institute"* Policy Brief No. 12, April 2008.

[3] Danyel Reiche,"Energy Policies of Gulf Cooperation Council (GCC) countries-possibilities and limitations of ecological modernization in rentier states", *Journal of Energy Policy* (May 2010), pp 2395-2403.

[4] B. Al-Yousafy and A. Alkorah, "Environmental and Economic Feasibility of Renewable Energy in the Arab Region," *Dar Alhayat*, March 5, 2007.

[5] World Development Indicators (CD-ROM), IBRD, World Bank, Washington, DC 2010.

[6] Mohammed Redha Qader, "Electricity Consumption and GHG Emissions in GCC Countries", *Energies 2009*, 2, 1201-1213; doi:10.3390/en20401201

[7] Deloitte: "Middle East Energy and Resources Managing Scarcity for the Future - Energy on Demand-The Future of GCC Energy Efficiency", Nov. 3rd, 2011.

[8] http://www.pv-magazine.com/news/details beitrag/ uae--1-gw-solar-project-launched_100005433/, accessed January 12, 2012.

[9] G. Walker, "Evaluating MPPT converter topologies using a Matlab PV model", *Journal of Electrical & Electronics Engineering*, Australia, Vol.21, No. 1. (2001), pp. 49-56.

[10] JA. Ramos Hernanz, J.J. Campayo Martín, I. Zamora Belver, J. Larrañaga Lesaka, E. Zulueta Guerrero, and E. Puelles Pérez," Modelling of Photovoltaic Module", *International Conference on Renewable Energies and Power Quality (ICREPQ'10),* Granada, Spain, March 23-25, 2010.

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