International Journal of Computing and Digital Systems
ISSN (2210-142X)
Int. J. Com. Dig. Sys. 8, No.2 (Mar-2019)

http://dx.doi.org/10.12785/ijcds/080204

Novel PV Panels Design Modeling to Support Smart Cities

Isa S. Qamber [1] and Mohamed Y. AL-Hamad [2]

[1] Dept. Electrical & Electronics Engineering, University of Bahrain, Isa Town, Bahrain
[2] Power Trade Senior Executive Market Operations, GCC Interconnection Authority, Dammam, K.S.A

Received 6 Oct. 2018, Revised 13 Nov. 2018, Accepted 7 Feb. 2019, Published 1 Mar. 2019

Abstract: Nowadays Photovoltaic (PV) became the new competitive energy resource. Therefore, it needs to be connected to the grid to reduce the demand from the authority, which means the flow of the load will be reduced. The production of the electricity as a solar energy will increase in the locations where the sun intensity is concentrated. The good location for solar energy is the six Gulf Cooperation Council (GCC) countries. These are six Middle Eastern countries; Kingdom of Saudi Arabia, Kuwait, the United Arab Emirates, Qatar, Kingdom of Bahrain, and Oman with high intensity of the solar radiation. The GCC countries have a good location for the solar energy Photovoltaic (PV) became the new competitive energy resource of the planet and it can be engaged in both Distribution and Transmission systems. In the present study, deriving the model's design of solar cell in five countries with the same house specifications. The Panel Generation Factor (PGF) considered satisfying the specification of the cells, which depends on the climate. This means that renewable energy provides many benefits for our climate, health and our economy. For the five countries the total (kWp) of PV panel capacity, number of PV panels needed for the design of 110 Wp PV module and Solar Charge Controller Rating are calculated based on PGF of each country.

Keywords: PGF, PV, Models, Solar Energy.

1. INTRODUCTION

The PV system converts sunlight directly into electricity [1]. Nowadays the house owners, as well as the industry, think about a way to generate their own electricity. To reach this aim, the house owners use their own roof to get part(s) of their electricity, which is generated by PV panels. This needs the house to be connected directly to the electric utility to satisfy the rest of the required demand for electricity. This means that the shortage of electricity required for the house can be obtained from the utility. At this stage, marketing solar power systems to the residential market are advisable for the present days [1]. There are two different types of PV electrical systems, the first type is the system that interacts with the utility power grid which has no battery. This type cannot operate without utility existence. At the same time, this system contributes the most with regards to bill saving. The second type is the system which interacts and includes a battery backup as well. This system is operating when energy outage occurs. This means that in this case the circuit is disconnected from the utility. It is clear that power is available at home, but it is limited. It should be known that the sunlight intensity on the surface varies throughout the day, as well as from day to day.

Albadi et al [2] addressed in their study the issue of PV systems in the electric distribution network. Their issue in the study to minimize the losses in the system. Their study considered Masirah Island distribution system in Oman. In the present study, the comparison between Bahrain and UK is considered and compared. In their study [2], the losses represent 2.1% of the total load. The authors highlight in their study that renewable-based distributed generation units they have considered are small. In their study, the modeling and simulation they have carried by using MATLAB. Optimizing size and location in their study concentrate on using Particle Swarm Optimization and Genetic Algorithm. In the present study, the Excel Sheets are used after finding the suitable formulas and Curve Fitting is used after obtaining the results of the countries considered to formulate the model which can be used for any other countries.

The study carried out by Alboaouh [3] proposed a control scheme to optimize PV output power. It utilizes the capabilities of the smart inverters. The PV utilizes

E-mail: iqamber@uob.edu.bh, mhamad@gccia.com.sa

power during the peak periods of the day. The researcher model takes into account the uncertainty associated with irradiance and load demand. The proposed model is tested on the IEEE123 bus system. The PV panels added to the IEEE123 bus system. During the peak load, the PV-control scheme minimizes the curtailments of the active power. In the study [3] the peak period refers to the period whenever the load demand is low and at the same time, the active power injected by the Photovoltaic is high. Regarding the customers who need a large amount of active power categorized as rich people and they need to install PV panels to reduce their electric bills.

George et al [4] in their study present a general methodology for assessing opportunities associated with optimal load management. The study methodology was carried out on an American house built in the year 1990s and equipped with a single-speed air-to-air heat pump, an electric water heater and PV collector [4]. The optimal size of PV was carried out in the study. The proposed method is general for assessing opportunities associated with optimal load management. The proposed billing mechanism [4] promote the integration of renewable energy sources taking into consideration an agreement between the utility and the consumers.

Hosseini et al [5] in their study concentrated on reliability improvement and cost reduction. To carry on the study and to satisfy that the index of the expected cost of interruption and the optimal operation mode of Distributed Generation (DG) resources. In their study, they used Monte Carlo simulation to obtain the model network component and a seven-state Markov model. The final results show that the total operation cost was reduced.

Marchena et al [6] in their study, monitoring and assessing small and medium solar energy plants. In their study, they formed a framework that allows the development of programs for automatic evaluation and monitoring the solar energy plants. The software used helps several solar energy plants built with different technologies. The proposed framework allows the different types of assessment for different models. The proposed framework is applied to 40 PV solar energy installations. The proposed methodology helps in classifying the problems that happened during the operation of both small and medium power PV plants.

Wurster and Schubert [7] in their study investigating the effects of current mismatch and shading on the power output of single PV modules. Two models were used to quantify the mismatch losses originating from the operation of in-parallel connected PV strings with different lengths. One PV system configuration reveals the origin of the mismatch effect and many investigations on mismatch losses in PV arrays exist.

Pfenninger and Staffell [8] in their study of PV solar, the power output from a given panel is calculated from the in-plane irradiance. In the study, it was found some losses are caused by the PV system's components. The researchers estimate the total PV output from different European countries. The researchers described PV power output simulations using meteorological reanalysis and satellite-measured data.

Anis and Nour [9] in their article highlighted that the main cause of losses on energy produced by PV during summer. In their work [9] they have analyzed the energy losses of PV arrays under a condition of the constant load in Cairo City (Egypt). Also, they concluded that it is impossible to eliminate entirely the PV array energy loss for a given load.

Qamber and AlHamad [10] in their study investigated the relationships between the Panel Generation Factor (PGF) and three factors (TPVPCap, PVPNeed, and SChCR). These three factors are defined later in the coming sections. The relationships are studied for both the Kingdom of Bahrain and the United Kingdom (UK). The three factors were defined versus PGF for each country. They concluded that the installation of solar cells in houses will reduce the electricity bills for the consumers.

The target of the study carried out by the researchers AlHamad and Qamber [11] is to engage the Photovoltaic technology in a way to lower the overloaded equipment and increases the electricity generated at consumer's side. In their study [11] they have concluded that solar tariffs are proving to be more economical than the conventional sources of power generation. As a final conclusion, they conclude that the investment in the GCC smart grid utilizes the budget reduction expected from reinforcement schemes to build a PV system in the residential areas.

Alnaser et al [12] in their study used two sets and each set has eight PV panels. The study was carried out in the Kingdom of Bahrain towards using renewable energy. The array installed in the University of Bahrain, which is smart and each array converts the DC to AC and posts it to the grid. As mentioned earlier that the researchers used two sets and recorded their results electronically (wireless) via antenna [12]. They recommended that panels are cleaned once a month to avoid an annual loss of electricity produced by the array.

2. Assumptions and Considerations

The electricity demand is increasing with the increase of electricity tariff as well. At the same time, the power cuts might increase also. Therefore, alternate energy is needed which is optional. Renewable energy is the other choice. In the present study solar energy is the other option. The rooftop solar panels become the choice for a population. The rooftop PV System is a photovoltaic system which is a small scale solar power generation plant. This kind of system is fixed on the available shadow free roof surface of residential or commercial buildings. At the same time, it is connected to the main building of an electric power system.

When sunrays fall on the PV modules, the produced electricity is fed to the main power junction box of the building, which is used by consumer electricity. There are two types of rooftop solar systems for buildings. The first type is known as Grid-connected Solar Rooftop system, where the second type is Off-grid Solar Rooftop system. The first type is producing the electricity which is produced by the solar panels and is consumed by the user and any residual electricity is fed back to the grid. The second type basically has batteries as electricity storage units. The only extra items in the system and the system is not connected to the grid. If the grid supply fails, you have an electric supply. The use of batteries increase the overall cost of solar plants and require frequent maintenance.

The solar rooftop has a number of benefits; the main benefits can be summarized as no more dependence on the utility Grid, the monthly electricity bills can be cut down (i.e. saving money), no more carbon dioxide generation by using the solar power generation (considered as Environment friendly), and becoming self-reliable customer. A typical rooftop panels system is illustrated in Fig. (1) [13]. Ali Sayigh the editor of the Renewable Energy in the Service of Mankind Book [14] explains the research advances for the renewable energy technologies from solar and PV, where the book includes case studies and examples to show how leading-edge research is being applied in practical life. At the same time, it highlights successful sustainability and green energy solutions from regions across the globe.

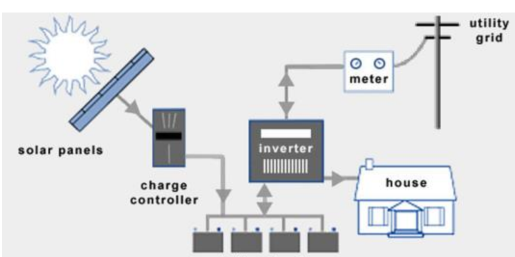

Figure 1. Typical Rooftop Solar Panels System [12]

The particular solution needs to be derived by considering a house with a number of appliances for the present study. These appliances are running with some assumptions. The considered appliances are Fluorescent, Lamp Saver, LED Lamp, Fan, Split Units AC (1 Ton, 1.5 Ton, and 2 Ton), Window Unit AC, Deep Freezer, Refrigerator, Dry Iron, Steam Iron, Water Heater, Washing machine, Vacuum Cleaner, Water Pump, Kettle, and Microwave. Each appliance is one or more piece(s). Even though, running of each appliance depends on the need at that time of running. For example, the AC is taken into consideration and is assumed that 60% of the total time its compressor unit is running. The appliances used in the present study are summarized in Table (1).

TABLE I. THE APPLIANCES CONSIDERED IN THE PRESENT STUDY

Appliances	Power (W)	Quantity	Total Power (W)	Time Running per Day (hour)	Energy (kWhr)/Day	
Flourescent	18	10	180	4	0.72	
Lamp Saver	20	15	300	6	1.8	
LED Lamp	18	5	90	8	0.72	
Fan	60	6	360	4	1.44	
Split Unit AC (1 Ton)	1303	2	2606	5	7.818	
Split Unit AC (1.5 Ton)	1954	3	5862	5	17.586	
Split Unit AC (2 Ton)	2605	3	7815	5	23.445	
Window Unit AC	1400	4	5600	5	16.8	
Deep Freezer	500	1	500	24	6	
Refrigerator	800	2	1600	24	19.2	
Dry Iron	1000	1	1000	2	2	
Steam Iron	1400	1	1400	2	2.8	
Water Heater	4500	4	18000	7	126	
Washing m/c	700	1	700	3	2.1	
Vacuum Cleaner	600	1	600	2	1.2	
Water Pump	700	1	700	12	8.4	
Kettle	1800	1	1800	1	1.8	
Microwave	650	1	650	1	0.65	
			49763	Total Number of Units per Day =	240.479	kWhr/Day

The number of energy units per day assumed to be 240.479 kWhr per day, where the total PV panels' energy needed is calculated as follows:

$$\text{Total Panel' Energy Needed} = \text{Energy (kWhr)}.(1.3) \tag{1a}$$

Therefore, the total Panel' Energy is 312.6227 kWhr per day based on the appliances assumption and consideration. The total kWp of PV panel capacity needed is calculated as:

$$\text{Total kWp of PV Panel Capacity} = \frac{\text{Total kWp of PV Panel Capacity Needed}}{\text{PGF}} \tag{1b}$$

Therefore, the total kWp of PV panel capacity is equal to 106.697 kWp for the UK. Table (2) recorded the kWp for the other four countries including the UK. The PV module considered is 110 Wp.

TABLE II. THE FIVE COUNTRIES VS TOTAL KWP OF PV PANEL CAPACITY NEEDED

Country	Total kWp of PV Panel Capacity Needed
Bahrain	53.5313
Egypt	39.5725
India	72.3664
Thailand	91.1436
UK	106.6972

The inverter size considered in the range of 25-30% bigger size for safety purpose. At the same time, the recommended battery size needs to be calculated through a number of factors. These factors are the total Watthours per day. Then, the expected efficiency for the battery is approximately 0.85, the depth of discharge is considered as 0.6, the nominal battery voltage is 12 Volt Vdc. The days of autonomy is 3 days, where these days are the number of days that needed for the system to operate when there is no power produced by the PV panels. The Battery capacity calculated as:

$$\text{Battery Capacity (Ahr)} = \frac{\text{(Total Watt} - \text{hr per day used by Appliances) x Days of autonomy}}{\text{(0.85 x 0.6 x Nominal Battery Voltage)}} \qquad (2a)$$

Under certain specifications, the Solar Charge Controller Sizing needed is typically rated versus Current and Voltage capacities. The solar charge controller is required to match the voltage of the PV array and batteries. The size of Solar Charge Controller Rating calculated as:

$$\text{Solar Charge Controller Rating} = \text{Total Short Circuit Current of PV Array x 1.3} \qquad (2b)$$

Based on the assumptions made and considered the results obtained and discussed in the coming section.

3. RESULTS

The PV system is a provider of reliable power during a grid outage. For this reason, it is important nowadays to deal with it and to be considered as a standby system or deal with it during the regular load providing that a large battery system is available that might be charged even by the utility grid. The PV system design is based on new technology. In addition, this type of technology might be energy storage or auxiliary generation. Therefore, during grid outages, the PV system has the potential to supply houses with electricity. This case, results from emergency cases or based on the power needed at any instant.

Fig. (2) shows the variation of the PGF for the five considered countries the United Kingdom, Thailand, India, Bahrain and finally Egypt. Egypt has the highest PGF, where the United Kingdom has the lowest one.

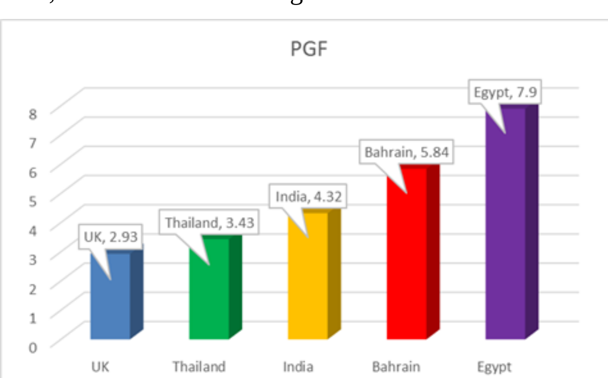

Figure 2. Variation of the PGF vs Countries

The coming equations (equations 3 to 8) are obtained using the curve fitting technique based on the results calculated for the five considered countries. The shape of the curves for the five considered countries was found as exponential basic. The exponential basic function is a multi-step process, where it should be noted that every problem is different based upon the available data or results obtained for it. As well, the exponential equation is one in which a variable occurs in the exponent.

Fig. (3) shows the variation of the total (kWp) of PV Panel Capacity Needed (TPVPCap) versus the countries. While Fig. (4) shows the PGF is inversely proportional to the total (kWp) of PV Panel Capacity Needed and obtained from the derived equation:

$$TPVPCap = 30.82863 + 261.7675 * e^{-(0.4248135 * PGF)} \qquad (3)$$

Which takes the form

$$TPVPCap = a + b\, e^{-c*PGF} \qquad (4)$$

Where:

a = 30.82863 ± 2.06

b = 261.7675 ± 16.17

c = 0.4248135 ± 0.0272

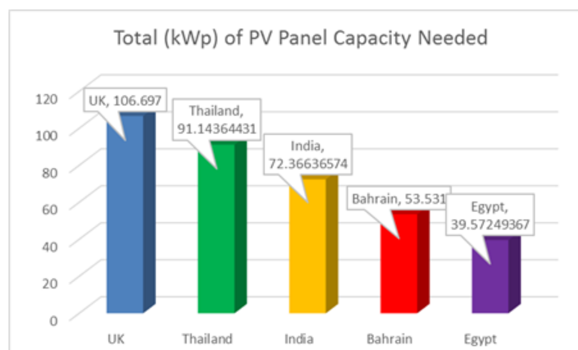

Figure 3. Variation of the Total (kWp) of PV Panel Capacity Needed vs Countries

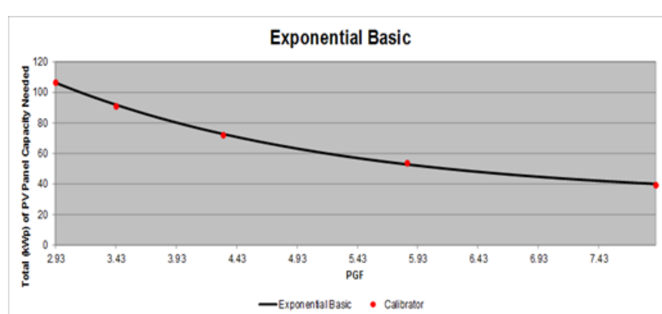

Figure 4. TPVPCap vs PGF

Meanwhile, Fig. (5) shows the variation of a number of PV needed of 110 Wp PV module vs countries. Furthermore, Fig. (6) shows the PGF is inversely proportional to the number of PV panels needed of 110 Wp PV module (PVPNeed) and obtained from the derived equation:

$$PVPNeed = 269.0427 + 2335.067*e^{-(0.4093051*PGF)} \quad (5)$$

Which takes the form

$$PVPNeed = a + b\, e^{-c*PGF} \quad (6)$$

Where:

a = 269.0427 ± 20.92

b = 2335.067 ± 144.1

c = 0.4093051 ± 0.02789

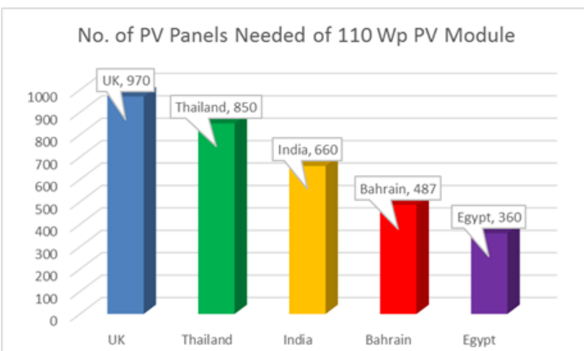

Figure 5. Variation of Number of PV Needed of 110 Wp PV Module vs Countries

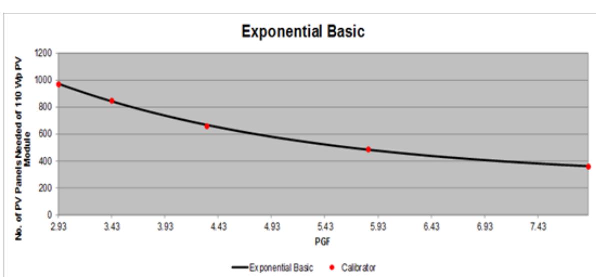

Figure 6. PVPNeed vs PGF

Meanwhile, Fig. (7) shows the variation of the solar charge controller rating vs countries. Finally, Fig. (8) shows the PGF is inversely proportional to the solar charge controller rating (SChCR) and obtained from the derived equation:

$$SChCR = 2645.214 + 22864.23*e^{-(0.\ 0.4106118*PGF)} \quad (7)$$

$$SChCR = a + b\, e^{-c*PGF} \quad (8)$$

a = 2645.214 ± 2.06

b = 22864.23 ± 16.174

c = 0. 0.4106118 ± 0.0272

The PV owners might realize the values they can gain from the PV system developed and installed in their property by getting a reduction in the monthly electricity bill. As well, the owners might receive payments from the electricity authority when the authority reached the case of buying electricity from the owner's extra power. This means that when the solar PVs are installed in houses, it is found that the required load from the grid network is reduced. This is one of the benefits that can be obtained by using a PV system.

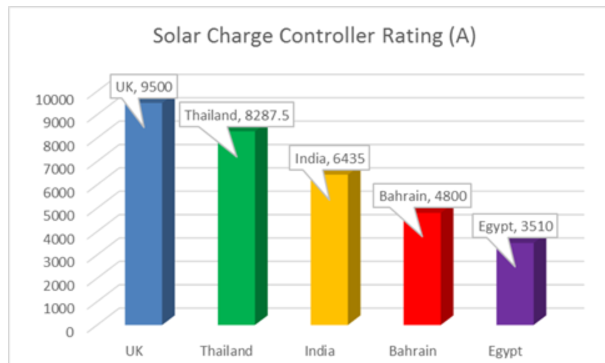

Figure 7. Variation of the Solar Charge Controller Rating vs Countries

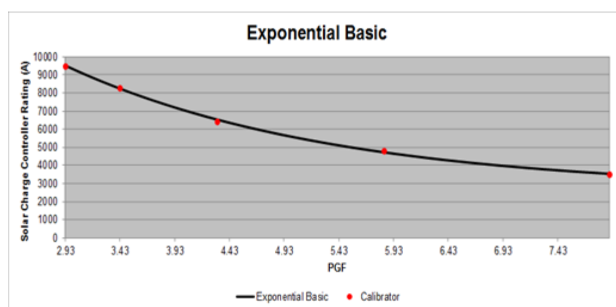

Figure 8. SChCR vs PGF

4. CONCLUSION

The three obtained models make it easier for researchers after obtaining the PGF, to reach the three variables. These variables are the total (kWp) of PV panel capacity needed, the number of PV needed of 110 Wp PV module, and the solar charge controller rating.

Many factors were considered in the present study to determine the final form of designing the PV solar panel for the five countries presented. The estimation of the effectiveness of using PV panels in the countries was carried out. From the obtained results in the present study, it is clear how the climate affects the results. As a conclusion, the higher number of panels needed is by the UK, Thailand, India, Bahrain and finally Egypt. It is clear as well that the PGF is inversely proportional with the Total (kWp) of PV Panel Capacity needed. At the same time, PGF is inversely proportional with the total (kWp) of PV panel capacity needed. Finally, PGF is inversely proportional with the solar charge controller rating. Therefore, solar PV technology can be designed and it is recommended to increase the electricity load system.

References

[1] California Energy Commission. "A Guide to Photovoltaic (PV): System Design and Installation", Consultant Report (Document Number 500-01-020), pp. 1-39, 2001.

[2] M. Albadi, H. Soliman, M. Thani, A. Al-Alawi, S. Al-Ismaili, A. Al-Nabhani, H. Baalawi, "Optimal Allocation of PV Systems to Minimize Losses in Distribution Networks Using GA and PSO: Masirah Island Case Study", J. Electrical Systems, Vol. 13, No. 4, (2017), pp. 678-688, 2017.

[3] Kamel A. Alboaouh. "Optimization of PV response under the uncertainty of load and irradiance during the peak", Energy Press, volume 1, pp. 12-13, 2017.

[4] E. Georges, J. E. Braun, V. Lemort. "A general Methodology for Optimal Load Management with Distributed Renewable Energy Generation and Storage in Residential Housing", Journal of Building Performance Simulation, volume 10, pp. 224-241, 2017.

[5] S. A. Hosseini, B. Vahidi, H. Askarian Abyaneh, S. H. H. Sadeghi, M. Karami. "A Seven-State Markov for Determining the Optimal Operating Mode of Distributed Generators", Journal of Renewable and Sustainable Energy, volume 7, 2015.

[6] I. M. Marchena, M. S. Cardona, L. M. Lopez. "Framework for Monitoring and Assessing Small and Medium Solar Energy Plants", Journal of Solar Energy Engineering, volume 137, 2015.

[7] T. S. Wurster, M. B. Schubert. "Mismatch Loss in Photovoltaic Systems", Solar Energy, volume 105, pp. 505-511, 2014.

[8] S. Pfenninger, I. Staffell, "Long-Term Patterns of European PV Output Using 30 Years of Validated Hourly Reanalysis and Satellite Data", International Journal of Energy, Vol. 114, pp. 1251-1265, 2016.

[9] W. R. Anis, M. A. Nour, "Energy Losses in Photovoltaic Systems", International Journal of Power Sources, Vol. 51, pp. 367-374, 1994.

[10] Isa S. Qamber, M. Y. Al-Hamad, "A General Methodology Made Cleaned PV Energy Panels for Bahrain and UK", Proceeding of SCS-2018, Smart Cities Symposium (IET), 22-23 of April 2018, Kingdom of Bahrain, pp. 44-47, 2018.

[11] M. Y. Al-Hamad, I. S. Qamber, "Smart PV Grid Reinforce the Electrical Network", World Renewable Energy Congress-17, E3S Web of Conference 23, 01002, 2017.

[12] N. W. Alnaser, M. J. Al Othman, A. A. Dakkel, I. Batarseh, J. K. Lee, S. Najmaii, A. Alothman, H. Al Shawaikh, W. E. Alnaser. "Comparison between Performance of Man-Made and Naturally Cleaned PV Panels in a Middle of a Desert", Renewable and Sustainable Energy Reviews, volume 82, pp. 1048-1055, 2018.

[13] Typical Rooftop Solar Panels Module: Retrieve https://www.google.com/search?q=solar+typical+rooftop&tbm=isch&tbs=rimg:Cc4sBmrZshyoIjjMTT3LhlQDt2A67L_10HbzKoIRmbr8bznv-I2ZJoBR5BRss1rAOc6KE5dcQSJX3DGVGL73u-oM3DyoSCcxNPcuGVAO3ESQUwLHWC3t1KhIJYDrsv_1QdvMoRFLtK3yxU7ggqEgmghGZuvxvOexHlfcvNc9silioSCf4jZkmgFHkFER7XftODXK-FKhIJGyzWsA5zooQR7Uf9y3-ncM0qEgnl1xBIlfcMZRFgMWlwxclKDCoSCUYvve76gzcPEc7h82bu5AHN&tbo=u&sa=X&ved=2ahUKEwifkO7ShODaAhUMu48KHW94ANcQ9C96BAgBEBg&biw=1366&bih=662&dpr=1#imgrc=1g4pMJd_3eK0oM

[14] Ali Sayigh (Editor), "Renewable Energy in the Service of Mankind: Selected Topics from the World Renewable Energy Congress WREC 2014", Vol I, Springer International Publishing, 2015.

Isa S. Qamber received the B.Sc. degree in electrical engineering from King Saud University - Saudi Arabia, in 1982, M.Sc. degree in 1984 from UMIST, United Kingdom, and the Ph.D. degree in reliability engineering from the University of Bradford, UK in 1988. In 1988, he joined the Department of Electrical Engineering and Computer Science, College of Engineering, University of Bahrain, as an assistant professor. He was an X-chairman from February 1996 until April 2000 for Department of Electrical and Electronics Engineering (University of Bahrain). For the period, 2008-2011 was the dean of College of Applied Studies. He was the Dean of Scientific Research for the period 2011-2014. Currently, he is a Professor in the Electrical and Electronics Engineering Department (University of Bahrain). Prof. Qamber is a Senior Member of the IEEE PES and Reliability Societies. In addition, he is a member in CIGRE, the Bahrain Society of Engineers and member in the Board of Bahrain Society of Engineers for the period 2004 up 2006. He established and chaired the IEEE Bahrain Section. His research interests include studying the reliability of power systems and plants. As well, his research interests include the Renewable Energy.

Mohamed Y. AL-Hamad received his B.Sc in Electrical Power Engineering from the University of Bahrain – 1996. He received his M.Sc. in Electrical Power Engineering in 2002 from the same university. He is doing this Ph.D. program in Power Trading in UOB since 2011. He is working in GCC Interconnection Authority since 15 May 2012 as a Client Interface Executive in Market Operations Section. He worked in the Electricity and Water Authority as Act. Head in Planning & Design Section, Distribution Directorate for 3 years, & he worked as a system control engineer for 8 years. He worked as an instructor in the University of Bahrain from 1996 to 2001. He has authored more than 10 papers in Electricity Engineering and Power Marketing. His research interests include studying the power trading and the Renewable Energy.