International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 08 | Aug 2019 www.irjet.net p-ISSN: 2395-0072

Modeling, Simulation and Control of a Photovoltaic Energy System with a Fuel-Cell Backup

Samia Abdelfatah[1], Elwy El-Kholy[2], Hossam Youssef[3] and Hilmy Awad[4]

[1]Researcher at Electrical Technology Department, Faculty of Industrial Education, Helwan University, Cairo, Egypt
[2]Professor of Power Electronics, Faculty of Engineering Shebin El Kom, Menoufia University, Menoufia, Egypt
[3]Professor Emeritus at Electrical Technology Dept, Faculty of Industrial Education, Helwan University, Cairo, Egypt
[4]Assistant Professor, Electrical Technology Dept, Faculty of Industrial Education, Helwan University, Cairo, Egypt

---***---

Abstract – *Although the photovoltaic (PV) energy systems provide a valuable solution to the energy crises, their intermittent nature necessitates the existence of backup systems for the continuous operation of the connected loads. This paper presents a PV system with a fuel-cell as a backup system for the continuous operation. Normally, the connected loads are energized by the PV within the nominal range of the irradiance. If the irradiance falls below a threshold value, the loads will be fed by the fuel cell. The proposed energy system contains a PV array, fuel cells, as well as the necessary power electronics devices and Analysis of operating conditions for each of the solar cells and fuel cells. The simulation results the proposed system can efficiently solve the intermittent nature of the PV energy systems.*

Key Words: Photovoltaic, Fuel cell, style, MPPT.

1. INTRODUCTION

It is well-known that electrical networks are very necessary for human life. However, increased demand for energy has led to global environmental concerns where that environmental pollution has led to many organizations and association to establish protocols and directives in order to regulate the generation of CO2 and other pollutants such as Kyoto Protocol and European Directive on renewable energy sources. This fact justifies the increased world's interest in renewable energy (RE) sources as they are the most environmentally-friendly sources [1-2].

Many researchers presented different proposed solution to enhance the quantity of electricity generated from clean and renewable sources of energy and related technologies are being sought, developed and implemented worldwide. These alternative sources of energy include wind, solar, geothermal, biofuels, tidal and waves. The renewable energy sources have its own drawbacks. For instance, solar panel has low efficiency and its power output depends on climatic conditions like insulation and temperature [3-7]. An attribute of optical arrays where the current changes almost linearly with solar radiation that negatively affects the performance of a DC motor driving a centrifugal pump and also the motor efficiency degradation was noticed under weak solar insulation [8-9].

The hybrid power systems exhibit higher reliability of generation than those that use individual system. So, hybrid system is the most desired solution in Renewable Energy system [10-11]. A hybrid PV/wind system (HPWS) is presented in [12-13] where, the wind energy has a disadvantage of that the wind isn't always blowing. This can cause serious problems for wind turbine developers who will often spend significant time, money check whether or not a special site is suitable and the generation of wind power that it is not a continuous energy source. The Fuel cells have some advantages compared to conventional power sources and other renewable energy sources. It has higher efficiency, noise free operation (since there are no moving parts). It has also pollution free completely since water is the result instead of CO2 emission from the fuel cell. In addition to that it has lesser maintenance and the fuel cell is economical to operate because it does not need any fossil fuel [14].

The proposed hybrid PV-FC generation system employs to operate the solar panel at its maximum power point, perturb and observe (P&O) algorithm. The proposed controllers extract the required load power either from the PV or the FC. In case of high irradiance, the normally and the connected loads are energized by the PV within the nominal range of the irradiance. When the insulation level decreases (shading) such that PV power is not enough to feed the load; there should be a switch in order to alternate between the PV and FC.

2. Description and Modeling of PV-FC Hybrid System.

A. Design of the System

The proposed hybrid system shown in Figure 1 relies mainly on PV power. In case of normal insulation levels, the PV panels feed the load via AC/DC boost converter employing the (P&O) algorithm for maximum power point tracking. The load here is represented by 3-phase induction motor where their speed is controlled by the V/F control method. When the insulation level decreases such that PV power is not enough to feed the load, the fuel cell is operated to compensate the load via AC/DC Converter. There should be a switch in order to alternate between the PV and FC as shown in Figure 1.

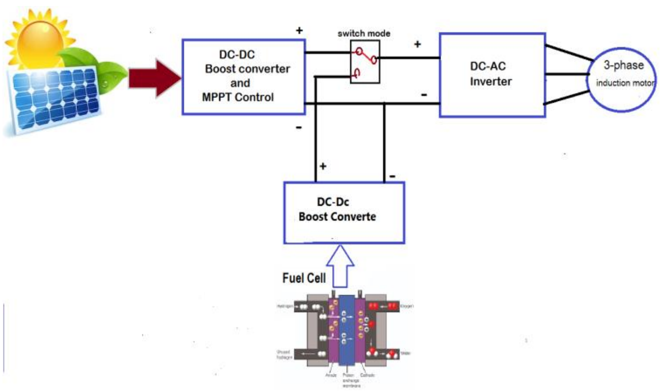

Fig – 1: PV - FC hybrid system.

B. Photo voltaic System

A solar cell is modeled by a current source and a parallel diode, shunt resistance R_{Sh} and series resistance R_S are added to the model as shown in Figure 2. R_S whose value is very small, R_{sh} is whose value is very high [15-19].

Where,

I is the solar cell current in Amp.

I_L is the light generated current in Amp.

I_D is the diode saturation current in Amp.

T is the array temperature in °K.

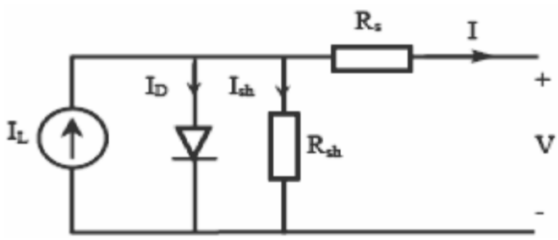

Fig – 2: Model for a solar cell.

$$I = I_L - I_O [\exp(q(V + I R_S)/KT)) - 1] - (V + IR_S)/R_{sh}$$

Where

$$I_D = I_O [\exp(q(V + I R_S)/KT)) - 1]$$

C. 0

D. Maximum Power Point Tracking (MPPT)

There are different techniques available in literature for tracking maximum power from PV panels examples are the (P&O) methods, the Incremental Conductance (IC) methods, the Neural Network method and the Fuzzy Logic method, [20-21]. Table 1 shows the characteristics of different Maximum Power Point Tracking (MPPT) techniques as perturb and observe (P&O) algorithm is adopted due its simplicity [22]. The solar PV system is connected to the inverter through a AC/DC converter. A boost converter is used to implement MPPT algorithm. Output voltage of the boost converter is equal to
VO = (1/ (1-D) Vs.

where

Vs is the input voltage and D is the duty ratio.

Perturb and Observe (P&O) MPPT technique is shown in Figure 3. Voltage V_{cell} and current I_{cell}_are measured from solar array to calculate power (Po). Block dv/dt compares the present value of power with previous value. If increment in power is positive then perturbation variable voltage is incremented by predefined step size. Output voltage of solar panel is compared with this varied voltage value and steady state error obtained is eliminated by PI controller. To avoid over saturation, a limiter should be placed at the output of PI controller which is compared with carrier wave to generate pulse for controlled switch IGBT of AC/DC boost converter [23].

Table -1: Characteristics of different MPPT techniques [23].

MPPT technique	Convergence speed	Implementation complexity	Periodic tuning	Sensed parameters
Perturb & observe	Varies	Low	No	Voltage
Incremental conductance	Varies	Medium	No	Voltage, current
Fractional V_{oc}	Medium	Low	Yes	Voltage
Fractional I_{sc}	Medium	Medium	Yes	Current
Fuzzy logic control	Fast	High	Yes	Varies
Neural network	Fast	High	Yes	Varies

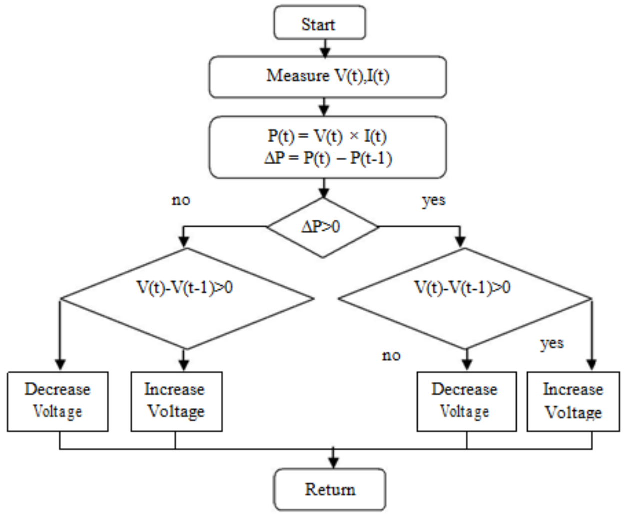

Fig – 3: Flowchart of P&O MPPT Technique.

E. Proton Exchange Membrane Fuel Cells (PEM FC)

A Proton Exchange Membrane (PEM) fuel cell consists of a polymer electrolyte membrane sandwiched between two electrodes (anode and cathode). In the electrolyte, only ions allowed passing through and the electrons are not allowed [24-25]. So, the flow of electrons an external circuit from anode to cathode to produce electricity due to the potential difference between the anode and cathode. The theory of the basic operation of the PEM fuel cell is fully explained in Figure 4. However; the overall electrochemical reactions for a PEM fuel cell is presented as follows:

Anode: $2H_2 \leftrightarrow 4H^+ + 4e^-$
Cathode: $O_2 + 4H^+ + 4e^- \leftrightarrow 2H_2O$
Overall: $2H_2 + O_2 \leftrightarrow \text{electricity} + \text{heat}$

The characteristics of PEMFC are given as shown clearly in Table 2.

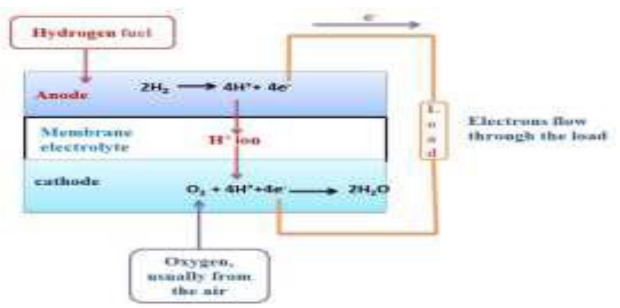

Fig – 4: Operation of a PEM fuel cell.

Table -2: Characteristics of the PEMFC

Fuel Cell Type	Operating Temperature	Typical Stack Size	Application	Efficiency
Polymer Electrolyte Membrane Fuel Cell Model	60-100°C Typically 80°C	<1KW-100KW	Backup power, portable Power. Distributed Generation. Transportation Specialty Vehicles.	60% Transportation

In this paper A MATLAB-Simulink Generic Model of PEM fuel cell stack is analyzed. By analysis of this model it is found that it is a concise model of PEM fuel cell. In this model a PEM fuel cell is broadly analyzed by keeping under consideration almost all the parameters which affect the performance of PEM fuel cell such as Flow rate, utilization of fuel and air, Partial pressure of fuel and air, Humidity and Temperature of stack and also stack consumption of air and fuel [26-27]. Further, the operation of PEM Fuel cell stack is performed under two conditions of absolute and Nominal values of fuel and air utilization.

$$P_b - P_{bi} = Z *$$

4. RESULTS AND DISCUSSIONS

Induction motor, 3-phase squirrel-cage rated, 6 HP, 220 V, 60 Hz, and 1725 rpm is fed by a 3-phase MOSFET inverter connected to a DC voltage source of 325 V through hybrid PV-Fuel cell. The applied load torque to the machine's shaft is hold at constant nominal value, of 12 N.m. Speed control of the motor by using the Constant V/Hz. At the start of the operation, the load is fed through the solar cells in the form of current. If it starts to draw a high current until it reaches the nominal current, the load is stabilized at work until the value of the solar radiation decreases. A change in the voltage value occurs and therefore a change in the voltage-frequency ratio occurs. Separate solar cells and run fuel cells, as the solar radiation shown clearly in Figure 5. DC voltage source (hybrid PV-Fuel cell) shown in Figure 6, however, Ia_Stator (A) is shown in Figure 7. The simulation should start in steady-state and the initial motor speed should be at 1720 RPM which is clearly shown in Figure 8 where the rms value of the stator voltages should be at 220V as shown in Figure 9 however, the frequency of 60Hz is shown in Figure 10.

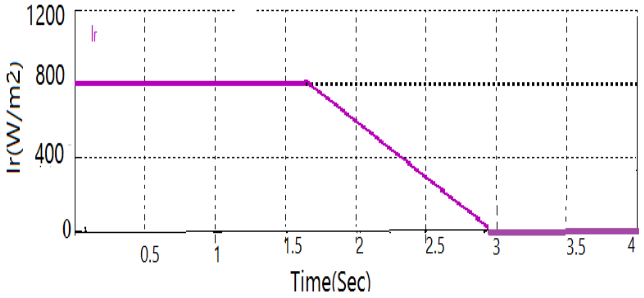

Fig – 5: Solar irradiance.

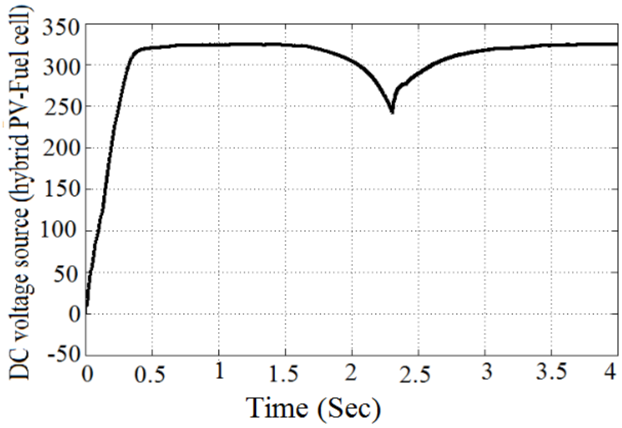

Fig – 6: DC voltage source (hybrid PV-Fuel cell).

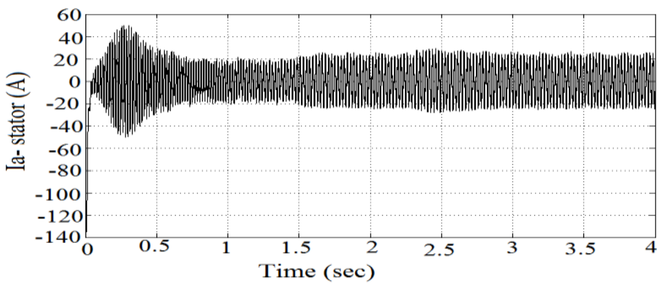

Fig – 7: Ia _ Stator (A).

At 0.6 second, it is shown that the speed is changed from 1725 to 1300 RPM. When the motor reaches a constant speed of 1275 RPM, the stator voltage (rms) value is decreased to 165.8V and the frequency to 45.2 Hz. At 1.8 seconds the voltage decreases and the current is also due to the decrease of solar radiation and shadows, which causes the instability of the ratio between voltage and frequency and thus changes the value of the speed than the required value. And at 2.3 second Solar cells are separated and fuel cells are turned on to feed the load.

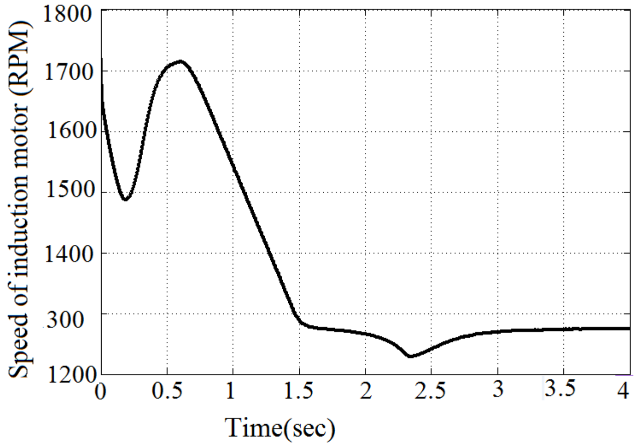

Fig – 8: Speed of induction motor (RPM).

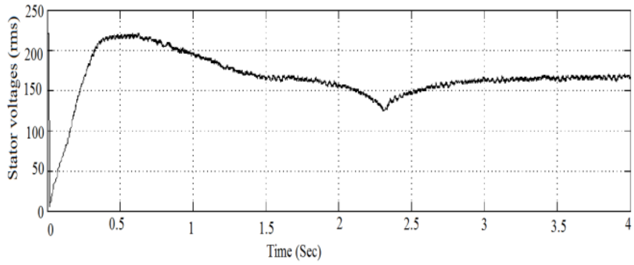

Fig – 9: Stator voltages (rms).

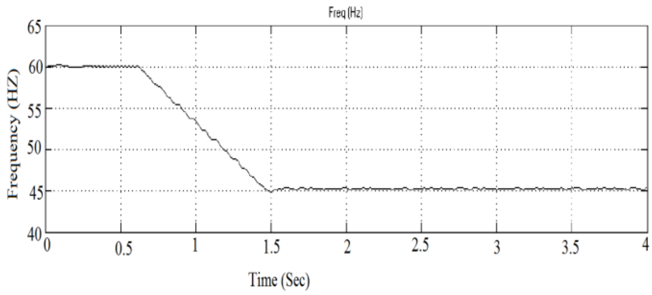

Fig – 10: Frequency (HZ).

6. CONCLUSION

Renewable energy (RE) sources are attracting more attention as alternative energy sources to conventional fossil fuel energy sources in spite of its own disadvantages. Solar panel has low efficiency and its power output depends on geographical and meteorological conditions such as insulation and temperature. The solar cells may not meet the energy demanding however, the hybrid system of PV with a fuel-cell meet this demands. The fuel-cell system is mainly exploited as a backup and extracts the maximum power from each hybrid power system component, Photovoltaic (PV) generator and Fuel Cell (FC) source. The results show the effectiveness of the system.

REFERENCES

1- S. Diaf a, G. Notton, M. Belhamel, and M. Haddadi, A. Louche "Design and techno-economical optimization for hybrid PV/wind system under various meteorological conditions" Applied Energy ,85 ,(2008), pp. 968–987.
2- Prof. Nitin P.Choudhary, Prof. Shubhangi Thak and Prof. Sandeep das "Pumping Station for Agriculture Purpose using Solar PV" International Journal on Recent and Innovation Trends in Computing and Communication , March 2015, Volume: 3 Issue: 3.
3- B. Amrouche, M. Belhamel, and A. Guessoum "Artificial intelligence based P&O MPPT method for photovoltaic systems" Revue des Energies Renouvelables ,volum 07, 2007.
4- J.A.Gow "Development of a photovoltaic array model for use in power-electronics simulation studies" IEEE Proc.-Electr. Power Appl., Vol. 146, No. 2, March 1999.
5- Vipin Dasa , Sanjeevikumar Padmanabanb, Karthikeyan Venkitusamya , Rajasekar Selvamuthukumaranc , Frede Blaabjergd , and Pi,erluigi Siano" Recent advances and challenges of fuel cell based power system architectures and control – A review" Renewable and Sustainable Energy Reviews Volume 73, June 2017.
6- Sami Ben Slama, Abderrahmen Ben Chaabène and Adnane "Efficient Design of a Hybrid (PV-FC) Water Pumping System with Separate MPPT Control Algorithm" IJCSNS International Journal of Computer Science and Network Security, VOL.12 No.1, January 2012.
7- Wagdy R. Anis , Ropret P. Mertens and Roger J" Coupling of a volumetric pump to a photovoltaic array". Solar Cells Volume 14, Issue 1, April 1985, Pages 27-42
8- Y.Ya0, P. Bustamante,and R.S.Ramshaw" Improvement of Induction Motor Drive Systems Supplid By Photovoltaic Arryys With Frequncy Control" ieee Transactions on Energy Conversion, Vol. 9. No. 2, June 1994
9- Y. Yorozu, M. RHirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," ieee Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 .
10- M. Sedighizadeh, and A. Rezazadeh"Comparison between Batteries and Fuel Cells for Photovoltaic System Backup" Proceedings of World Acadamy of Scince, Egineering and Technology. Echology Volume 1 December 2007
11- Kodjo Agbossou, Mohanlal Kolhe, Mohanlal Kolhe, Jean Hamelin, and Tapan K. Bose" Performance of a Stand-Alone Renewable Energy System Based on Energy Storage as Hydrogen" ieee Transactions on Energy Conversion, VOL. 19, NO. 3, September 2004
12- S. Diaf a, G. Notton , M. Belhamel , and M. Haddadi c , A. Louche a"Design and techno-economical optimization for hybrid PV/wind system under various meteorological conditions" Applied Energy ,volume 85, 2008.
13- Shafiqur Rehman, Md. Mahbub Alam , J.P. Meyer b , and Luai M. Al-Hadhrami "Feasibility study of a wind epvediesel hybrid power system for a village" Renewable Energy volume 38 ,2012.
14- Salwan S. Dihrab, K. Sopian" Electricity generation of hybrid PV/wind systems in Iraq" Renewable Energy, volume 35 ,2010 ,1303–1307
15- M.Sujith, R.Mohan, and P.Sundravadivel" simulation analysis off 100KW integrated segmented energy storage for grid connected PV system"International Journal of Electrical Engineering and Technology (IJEET) Volume 3, Issue 2, July.
16- Oscar Khaselev and John A. Turner" A Monolithic Photovoltaic-Photo electrochemical Device for Hydrogen Production via Water Splitting" SCIENCE ,VOL. 280, 17 APRIL 1998
17- Mustafa A. Al-Refai" Matlab/Simulink Simulation of Solar Energy Storage System" International Journal of Electrical, Computer, Energetic, Electronic and Communication Engineering Vol:8, 2014
18- A. Kirubakaran , Shailendra Jain, R.K. Nema"A review on fuel cell technologies and power electronic interface" Volume 13, Issue 9, December 2009
19- K. Ashok Reddy1 , Kota Srinivas2 , G.S. Ayyappan3" Power Management in a Standalone Solar/ Fuel cell/ Battery Hybrid Power system" International Journal of Engineering Research a
20- Gert K. Andersen" A new power converter for fuel cells with high system efficiency" INT. J. Electronics, 2003, VOL. 90, NOS. 11–12, 737–750.
21- . Bhubaneswari Paridaa, and S. Iniyanb, Ranko Goicc" A review of solar photovoltaic technologies" Renewable and Sustainable Energy Reviews . Volume 15, Issue 3, April 2011.
22- Kamil, Nevzat" Experimental analysis of an alternator excited with photovoltaic cells for small power plants" Turk J Elec Eng & Comp Sci, Vol.19, No.3, 2011.
23- Mohammed Ali Elgendy and Bashar Zahawi "Comparison of Directly Connected and Constant Voltage Controlled Photovoltaic Pumping Systems" IEEE Transactions on Sustainable Energy, VOL. 1, NO. 3, October 2010.
24- Daoud and A. Midoun "Maximum power point tracking techniques for solar water pumping systems" Revue des Energies Renouvelables Vol. 13 ,2010.
25- Roberto, Sonia "energy comparison of MPPT technique for PV system" journal of electromagnetic analysis and application ,vol 3 ,January 2008.
26- Woon Ki Na and Bei Gou "Feedback-Linearization-Based Nonlinear Control for PEM Fuel Cells" IEEE Transactions on Energy Conversion, Vol. 23, No. 1, March 2008.
27- Faheem Khan , Arshad Nawaz , Malik Ansar Muhammad , and Muhammad Ali Khadim "Review and Analysis of MATLAB® Simulink of PEM fuel cell stack" International Journal of Engineering & Computer Science IJECS-IJENS Vol: 13 No: 03

BIOGRAPHIES

Samia Abdalfatah was born in Sharkia Governorate, Egypt, in 1985. She received the B.Sc. in Industrial Education from Helwan University in 2007 and M.Sc. in Industrial Education from Suez University Egypt, in 2015. She is currently working as an Assistant lecturer in the Faculty of Industrial Education, Department of Electrical Technology, Helwan University.

Elwy E. El-Kholy was born in Menoufia, Egypt, in 1963. He is a Professor of power electronics, Faculty of Engineering Shebin El Kom , Menoufia University, Menoufia, Egypt He received the B.Sc., M.Sc., and Ph.D. degrees in electrical engineering from Menoufia University, Shebin El-Kom, Egypt, in 1986, 1992, and 1996, respectively., He is the Dean Faculty of Engineering, Menoufia University.

Hossam Youssef, was born in El Fayoum, Egypt in 1959. He obtained his Ph.D. from Polytechnic Institute (Leningrad) USSR – 1990. He is currently working as an Associate Professor at Department of Electrical Technology, Faculty of Industrial Education, Helwan university. He is the head of Electrical Technology Department. He worked as an Associate Professor of Electronic Department (College of Electronic & Communications, Jeddah, KSA between 2003 and 2013. He gained a Post Doctor Scholarship in Queen's university of UK (2001-2002).

Hilmy Awad received the B.Sc. degree in electrical power and machines from Zagazig University, Zagazig, Egypt, in 1993 and the M.Sc. in electrical engineering from Eindhoven University of Technology, Eindhoven, The Netherlands, in 1999. He obtained his Ph.D. degree at the Department of Electric Power Engineering, Chalmers University of Technology, Gothenburg, Sweden on 2004. He is currently working as an assistant professor at the faculty of Industrial Education, Cairo, Egypt. His research interests include power electronics applications, renewable energy systems, and power quality problems.