Energy generation by crystalline silicon photovoltaic network per meter square in Iraq

Tariq Emad Ali[1], Mohammed A. Abdala[2], Ameer Al-Khaykan[3], Dhulfiqar A. Alwahab[4], John M. Counsell[5]

[1]Department of Information and Communication Engineering, Al-Khwarizmi College of Engineering, University of Baghdad, Baghdad, Iraq
[2]Head of Medical Instruments Techniques Engineering Department, Al-Hussain University College, Kerbala, Iraq
[3]Air Conditioning and Refrigeration Techniques Engineering Department, Al-Mustaqbal University College, Babylon, Iraq
[4]Faculty of Informatics, Eötvös Loránd University, Budapest, Hungary
[5]Head of Electronics and Electrical Engineering Department, University of Chester, Chester, United Kingdom

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ABSTRACT

Iraqi people have been without energy for nearly two decades, even though their geographic position provides a high intensity of radiation appropriate for the construction of solar plants capable of producing significant quantities of electricity. Also, the annual sunny hours in Iraq are between 3,600 to 4,300 hours which makes it perfect to use the photovoltaics arrays to generate electricity with very high efficiency compared to many countries, especially in Europe. This paper shows the amount of electric energy generated by the meter square of crystalline silicon in the photovoltaic (PV) array that already installed in 18 states in Iraq for each month of the year. The results of the meter-square of PV array in three tracking positions are presented in this paper. This paper shows that the average electricity generated in North cities (Dohuk, Al-Sulaymaniyah, and Erbil) are less than the southern cities in the winter season (three positions) by about 40-50%. Iraq has a stable PV electrical generation during all the year in all regions except the North cities while the highest cities in electricity generation are (Najaf and Al-Anbar).

Corresponding Author:

Tariq Emad Ali
Department of Information and Communication Engineering, Al-Khwarizmi College of Engineering, University of Baghdad
Baghdad, Iraq
Email: tariqemad@kecbu.uobaghdad.edu.iq

1. INTRODUCTION

Each country may have renewable energy resources, and by implementing advanced technologies that enable optimum use of these energies, effective solutions to all challenges that impede their use can be given [1]. Because of nonstop technical growth and price decrease, photovoltaic solar projects that produce energy from Solar radiation are expected as a knowledge choice that will meaningfully contribute to the renewable energy supply [2], [3]. Sampaio and González [4] conducted a systematic literature review on the various methods of extracting electricity, their benefits and drawbacks, applications, the existing market, and costs. They used a non-probabilistic sample size and used a qualitative and quantitative approach. According to the findings of the study, photovoltaic energy research is on the rise and could play a key role in achieving a high-tech future [5], [6]. The output of a 960 kWh photovoltaic (PV) device in southern Italy is investigated by Malvoni *et al.* [5]. The monthly average of energy yields, losses, and performance is calculated using data collected over 43 months [7], [8]. The software asset management (SAM) tool overestimated the amount of energy pumped into the system annually on median by 3.0% and 3.3% for PVsyst, but PVsyst outperforms t in the long run [9]. Ali in [10] investigated the PV effect caused by a point force applied to the surface of centrosymmetric materials such as a single crystal of strontium titanate (SrTiO3) and a single crystal of rutile titanium dioxide (TiO2). The findings show that the impact of strain gradient and floating photovoltaics (FPV) on nanoscale electronic properties is still a mystery [11], [12]. The performance, power losses, and deterioration of a 200 kW roof-integrated crystalline PV system set up at the institutional review board (IRB) Complex-5 in Chandigarh, India, were predicted by Vologdin *et al.* [13]. For forecasting energy generation and loss, they used the PVsyst simulation method. On an annual basis, the projected results show that 292,954 kWh of energy can be produced from the system.

2. PHOTOVOLTAICS SYSTEM

A photovoltaic system, commonly referred to as a PV system or a solar power system, is a type of power system that harnesses solar energy using photovoltaics. A solar inverter transforms direct current to alternating current, solar panels collect and convert sunlight into energy, mounting, cabling, and other electrical components are all included in its construction [14], [15]. As storage device prices are anticipated to decline, it may also provide an integrated battery solution and make use of a solar tracking system to improve the system's overall efficiency. Today, grid-connected PV systems predominate, with off-grid or standalone systems making up a tiny portion of the market [16], [17]. Solar panels are the components that convert receiving light into electrical energy. They are composed of several solar cells that are joined together and positioned on structural components to power electronic power conditioning units [18]. The great majority are free-field systems that depend on one of the following kinds of ground-based structures:

- Set arrays: in many projects, the solar's installed at a static predisposition that is determined to offer the best yearly production outline. Solar's are usually inclined slightly less than the site's latitude and pointed towards the equator [19], [20].
- Dual-axis trackers: solar would be oriented naturally to the rays of the sun to optimize the intensity of incoming direct radiation. Dual-axis trackers accomplished monitoring the sunlight in its regular circle. When the sun shifts and the array orientations change, these arrays must be moved apart out to minimize interceding, necessitating the use of more ground. They also necessitate further complicated machines to keep the solar at the correct angle [21].
- Single-axis trackers: realizes some of the performance profits of monitoring less property area, resources, and price penalties. Entails following the sunlight in one measurement-on its regular path through the sky. The axes of single-axis tracking systems are approximately north to south [22], [23].

3. CRYSTALLINE SILICON PHOTOVOLTAICS

In photovoltaics with crystalline silicon, there are two types of solar cells to choose from: i) mono-crystalline silicone from a high-purity single crystal ingot formed by slicing wafers; ii) multi-crystalline by sawing a cast block of silicon into bars and then wafers. Because of their high performance, crystalline silicon photovoltaics are a fascinating technology for applications where space is limited [24]. Electricity generation is increasing every day from PV systems. With today's technology, 10% to 20% of the PV system efficiency can be attained. Environmental factors such as the level of weather environments, and losses resulting from improper setting up will distress the effectiveness of PV and have decreased overall energy efficiency [25]. Assessment and evaluation of such losses caused by system elements including cables, inverters, and batteries, as well as losses caused by weather conditions like shade, dust, snow, rain, and temperature. Because of the low energy yield of PV systems, it is essential that the energy produced is transmitted to consumers with the minimum possible losses [25].

4. GEOGRAPHICAL NATURE AND IMPACT OF IRAQI CLIMATE IN THE USE OF PV MODULES

The Mediterranean climate dominates Iraq's northern and northeastern areas, which are largely mountainous. Iraq is one of the countries with the highest rate of solar radiation exposure. In the summer, the daily average dropped solar radiation was 850 W/m^2, while in the winter, it was 450 W/m^2. Almost the entire country of Iraq could be used to construct large-scale solar power plants. Iraq has very hot summers and mild winters, with the peak temperatures in June, July, and August between 43 °C and 50 °C, and the lowest in January between 1 °C and 8 °C [16], [17]. Dry air masses from the Mediterranean impact the country from June to September. Winds moving from the south to the south-east impact the country from April to June and from mid-September to November.

5. RESULTS AND DISCUSSION

After the Iraqi irradiation calculation, this section presents the quantity of electrical energy produced by a one-meter square of monocrystalline silicon PV array for 365 days per year (12 months) and the quantity of irradiation obtained from the same PV array in each city in Iraq from north to south. The results show the average monthly output of electricity from one square meter of photovoltaic mono-Si determined by monitoring irradiation in three positions for each Iraqi city. Figures 1(a) to 1(d) shows some results for PV energy output for the vertical axis for four different locations. PV module slope or vertical control system: the angle at which the panel is positioned relative to the horizontal angle. This implies that the horizontal slope of the panel corresponds to 0°, and the vertical axis corresponds to 90°. The vertical axis irradiation monitoring is usually intended to optimize the output of PV energy. Azimuth of a PV or inclined tracking device: the azimuth is the orientation, or angle, of the PV modules with respect to the direction of due south; (-90°) denotes east, 0°, south, and 90°, respectively. Trackers with two axes: The panels are rotated along both horizontal and vertical axes in this tracking device so that the sun's rays are still perpendicular to the surface. This form of tracking system gives the PV panels the highest power output. Generally, the amount of electrical power generated in vertical axis tracking is completely different than the inclined axis depending on the season and the position of the city. At the same time, the two-axis tracking system shows the best results and is better than the other two systems.

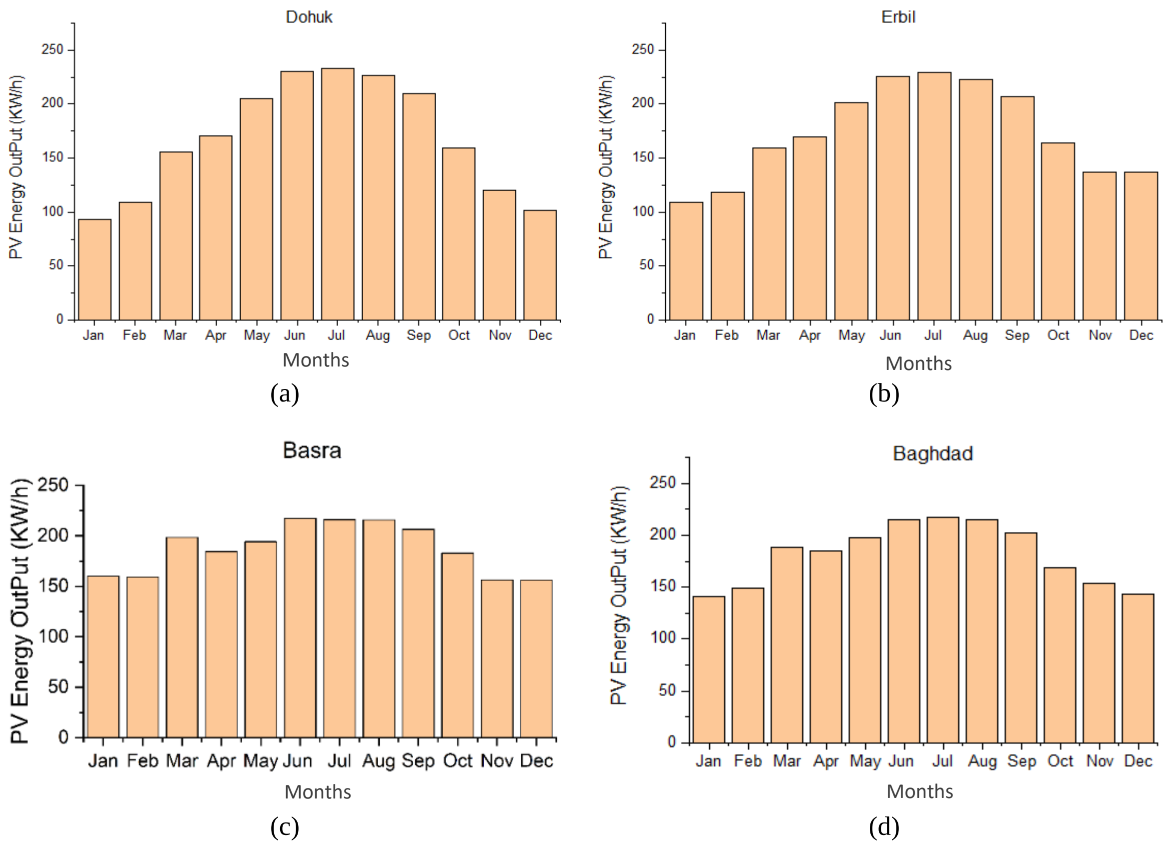

Figure 1. Monthly energy output from tracking PB (a) Dohuk, (b) Erbil, (c) Basra, and (d) Baghdad

Table 1 summarize the result for PV energy output for the vertical axis, Table 2 summarizes the result for PV energy output for the inclined axis, Table 3 summarizes the result for PV energy output for the two-axis and Table 4 summarize all the result as it shows the Iraqi cities can be divided into three regions, the northern cities, middle lands and the southern cites in two seasons winter season (November-April) and the summer season (May-October) which the sun's rays are vertical or close to vertical during the summer and tilted or close to slanting during the winter days, and the daytime is longer during the summer than in the winter months, with an increase of three hours and 48 minutes. In other words, the length of the day in summer around 14 hours and 4 minutes, while in winter it reaches 10 hours and 16 minutes. In addition to the length of the day in summer, the sky of Iraq is characterized by its clarity and cloudlessness, and its air is characterized by a lack of atmospheric humidity, which helps to reach the largest amount of solar radiation directly to the surface of the earth.

Table 1. Summary of PV generation for all Iraqi cities (vertical axis)

	Vertical Axis											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dohuk	93.2	109.3	155.4	170.7	205.5	229.9	233	226.1	209.8	159.1	119.9	101.6
Erbil	108.8	118.4	159.1	169.5	200.9	225.5	229	222.5	206.9	164.4	137.4	137.2
Sulaymaniyah	102.6	104.7	144	161.2	195.4	228.3	228.4	224.2	207.4	15.6	128.8	110.8
Al-Mousal	113.6	127.1	173.6	178	211.1	230.7	233.2	222.4	208.3	170.5	140.8	120.8
Kirkuk	121.7	131.4	174.7	177.8	200.7	223.8	225.3	220.2	205.6	168.4	144.4	129.1
Salah Al-din	133.2	142.2	187.2	182.8	205.5	221.4	223.4	217.4	205.5	163	150.8	135
Al-Anbar	162	161.8	204.7	202.2	216.9	332.7	239.7	227.5	214	182.9	166.9	165.2
Diyala	133.7	138.6	179.8	180.7	199.7	219.4	219.5	216.7	204	165.3	147.5	137.4
Baghdad	140.6	149	188.2	184.9	198	215.2	217.6	214.8	202.7	168.2	153.2	143.1
Babil	142.4	152.6	187.6	183.5	193.5	212.8	216.7	211.7	199.8	168.8	149.3	145.1
Kerbala	144.5	157.3	195.5	189.9	201.1	220.2	224.4	217	205	172.7	153.1	145.1
Najaf	163.7	167.7	206.4	197.7	207.3	221.9	226	218.4	207	178.5	159.9	157.7
Wasit	133	143.9	183	180.2	195.1	220.5	218.9	216	205.1	167.5	144.9	140.5
Al-Qadisiyah	150.6	155.9	196.5	184.7	192.9	215.1	216.2	212.8	202.1	173.5	152.5	149.8
Al-Muthanna	164.5	1641	200.5	158.4	193.6	214.1	215.8	213.9	204.4	186.7	156.3	161.4
ThiQar	148.7	155	189	181.1	191.4	216.7	214.3	213.7	206.6	173.3	151.6	149.2
Misan	146.2	154.1	187.7	179.2	191	2158	212.1	211.9	202.9	174.4	149.6	146.8
Al-Basra	160	159.5	198.4	184.5	194.2	217.2	216.2	215.8	206.5	182.9	156.5	156.2

Table 2. Summary of PV generation for all Iraqi cities (inclined axis)

	Inclined Axis											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dohuk	89.1	108.3	158.1	174.3	208.3	230.8	236.5	230.9	214.4	159.1	115.4	96.1
Erbil	105.6	117.8	161.9	173.1	203.4	226.6	231.3	227.4	211.6	165.1	133.4	116.2
Sulaymaniyah	99.2	104	146.5	14.8	198.3	229.9	231.1	229.6	212	166.1	125.2	106
Al-Mousal	110.5	126.3	176.3	182.5	213.5	231.5	235.3	226.9	212.8	171	136.9	115.8
Kirkuk	118.3	130.7	177.7	181.5	202.8	224.4	227.1	224.8	210.3	169.1	140.8	123.9
Salah Al-din	129.7	141.4	190.2	186.4	207.5	221.6	224.8	221.6	210.2	164.6	146.8	129.7
Al-Anbar	157.4	161	208.4	206.7	219.3	232.9	241.6	232.2	220.3	183.8	163.1	150.4
Diyala	130	138	182.6	184.5	201.2	219.6	221.2	221.2	208.7	166	144.1	132
Baghdad	136.8	148.3	191.5	188.9	198.9	215.3	219	219.2	207.4	169.1	150.2	137.4
Babil	138.8	152	191.2	187.7	195.5	213	218.3	216.2	204.8	169.9	146.1	139.5
Kerbala	140.7	156.5	199	194.1	203.2	220.4	226.1	221.5	209.9	173.6	149.9	139.4
Najaf	159.2	166.9	210.2	202.1	209.4	221.8	227.4	223	212.1	179.5	156.6	151.5
Wasit	129	143.2	186	184.4	197.5	221.2	220.8	221.2	210.1	168.4	141.6	134.8
Al-Qadisiyah	146.5	155.3	200.1	188	194.9	215.3	217.7	217.6	207	174.7	149.6	144
Al-Muthanna	159.9	163.5	204.6	189.9	195.5	214.1	217.3	218	204.7	209.7	188.4	155.1
ThiQar	144.7	154.6	192.9	185.4	193.8	216.9	215.8	218.6	208.6	174.6	148.5	143.4
Misan	144	153.8	191.2	183.4	193.1	216.1	213.6	216.9	208	175.6	146.6	141
Al-Basra	155.4	159	202.2	189	196.3	217.7	217.7	220	211.9	184.4	153.1	150.1

Table 3. Summary of PV generation for all Iraqi cities (two-axis)

	Two Axis											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Dohuk	94.2	110.7	158.5	175.6	214.7	241.9	245.7	233.9	214.7	161.7	121.7	103.8
Erbil	11.6	120.3	162.2	174.6	210.2	238.3	240.9	230.7	211.8	167.6	140.5	125.3
Sulaymaniyah	105.5	106.5	146.8	166.1	204.5	241.1	240.1	232.6	212.3	168.9	132	114.4
Al-Mousal	116.6	129.1	176.7	184.1	220.7	243.7	245.3	230.3	213.1	173.6	144.1	124.8
Kirkuk	125	133.6	178.1	183.2	210.1	236.7	237.2	228.4	210.5	171.5	1479	133.2
Salah Al-din	136.8	144.5	190.6	188.2	215.1	234.3	235.4	225.4	210.4	166.7	154.1	138.9
Al-Anbar	166.4	164.5	208.8	208.8	228.1	247.2	253.9	236.6	220.6	185	170.7	161
Diyala	137.2	141	183	186.3	208.7	232.2	231.4	225	208.9	168.1	151.1	141.7
Baghdad	144.3	151.6	191.9	190.8	207.7	228.2	229.8	223.2	207.6	171.1	157.2	147.4
Babil	146.3	155.4	191.6	189.6	203.2	225.8	229.1	220.2	204.8	171.9	152.9	149.5
Kerbala	148.3	160.1	199.5	196	211	233.6	237.2	225.6	210.2	175.7	156.8	149.3
Najaf	168.1	170.5	210.6	204.3	217.8	235.6	239.2	227.4	212.4	181.5	163.4	162
Wasit	136.2	146.5	186.5	186.1	204.8	234	231.2	225	210.3	170.6	148.4	144.9
Al-Qadisiyah	154.6	158.7	200.5	190.9	202.7	228.6	228.7	221.8	207.3	176.8	156.4	154.3
Al-Muthanna	168.7	167	205	192	203.6	227.8	228.7	223.4	209.9	190.5	159.7	166
ThiQar	152.7	158	193.3	187.3	201.4	230.2	226.6	222.8	208.8	176.6	155.3	153.7
Misan	152.1	157.2	191.6	185.3	200.8	229.2	224.2	220.9	208.2	177.7	153.3	151.1
Al-Basra	164.1	162.4	202.6	191	204.2	231.4	228.9	225.3	212.2	186.5	160.1	160.7

Table 4. Summary of PV generation for all Iraqi cities

State Name	Average Summer generation (May-October)			Winter generation (November-April)			Annual generation		
	Vertical axis	Inclined axis	Two axes	Vertical axis	Inclined axis	Two axes	Vertical axis	Inclined axis	Two axes
Dohuk	210.51	213.33	218.76	105.016	123.6	122.41	315.526	336.93	341.17
Erbil	208.8	210.9	216.51	135.7	138.71	139.1	344.5	349.61	355.61
Al-Sulaimaniyah	208.22	211.17	216.58	125.35	124.28	128.55	333.57	335.45	345.13
Al-Mousal	212.7	215.17	221.62	142.32	141.38	145.87	355.02	356.55	367.49
Kirkuk	207.3	209.7	216.6	146.5	145.5	150.2	353.8	355.2	366.8
Salah Al-din	222.7	225.1	231.2	155.2	154.03	159.1	377.9	379.13	390.3
Al-Anbar	218.95	221.68	228.57	175.6	174.5	180.03	394.55	396.18	408.6
Diyala	204.02	206.3	213.44	152.95	151.87	157.05	356.97	358.17	370.49
Baghdad	201.75	204.98	212.65	159.88	158.88	164.9	361.63	363.86	377.55
Babil	205.5	208.6	217.6	160.08	159.22	165.2	365.58	367.82	382.8
Kerbala	206.7	209.12	218.6	160.9	163.3	168.3	367.6	372.42	386.9
Najaf	209.78	212.2	222.5	165.52	174.42	179.82	375.3	386.62	402.32
Wasit	203.85	199.87	212.6	154.22	153.2	158.1	358.07	353.07	370.7
Al-Qadisiyah	202.1	204.5	210.98	172.52	163.92	169.23	374.62	368.42	380.21
Al-Muthanna	201.75	207.17	215.5	172.03	171.03	176.4	373.78	378.2	391.9
ThiQar	202.22	204.72	209.15	162.48	161.58	166.72	364.7	366.3	375.87
Misan	201.53	203.88	210.17	160.9	160	165.1	362.43	363.88	375.27
Al-Basra	205.52	208	214.75	169.18	168.17	173.48	374.7	376.17	388.23

The results show the three northern cities (Dohuk, Erbil, and Al-Sulaymaniyah) have the lowest generation in the winter season which is almost half the generation of the summer season, while in the middle land and southern cities the generation roughly is the same generation during all the year. However, at the same time, the southern cities show the best generation during all the year, which is very helpful to keep constant generation in all months. The highest generation cities in all the years are Najaf and Al-Anbar, on the other hand, the cities which have the lowest generation, are (Dohuk, Erbil, and Al-Sulaymaniyah). In the summer season, the vertical tracking axis gives a much better generation than the inclined axis except for Wasit city. While in winter the vertical axis gives better results than the inclined axis except for (Wasit and Al-Qadisiyah) cities which give a higher number. Finally, the two axes tracking system gives the best generation during all the year and in all cities.

6. CONCLUSION

This paper showed the amount of electrical energy generated by a one-meter square PV array made from monocrystalline silicon for each Iraqi city from the North Dohuk City to the end of South Iraq Basra City (18 Iraqi states). This research paper, can show the exact area of photovoltaic arrays required for installation for any size of PV field and also show how useful using this type of PV array is in each city of the year. At the same time, it will help the government of the interested companies who would like to build PV farm since Iraq does not has any farm or project connected with the national grid. The results show the average of the electricity generated in north cities especially (Dohuk, Al-Sulaymaniyah, and Erbil) are less than the southern cities in the winter season in all three positions resulting in about 35% from the Basra City. While in the summer season the 3 cities are generated slightly higher than other cities even higher than the Basra City. Also, the highest cities in generating electricity are (Najaf and Al-Anbar) all the year.

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BIOGRAPHIES OF AUTHORS

Tariq Emad Ali has B.Sc. and M.Sc. in Electronic and Communication Engineering, College of Engineering, Baghdad University. He is a lecturer at Baghdad University, Al-Khwarizmi Collage of Engineering, Information and Communication Engineering Department. He has 6 published scientific and technical papers including IEEE explorer. Mr. Tariq Emad has 12 years of academic and practical and consulting experience in Networking and Communication. He currently teaches and conducts research programs in the areas of software computer networks, soft computing, intelligent agents, Ad Hoc networks, wireless sensor networks, routing protocols and security of VANETs, smart antenna in MANETs and WiMAX networks, SDN networks, IoT, IOE, and IOV. He can be contacted at tariqemad@kecbu.uobaghdad.edu.iq.

Mohammed A. Abdala was born in Baghdad, IRAQ, 5/12/1962. Doctor of Philosophy (Ph.D.), Electronic Engineering-Transconductance and Noise Analysis in GaAs MESFETs. Lancaster University, UK. Oct. 1991. Master of Science (M.Sc.), Semiconductor Devices, Lancaster University, UK. Oct 1988. Bachelor of Science (B.Sc.) (Hons.), Electrical and Electronic Engineering. Grade: Distinction, University of Technology, Baghdad, Iraq. June 1984. He is now the head of the Medical Instruments Engineering Department at Al-Hussain University College, Iraq. He has more than 30 years of academic and consulting experience in networking, microelectronics, solid state electronics, software engineering, pattern recognition, and verification. He published more than 45 scientific and technical papers. He currently teaches and conducts research programs in the areas of image processing, Genetic and PSO optimization algorithms, pattern recognition and verification, VHDL implementation of image compression algorithms, software engineering, and E-commerce, wireless sensor networks, wireless Ad Hoc networks, software defined networks and others. He supervised over 60 postgraduate theses and over 80 graduate projects and examined over 100 M.Sc. and Ph.D. theses. Associate Professor Dr. Abdallah is a Senior Member of the IEEE and Iraqi Engineers Union. He is an Editor-in-Chief of i-manager's Journal on Information Technology (JIT) in India and editorial board member of several journals in Italy, India, and Iraq. He is a PC member and reviewer for many worldwide conferences. He can be contacted at mohammedalmushdany@yahoo.com.

Ameer Al-Khaykan received the Ph.D. degree in Electrical and Electronic Engineering from University of Chester in UK. He has many years of experiences in electrical engineering, energy system, renewable energy, sustainable energy system, DC system design and new control systems. Design many projects in Smart Gird and CCHPV and Local Energy System with intelligent Control System Design. He is Head of Depart of the Electrical Power Techniques Engineering Department at Alhussain University College, researcher and visitor lecturer at University of Chester. Expertise in supporting energy marketing. Strong ability to enhancing Higher Education through developments the interactive curriculum at Chester University. Dr. Al-Khaykan is a research member in EPSRC. IEEE student member, IET student member, IEEE conference reviewer, Iraqi Engineering Union (consultation level), editor and reviewer in international journal 'Energy and Building'. He can be contacted at Ameer_khaykan@gmail.com.

Dhulfiqar A. Alwahab he an assistant professor at the Faculty of Informatics, Eötvös Loránd University. My research is in-network congestion investigation using active queuing management (AQM), and telecommunication networks. I am an IC3 and CCNA, CCNP, DEVOPS certified and I am an instructor at the Cisco and AWS academies. I have publications in IEEE, ACM, and Springer. He can be contacted at aalwahab@inf.elte.hu.

John M. Counsell has 25 years' experience in advanced control systems applied to complex energy systems such as hybrid systems and local/community energy systems using multiple sources of electrical and heat generation. He is the Head of Department of Electronic and Electrical Engineering at the University of Chester and manages the energy system and control research team. Through his career he has worked closely with the electricity supply industry, private sector business, and academia. Expertise and successes in control systems span aerospace, robotics, and local energy systems modelling and control. He invented the CELECT control system for demand side response for storage heating in the UK in 1994 and is the only DSR system recognized in Part L of UK's Building Regulations. He can be contacted at j.counsell@chester.ac.uk.