INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 8, Issue 1, 2017 pp.63-72
Journal homepage: www.IJEE.IEEFoundation.org

Management of electricity peak load for residential sector in Baghdad city by using solar generation

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Received 25 July 2016; Received in revised form 1 Sep. 2016; Accepted 7 Sep. 2016; Available online 1 Jan. 2017

Abstract
Load management strategies such as peak reduction, load shifting and energy conservation are effective solution to save and optimally usage of electricity. Solar cells - photovoltaic systems (solar PV) are one of the modern methods used in the management of peak loads in the electric power system because PV generation coincides with peak load hours in the day. The aim of this work is implementation of management techniques using solar cells for residential sector in Baghdad city. The estimation of solar radiation data and PV system design has been simulated based on MATLAB software. In this study, a 20% efficiency monocrystalline silicon rooftop PV generator of 2kWp with six panels and overall area 10m² has been proposed for each customer in the residential sector of Baghdad. The panels are orientated towards south (azimuth angle equals zero) with a tilt angle equals 18° for summery months and 48° for wintery months. The obtained results of demand saving range between 17% for January and 27% for April while 20% for June. The annually demand saving for each consumer is 20%. As well as to the demand saving, this study presents the capability of application the load-shifting technique from high load periods to low load periods, and ability to store the surplus energy produced from PV generator in batteries for usage this energy at a later time.

Keywords: Management; DSM; PV system; Solar radiation; Peak load; PV generation; Demand saving.

1. Introduction

The demand for electricity differs in each area and therefore depends on numerous factors, such as the price of electricity, the weather conditions, the time of day, the type of activity and the type of the season [1]. Peak load is the maximum electrical load consumed at critical hours. It can be met by combustion turbine, renewable energy resources and load management [2]. Since electricity is an essential input in all the sectors of any country, hence it is needed to focus on means by which electricity can be saved and effectively utilized. The effective solution to above said problems is demand side management (DSM) strategies which represented by peak clipping, load shifting, valley filling and energy conservation as shown in Figure 1. DSM is the planning, implementation, and monitoring of all activities designed to influence customer use of electricity in ways that will produce desired changes in the load profile. The major benefits of DSM are reducing the generation margin and improving transmission grid, distribution network and operation efficiency. Numerous studies in China and other countries have found that DSM programs can reduces the electricity use and peak load by approximately (20-40)% [3].

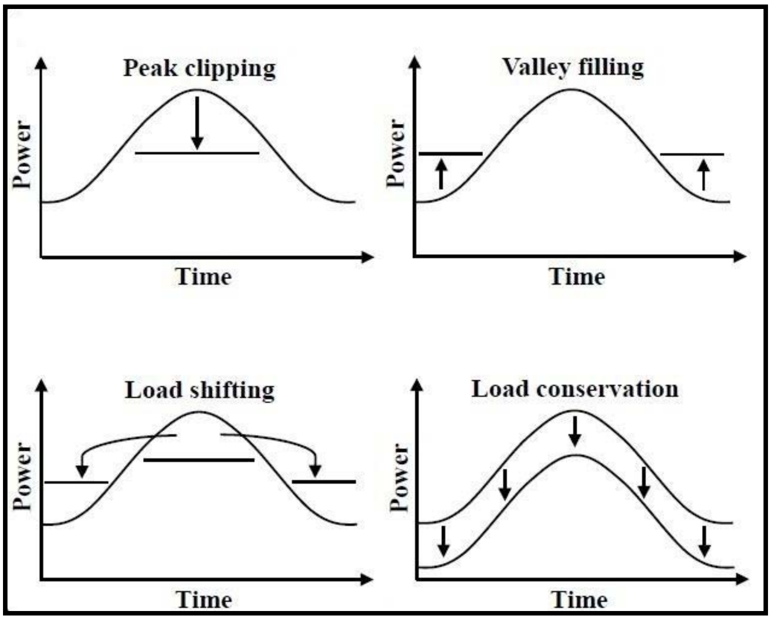

Figure 1. Demand side management techniques [4].

The conventional fossil fuel energy sources such as petroleum, natural gas and coal which meet most of the world's energy demand today are being depleted rapidly. Also, their combustion products are causing global problems such as the greenhouse effect and pollution which are posing great danger for our environment and eventually for the entire life on our planet. Photovoltaic generators which directly convert solar radiation into electricity have a lot of significant advantages such as being inexhaustible, pollution free, silent, free fuel and high lifetime. Photovoltaic power output period partially coincides with the peak electricity demands of the day, consequently DSM applications of PV system has been interested recently [5].

Today, all the world begins use the solar energy as non-fossil energy source and in the last six years it used as management tool. So, number of previously published researches within DSM and solar cell technology which are shown as follows. S. J. Lewis, 2011 [6] presented the effect of PV systems on the network and ways to minimize the negative impacts. Management strategies suggested are a monitoring program and energy storage. A. Batman, et al., 2012 [1] introduce a study to determine solar power generation potential and its impact on peak demand in Istanbul, Turkey. Measured data with technical and commercial parameters were used to perform the calculations as well as Different tariffs such as time-of-use was considered in this study. M. A. Salam, et al., 2013 [7] discussed the design and analysis of Photovoltaic system to supply lighting load. Optimization simulation model was developed using the renewable energy software HOMER. Y. B. Almutairi, 2014 [8] introduced the solar energy for peak shaving during peak loads and investigated the feasibility of using grid-connected solar system for electricity generation in a Ministry in Kuwait. PVsyst software is used to find the optimal design for total connected load. Based on the study results, the development of grid-connected photovoltaic (PV) solar system could be economically viable and provide peak shaving during peak loads. A. H. Abbas, et al., 2015 [9] developed a methodology for estimating the optimal design of a stand-alone hybrid wind/photovoltaic (wind/PV) system by using the direct algorithm to achieve a minimum cost of energy production while satisfying the energy demand. In this work, DSM techniques such peak shaving and load-shifting are implemented using PV system.

2. Mathematical model for solar radiation and PV system design

Solar radiation is the rate at which radiant energy of the sun is incident on a surface per unit area of surface [10]. Neglecting the reflection component, the hourly global solar radiation on a horizontal surface in clear sky, R_h (W/m^2) is given by [11],

$$R_h = R_a 0.7^{m^{0.678}} \tag{1}$$

where m is the air mass given by,

$$m = \sqrt{[1229 + (614\cos\theta_z)^2]} \; - 614\cos\theta_z \tag{2}$$

And R_a is the extraterrestrial irradiance on a horizontal surface given by,

$$R_a = R_{sc}[1 + 0.033\cos\frac{2\pi J}{365}]\cos\theta_z \tag{3}$$

where R_{sc} is the solar constant=1.367 kJ/m².s, J is the day number starting from 1-Janaury, and θ_z is the angle of incident on a horizontal surface (zenith angle) obtained from,

$$\cos\theta_z = (\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta) \tag{4}$$

where ϕ is the geographical latitude, and δ is the solar declination angle given by,

$$\delta = 23.5\sin[\frac{360}{365}(J + 284)] \tag{5}$$

And w is the hour angle calculated from,

$$w = 15(12 - ST) \tag{6}$$

where ST is the local solar time which calculated from the local standard time (LT) and the equation of time (ET) as follows,

$$ST = LT + \frac{ET}{60} + \frac{4}{60}(L_s - L_L) \tag{7}$$

where L_s is the standard meridian for the local time zone, L_L is the longitude of the location in degree, and ET is the equation of time given by,

$$ET = 9.87\sin 2B - 7.53\cos B - 1.5\sin B \tag{8}$$

where

$$B = \frac{360(J - 81)}{365} \tag{9}$$

Now, the solar radiation on a tilted surface (R_T) can be estimated as follows [10],

$$R_T = R_h \times \frac{\cos\theta}{\cos\theta_z} \tag{10}$$

where ($cos\theta/cos\theta_z$) is the geometric factor ratio (R_b), and θ is the angle of incident on a tilted surface obtained from,

$$\begin{aligned}\cos\theta &= \sin\delta\sin\phi\cos\beta - \sin\delta\cos\phi\sin\beta\cos\gamma + \cos\delta\cos\phi\cos\beta\cos\omega \\ &+ \cos\delta\sin\phi\sin\beta\cos\gamma\cos\omega + \cos\delta\sin\beta\sin\gamma\sin\omega\end{aligned} \tag{11}$$

where β is the tilt angle, and γ is the azimuth angle (equals zero if the solar panels oriented due south, negative if the orientation due east, and positive if the orientation due west).
The DC power output from PV generator (P_{PV}) depends on the incident irradiance (R_T), the surface area of module (S_{PVG}), and its efficiency (η_P) and is given by [12]:

$$P_{PV} = \eta_P \times R_T \times S_{PVG} \quad (12)$$

The PV generator efficiency (η_P) is, in turn, dependent on the PV module operating temperature (T_M) and cell material and can be expressed as,

$$\eta_P = \eta_R \times [1 - \beta_P (T_M - T_R)] \quad (13)$$

where η_R is the module efficiency at the reference temperature (at 25°C), β_P is the thermal efficiency coefficient of the cell material (%/°C), T_R is the reference temperature (25 °C), and T_M is the module operating temperature, given by,

$$T_M = T_A + k \times R_T \quad (14)$$

where T_A is the ambient temperature, and k is the module thermal coefficient(°C.m^2/W) which equal to 0.02. The losses of PV power conversion chain can be divided into, wiring losses, inverter losses and dust losses. So, the available power at the inverter output (P_{AC}) is given by:

$$P_{AC} = P_{PV} - (\%Losses \times P_{PV}) \quad (15)$$

3. Input data

The input data and assumptions of mathematical model for the case study (Baghdad city) can be explained as follows:

1. Geographical latitude of Baghdad (ϕ)= 33.33°.
2. Longitude of Baghdad (L_L)= 44.11°.
3. Standard meridian for Longitude of Baghdad (L_s)= 45°.
4. Local standard time (LT)= 1-24 hours.
5. Day number (J)= 1-365 days.
6. Solar constant (R_{sc})= 1.367.
7. Azimuth angle (γ)= 0°.
8. Module thermal coefficient (k)= 0.02.
9. Reference temperature (T_R)= 25.
10. Losses of system (% Losses)= 20%.
11. Ambient temperature (T_A) is the maximum average air temperature during daytime for each month as illustrated in Table 1 [13].
12. Specifications and design parameters of solar panel used for this work are illustrated in Table 2.

4. Simulation procedure

In this work, MATLAB software is used for estimation the hourly and monthly solar radiation on a tilted surfaces in Baghdad city, then PV generation is calculated for 2kWp PV system for residential sector. The flowchart of the proposed system is as shown in Figure 2.

Table 1. Monthly and seasonal temperature means in Baghdad city [13].

Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
$T_{A(min)}$(°C)	4.09	5.58	9.39	14.75	19.88	23.15	25.2	24.24	20.55	15.87	9.83	4.09
$T_{A(max)}$(°C)	15.7	18.6	22.79	29.29	36.1	41.06	43.63	43.36	39.97	33.23	24.2	15.71
$T_{A(mean)}$(°C)	9.9	12.1	16.1	22.0	28	32.1	34.4	33.8	30.2	24.5	17.0	9.9

Table 2. Design parameters and specifications of the PV system.

Parameter	Value
System size	2 kWp
Nominal power of Panel	327 W
Panel area	1.6 m²
Panel efficiency (η_R)	20 %
Number of panels	6
System surface area (S_{PVG})	10 m²
System losses	20 %
Temp coefficient (β_P)	–0.38 % / °C
Cell type	Monocrystalline
Operating temperature	-40 °C to +85 °C

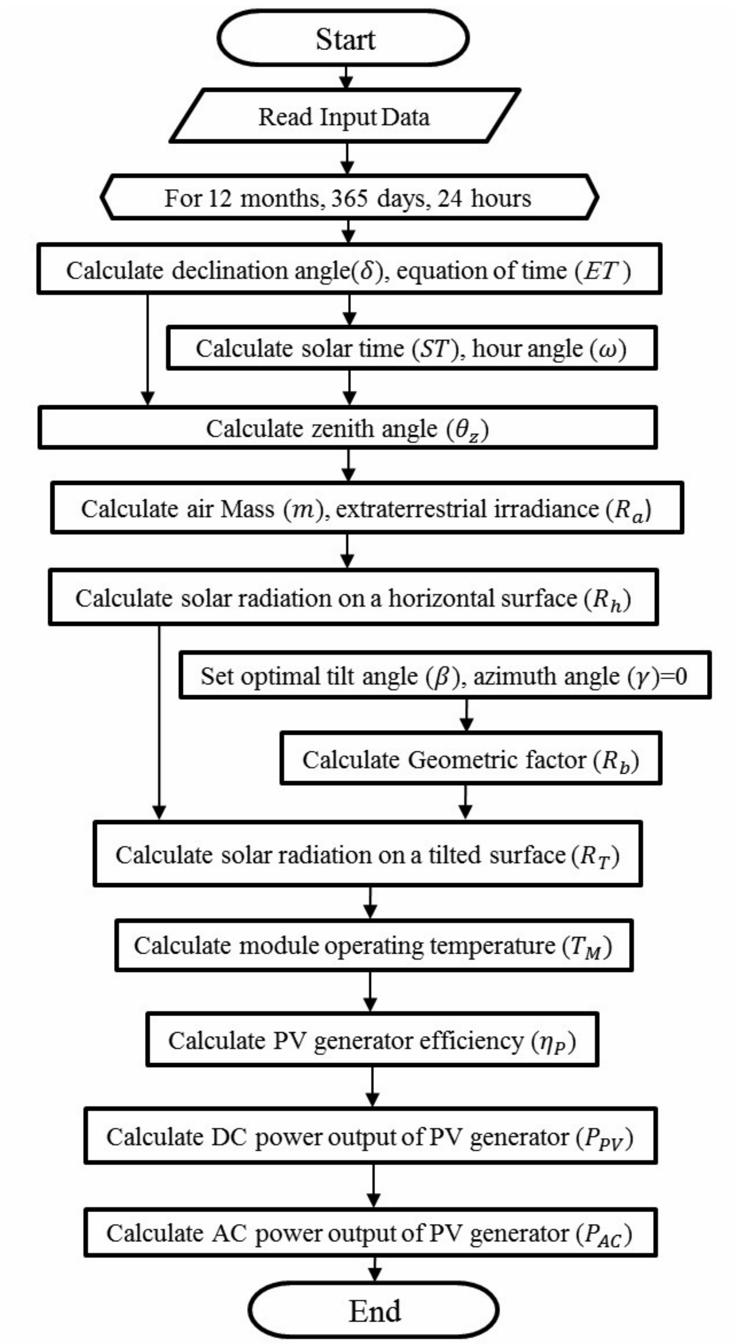

Figure 2. Flowchart for estimation solar radiation and PV generation.

5. Results and discussion

The first step of this work is optimization the tilt angle of the panels because this will influence on the amount of PV generation that can be produced from the sites in which the solar cells to be set up, and hence on peak demand. Therefore, the annually optimal tilt angel has been obtained by varying the slope of the surface from 0-90°. Table 3 illustrates the annually solar radiation with different tilt angles. It is obvious that the maximum annually solar radiation at tilt between 30° and 35°. This indicates that the yearly optimal tilt angle is approximately equal to the latitude of Baghdad (33.33°).

Table 3. Yearly solar radiation with different tilt angles.

Tilt angle	0°	10°	**20°**	**30°**	**35°**	40°	50°	60°	90°
Annually average radiation (kWh/m^2/day)	5.3	5.7	**6**	**6.08**	**6.04**	5.9	5.6	5.1	2.8

Also, the monthly optimal tilt angle ($\beta_{optimal}$) has been obtained as in equation (16) [14]. So, the optimal tilt angles for each month are obtained as shown in Figure 3.

$$\beta_{optimal} = \phi - \delta \tag{16}$$

But, it is difficult to implement a tilt angle each month, so we suggest a seasonally optimal tilt angle as illustrated in Table 4. In this work, we depend on 18° tilt angle for summer months and 48° for winter months. Figure 4 shows the hourly radiation on optimally tilted panels for each month and output PV generation.

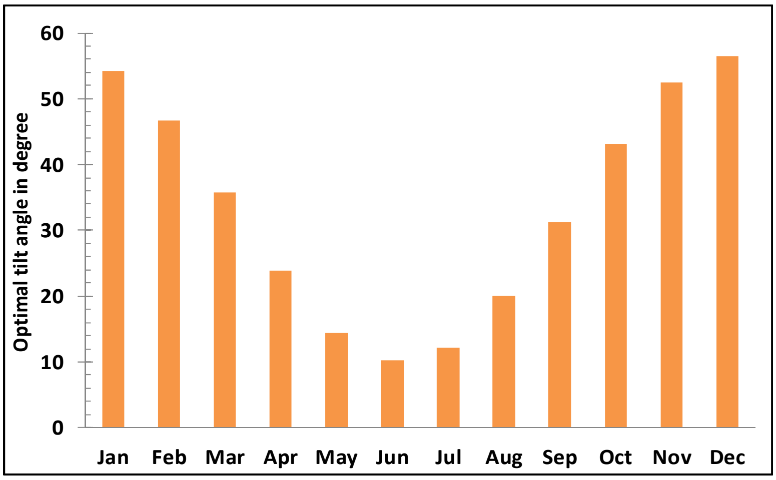

Figure 3. Monthly optimal tilt angle for Baghdad city.

Table 4. Monthly and seasonally optimal tilt angle.

Summer season		**Winter season**	
Month	Optimal tilt angle	Month	Optimal tilt angle
Apr.	23°	Oct.	43°
May	14°	Nov.	52°
Jun.	10°	Dec.	56°
Jul.	12°	Jan.	54°
Aug.	20°	Feb.	47°
Sep.	31°	Mar.	36°
Average	**18°**	**Average**	**48°**

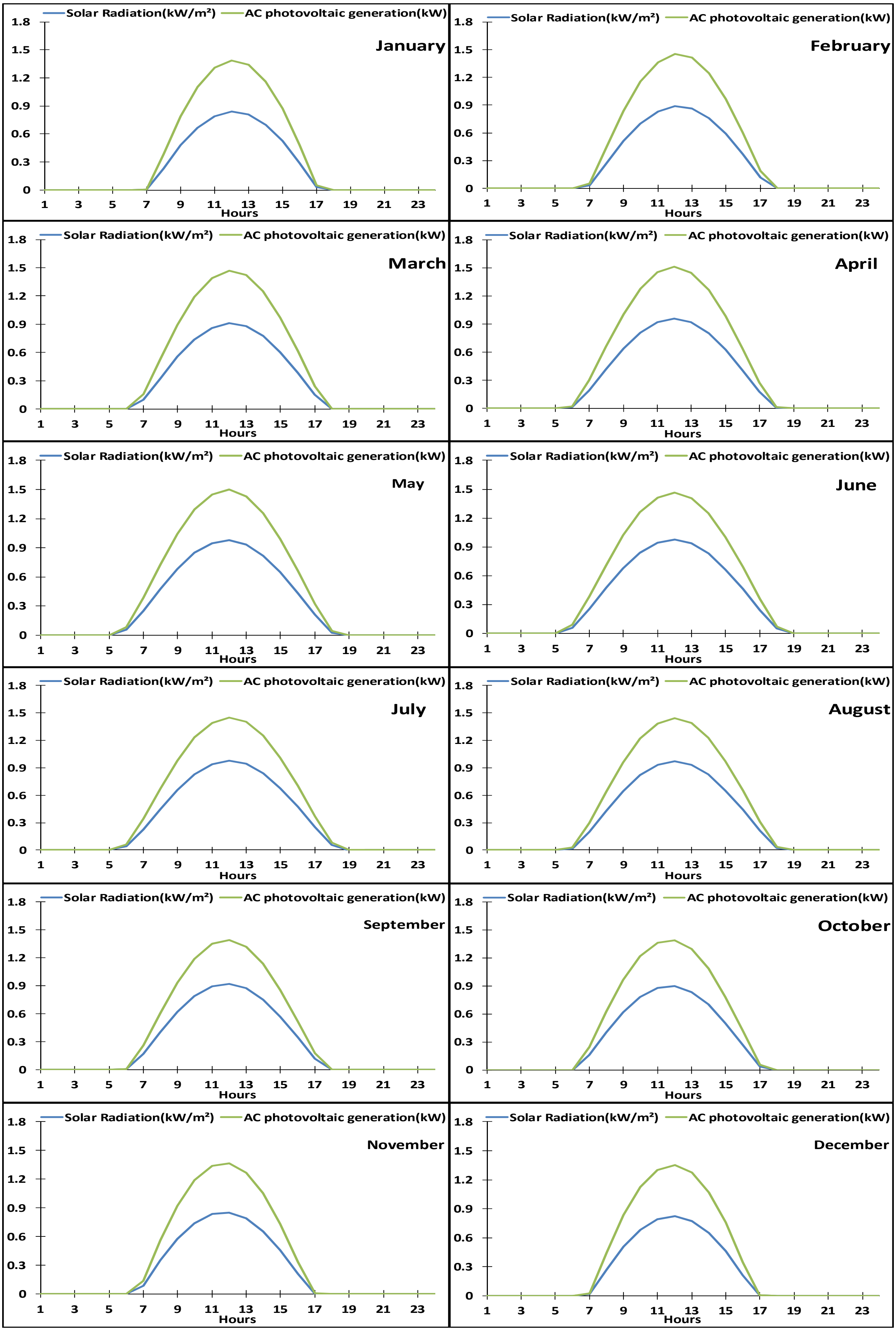

Figure 4. Hourly average solar radiation and PV generation for each month with 2kWp PV system.

It is clear from previous figure that the power output from PV system varies throughout the day and the season. This variation is due to the angle of the sun is higher during the daytime and weather conditions effectiveness.
A load profile gives a relationship between the electrical load and time [15]. The impact of the PV generation on the electricity demand of each residential costumer of Baghdad for two different months (summery month and wintery month) can be seen from Figure 5 where the area filled with a green color in the figures represents the demand saving from using a PV system. The data for load demand are collected from Iraqi ministry of electricity-national control center.
The annually and daily energy of each month per consumer with demand saving as illustrated in Table 5.

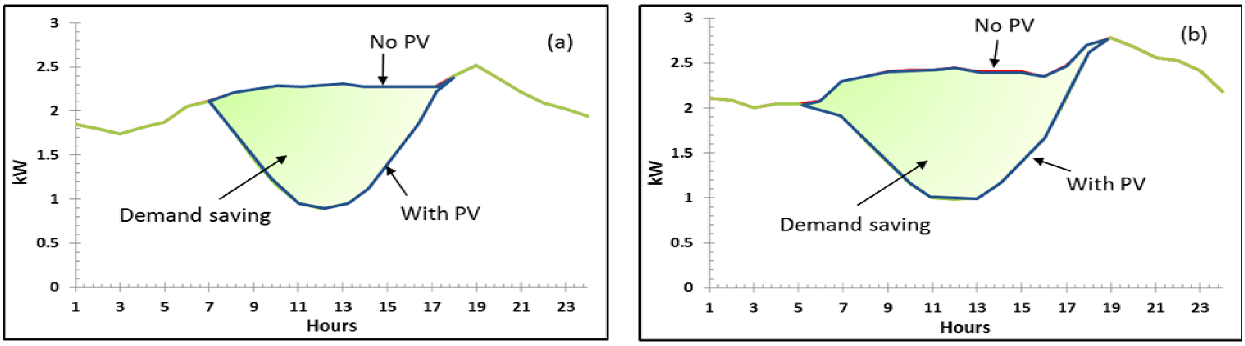

Figure 5. Impact of solar generation on peak demand for: (a) January, (b) June.

Table 5. Daily consumption with demand saving of each month.

Month	Old load (kWh/day)	New load (kWh/day)	Demand saving
January	51	42	17 %
February	50	41	19 %
March	37	27	27 %
April	40	29	27 %
May	54	43	21 %
June	57	45	20 %
July	61	50	18 %
August	65	54	16 %
September	59	50	16 %
October	50	40	19 %
November	40	31	22 %
December	49	41	17 %
Yearly	**51**	**41**	**20 %**

From the previous table, we notice the following points: firstly, the demand saving is maximum in the March and April months because of low loads demand, secondly, the demand saving of wintery months (such as January) is approximately equal to demand saving of summery months (such as June). This is due to decrease the PV generation in wintry months with decreasing in load demand. On other hand, the solar generation rises in the summery months with increasing the load demand. Subsequently, the percentages of demand saving is still converging to each other's.
This study shows the application of demand side management by using PV generation. The applied strategies of DSM are:

1. Peak clipping because the peak loads in the daytime is reduced after taking the effect of PV generation. But the problem is only diurnal peak is reduced, while the nightly peak doesn't influenced by solar generation. Consequently, we need an alternative method in which the solar energy can be stored and then discharged as shown in Figure 6. The element which has ability to do this function is battery.
2. Load-shifting because there are surplus energy from PV generation during the daytime. This technique enables the consumer to shift the loads away from peak periods as shown in Figure 7 where this is called active demand side management (ADSM). Also, this strategy enables the

consumer to reduce the size of the battery by shifting the loads and subsequently reduces the cost. For example, we have a storage of 5kWh designed to peak shaving at night. If the costumer has ability to shift deferrable loads to low load periods, the battery storage can be reduced to 3kWh according to the necessity of power.

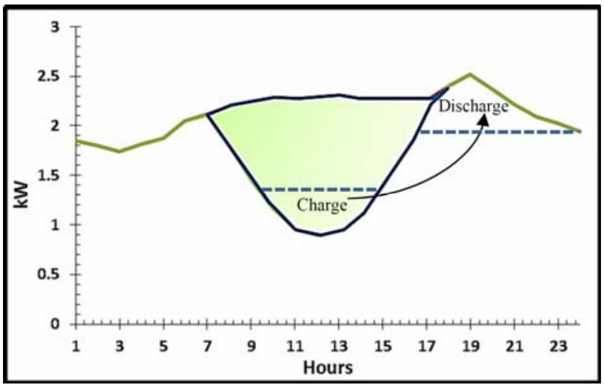

Figure 6. Principle of storage process.

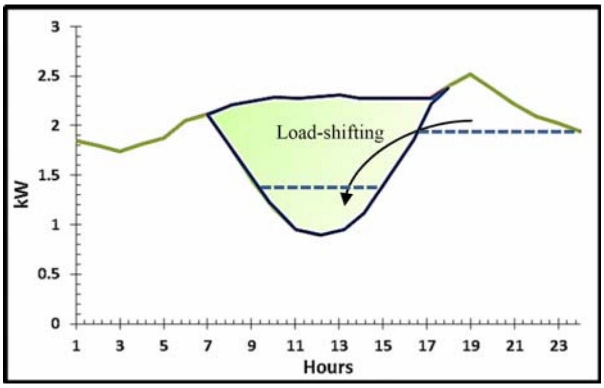

Figure 7. Principle of load-shifting.

6. Conclusions

In this work, we suggest a 2kWp photovoltaic system for each costumer of residential sector in Baghdad city to supply the loads partially and to provide ability of load-shifting, peak clipping techniques. The optimization of orientation the panels is proposed with 18° and 48° tilt angle for summery and wintery months respectively. The annually demand saving is 20% for each consumer. It is found that the percentages of demand saving increase in the summer though high loads periods because the PV output coincides with peak loads. The main objective of this study is showing the application of demand side management by using PV generation. Therefore, this work can be updated to be a starting point for a future works such as energy management for electrical load profile shaping based on battery system design with a control methods to manage the power that charges the batteries.

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