Visibility and Potential of Solar Energy on Horizontal Surface at Kuwait Area

F. Q. Al-Enezi, J. K. Sykulski, and Nabil A. Ahmed

***Abstract*—In this paper, an overview of the production and consumption of Kuwait electrical energy, installed capacity and peak loads are presented. The results show that Kuwait has a serious situation because of the electrical energy lacking and load peaking. Based on the fact that Kuwait has enough budgets to transform all the power station powered by oil with renewable energy sources turning to greener Kuwait. The paper also is identifying and analyzing the geographical and temporal variability of solar energy inside Kuwait. The fundamental solar models are modified to estimate and identify daily and hourly solar radiation on horizontal surfaces on the basis of the more readily available meteorological data. The presented results prove that Kuwait has an abundance of solar energy capability in terms of almost cloudless atmosphere for nine months and twelve hours solar time a day over the year. The daily global and monthly averaged solar intensity on horizontal surface at Kuwait area is ranging from 3 Wh/m^2 in winter to 8 kWh/m^2 in summer. Monthly averaged clear sky solar radiation on horizontal surfaces at Kuwait area is ranging from 500 W/m^2/day to 1042 W/m^2/day.**

***Keywords*—Solar radiation, meteorological data, extraterrestrial insolation, solar time, hour angle, peak loads.**

I. Introduction

Given the importance of the electric utility and its fundamental role and effective in the modern, civil societies, Kuwait tries to provide support for development to stay in line with the growing demand for its services, especially in light of the natural growth of population and expansion of development projects at all levels. Energy demand in Kuwait is rapidly increasing, as it can be seen for the past half century, the electrical demand has quintuple. So, it is no secret at a high cost incurred by the State budget in order to keep providing this service to all consumers without interruption, especially in light of the dependence on oil and its derivatives in the operation of electric power stations. Due to the increasing global demand for oil and because it represents the main income for Kuwait it has to be a serious stand to stop the wasteful consumption of electricity as well as reduce energy fuel used in the operation of this facility.

Based on the foregoing, Kuwait during the past years and through government foundations and academic centers did not overlook to provide campaigns and practical solutions to reduce waste and excessive consumption of electricity, which is one of the highest rates in the world [1], in the hope of general consumers to take rational and moderate way of life especially that the reduction refers to the extravagance of the extent of urbanization and awareness made in any society.

To reduce the extravagance and waste, this paper tries to find solutions to the rationing of energy use in order to preserve Kuwait oil wealth and to secure future needs of seriously during the orientation towards the use of alternative and renewable energy in power generation and uses of solar energy and its photovoltaic (PV) generation. Prior to investigating the potential and feasibility of solar energy in Kuwait, the paper presents an overview and information about the production and consumption of Kuwait electrical energy.

II. Production and Consumption of Kuwait Electrical Energy

The primary source of electrical energy in Kuwait is the chemical energy contained in nature gas and liquid oil products. The electrical utility in Kuwait mainly employs thermal power stations for the generation of power needed to satisfy demand. However, gas turbines (GT) are also used which make up around 28.7 % of total installed capacity. These GT are usually used in emergencies and during the time of peak loads [2] in spite of its high operational costs and low thermal efficiency. Power generating plants use different types of fossil fuel available in Kuwait such as natural gas, heavy fuel oil, crude oil and gas, depending on boiler design such that priority is given to natural gas within the limits of the available quantities. The older plants can burn natural gas and gas oil in case of emergency while the newer ones are capable of burning the four types of fuel. Table 1 shows the electrical load consumption in Kuwait for selected years, while Fig. 1 illustrates the Kuwait installed capacity and peak loads for selected years.

The consumption of electrical energy in Kuwait indicates that almost one half of the generated energy in Kuwait is consumed for domestic purposes because both the government and the citizens are still establishing more and

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more residential areas every year [3]. On the other hand, most of the load in residential, industrial and commercial areas is due to air conditioning (A/C) systems [4].

Table 1: Electrical Load for selected years

Year	Peak load (MW)	Installed Capacity (MW)	Mean Annual Rate of Peak Lead Growth During 10 Years (MW)
1979	1950	2578	-
1989	4150	7411	7.9 %
1999	7160	8289	5.6
2009	11960	12579	8.4

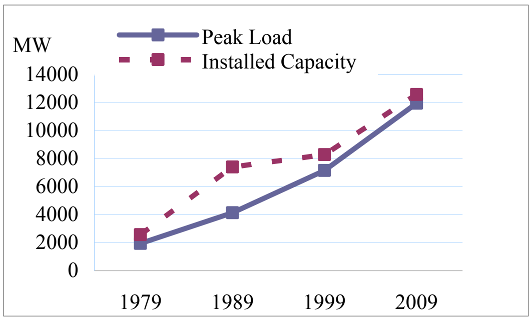

Fig. 1. Kuwait installed capacity and peak load for selected years.

According to the maximum and minimum load distribution shown in Fig.2 for 2010 year, Kuwait electrical load is characterized by high load in summer and low load in winter depending on the increase and decrease in the values of temperatures and relative humidity.

III. Models for Estimating Solar Radiation

Solar energy is clean, quiet, abundant and a renewable energy source, which produces no pollution to the environment [1]. Therefore, solar energy as renewable energy source is occupying one of the most important places among various alternative energy sources and being increasingly adapted in many applications [5]-[6].

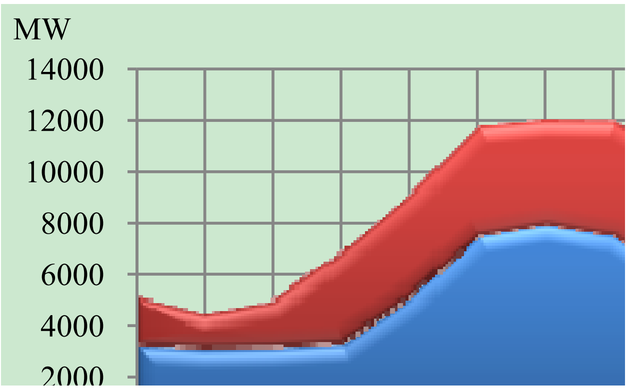

Fig. 2. Maximum and minimum loads during 2010.

An accurate knowledge of solar radiation (SR) availability at a particular geographical location is of vital importance for the development of solar energy systems and for the estimation of their efficiencies and output [7]. The knowledge of SR data is a prerequisite for the modeling and design of all photovoltaic systems [8]-[9]. The familiarity of SR data is valuable for architects, agriculturalists, air conditioning engineers and energy designers for the proper design and operation of engineering projects. The information of SR is also useful for the atmospheric energy-balance, climatology and pollution studies [10]-[12]. There are hundreds models with different techniques available which correlate the global SR to other climatic parameters such as sunshine hours (solar time), maximum temperature and relative humidity.

The basic and fundamental empirical model was proposed by Angstrom in 1924 [13]. Most of authors modified the Angstrom model for estimating SR data at their places of interest. Since, some researchers proposed trigonometric models; a few authors suggested linear logarithmic models, whereas, the others presented quadratic models. This model is widely used for measurements of SR until 1970 when the National Oceanic and Atmospheric Administration (NOAA) in United States and later by the National Renewable Energy Laboratory (NREL) established the first SR data base for 239 sites in the United States [14]. In 1973 during the oil crises, many countries that importing oil and has limited fossil fuel resources started in deep the research for SR to guarantee their national energy security.

IV. A Global Model for Global SR on Horizontal Surface

Estimation of SR is considered as the most important parameter for the design and development of various solar energy systems. The foremost objective of the present study was to present a simple formulated approach for both daily and hourly global SR intensity on horizontal surfaces at the earth's surface. This approach will be modified and formulated to be applied for Kuwait area taking the in consideration the Kuwait geographical parameters and its climate conditions. Table 2 lists the typical day number for the first day of each month.

Table 2: Day number for the first day of each month

Month	n
January	1
February	32
March	60
April	91
May	121
June	152
July	182
August	213
September	244
October	274
November	305
December	335

The declination angle of the sun can be approximated by using Cooper equation as

$$\delta = 23.45 \sin\left(\frac{360(n+284)}{365}\right) \quad (1)$$

where δ is the declination angle of the sun in degrees and n is the day number (from 1 to 365).

Solar time, which is the most commonly used parameter for estimating global SR [15], is determined from the movements of the sun. For trigonometric calculations in the following, solar time t in hours is expressed as an hour angle *H*, in degrees:

$$H = 15^{\circ}(t - 12) \tag{2}$$

The standard convention used is that, H is positive after solar noon and negative before solar noon. Hence, the solar altitude angle is obtained from equation (3) and it depends on the latitude angle of the site, day number and, most importantly, the time of day [16].

$$\sin\beta = \cos L \cos\delta \cos H + \sin L \sin\delta \tag{3}$$

where β is solar altitude angle in degrees and L is the latitude angle of the site ($L = 29.33^{\circ}$ for Kuwait area).

An easy calculation of sunrise time and sunset time can be found from a simple manipulation of (3). At sunrise and sunset, the solar altitude angle β is zero. It follows that the sunrise hour angle or sunset hour angle H_{SR} can be calculated as

$$H_{SR} = \cos^{-1}(-\tan L \times \tan\delta) \tag{4}$$

The goal is to present a simple formulated model for daily global solar radiation intensity on horizontal surfaces at the earth surface. This model incorporates improvements in methodology as well as algorithm to calculate the SR based on the model of J. Duffie and W. Beckman [17] which is based on the estimation of the extraterrestrial (ET) solar insolation, S_{ET}, which passes perpendicular through an imaginary surface just outside of the earth's atmosphere. The ET insolation depends on the distance between the earth and the sun, which varies with the time of year. It also depends on the intensity of the sun, which rises and falls with a fairly predictable cycle. The ET insolation really consists of the three components of SR (beam, diffuse and reflected) in a clear sky and Kuwait climate for almost nine months (from 1st of March to 30th of November) is cloudless atmospheres. Also, this approach is suitable for dry and temperate areas as Kuwait region.

The starting point for a clear sky daily global SR calculation is with an estimate of the ET insolation, S_{ET}, in W/m^2. One expression that is used to describe the day-to-day variation in ET solar insolation is the following:

$$S_{ET} = S_0\left[1 + 0.34\cos\left(\frac{360n}{365}\right)\right] \tag{5}$$

The solar constant, S_0, is an estimate of the average annual ET insolation and the accepted value of S_0 is 1377 W/m^2. Now, the average daily ET solar insolation on a horizontal surface, S_{ET} (ave), in Wh/m^2-day can be calculated by

$$S_{ET}(\text{ave}) = \frac{24}{\pi}S_0\left[1 + 0.034\cos\left(\frac{360n}{365}\right)\right]$$
$$\times\left[\cos L\cos\delta\sin H_{SR} + \left(\frac{\pi}{180}H_{SR}\right)\sin L\sin\delta\right] \tag{6}$$

or

$$S_{ET}(\text{ave}) = \frac{33048}{\pi}\left[1 + 0.034\cos\left(\frac{360n}{365}\right)\right]$$
$$\times\left[\cos L\cos\delta\sin H_{SR} + \left(\frac{\pi}{180}H_{SR}\right)\sin L\sin\delta\right] \tag{7}$$

In clear sky atmosphere calculations, the clearness index K_t is defined as is the ratio of the horizontal insolation at the site S_H to the ET insolation on a horizontal surface above the site and just outside the atmosphere S_{ET}(ave) and is given by

$$K_t = \frac{S_H}{S_{ET}(\text{ave})} \tag{8}$$

A high clearness index ($K_t > 0.5$) corresponds to clear skies in which most of the SR will be direct beam while a low one ($K_t < 0.5$) indicates overcast conditions having diffuse SR. A monthly averaged clearness index for the site of Kuwait can be obtained from National Aeronautics and Space Administration (NASA) website for Kuwait area over 22 years (1983 – 2005) [18], as given in Table 3.

Table 3: Monthly averaged clearness index for Kuwait area

Latitude 29.33° Longitude 47.5°	**22-Year Average K_t**
January	0.52
February	0.57
March	0.56
April	0.56
May	0.62
June	0.69
July	0.68
August	0.67
September	0.65
October	0.60
November	0.50
December	0.47
Annual Average	**0.59**

From the best curve fitting for the values of K_t in Table 3, clearness index can be expressed to a good accuracy as a function of day number n, as

$$K_t = -0.3807\times10^{-6}n^2 + 0.001124n + 0.6139 \tag{9}$$

According to (8), the daily global SR on horizontal surfaces, S_H, in Wh/m^2 can be found from

$$S_H = K_t S_{ET}(\text{ave}) \tag{10}$$

Hour by hour SR data are essential if the radiation on the horizontal surfaces is to be estimated. Following the same procedure for the daily radiation except to express the hour angle in terms of solar time in hours (Local Apparent Time, LAT) as in (2) and let the solar time t varies between sunrise time to sunset time according to the longitude of site.

For Kuwait area with a longitude of 47.5°, the standard sunrise time and sunset time are 6:00 AM and 18:00 PM, respectively, which is obtained from Kuwait Metrological Center [18], as

$$S_{ET}(\text{ave}) = \frac{33048}{\pi}\left[1 + 0.034\cos\left(\frac{360n}{365}\right)\right] \times\left[\cos L\cos\delta\cos H + \sin L\sin\delta\right] \qquad (11)$$

From (11) and substituting S_{ET}(ave) into (10), the hourly global SR on horizontal surfaces can be readily estimated.

V. Availability of SR in Kuwait

Kuwait has a dangerous situation because of the electrical energy lacking and load peaking which is unacceptable. Kuwait has an abundance of solar energy capability. Unfortunately, Kuwait SR measurements are not easily available because of not being able to afford the measuring equipments and techniques involved. Therefore, the developed model is to estimate and identify the SR on horizontal surfaces on the basis of the more readily available meteorological data.

The meteorological data for Kuwait area such as latitude angle (L = 23.99º), longitude angle (γ = 47.5°), clearness index K_t (almost cloudless atmosphere for nine months), solar time t (varies from 6:00-18:00) and the corresponding hour angle H are used in the developed model and the intensity of daily and hourly global SR on horizontal surfaces S_H for Kuwait area is obtained as a function of both day number n (with a day number step of one day) and time (with a time step of one hour) using the previous developed model. These results can be obtained for any day of the year and for any hour of the day. Consequently, the total solar energy received by Kuwait area during each hour or day or month. The obtained results will be discussed in details in the following section.

VI. Results and Discussions

The results of the developed model of the daily SR on horizontal surfaces at Kuwait area are graphically represented. As shown in Fig. 4, it is observed that the daily SR on horizontal surface in Kuwait is increased rapidly from 3786.5 Wh/m^2 in 15th of January to 7984.9 Wh/m^2 in 15th of June and decreased very rapidly to 3691.6 Wh/m^2 in 15th of November. It reaches its peak values during months from April to August (for n from 91 to 244) and the maximum daily SR occurs exactly in June as shown in Fig. 5. These results are indicating very good agreement between the calculated data and the climatic conditions, because during hot months in Kuwait (April–August) the solar altitude angle β reaches its highest values from 64.69º in 1st of April to 83.85º in 30th of June and again to 68.77º in 31st of August (Fig. 3) and this explain the high temperature degrees in Kuwait during these months. This be in conformity with the clear sky atmospheres and high clearness index K_t values for these months with average K_t varies between 0.56 in April to 0.67 in August (see Table 3). Even for the rest months of the year (September – March), we have high values for daily or averaged monthly SR on horizontal surfaces with a minimum value of not less than 2902 Wh/m^2 occurs in December, which is still high if we compare it to the daily or monthly SR in some cities in Europe, for example, London has monthly averaged SR on horizontal surfaces not more than 2800 Wh/m^2 in June.

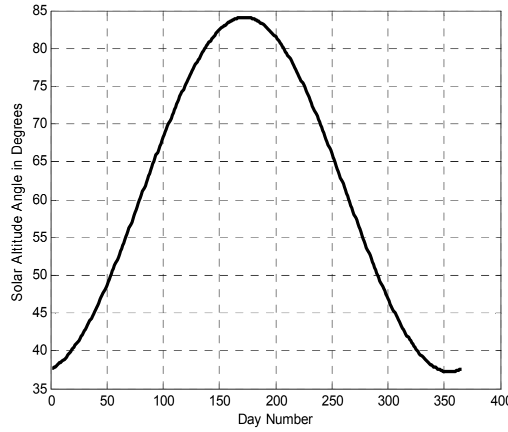

Fig. 3. Daily solar altitude angle in degrees at solar noon at Kuwait area.

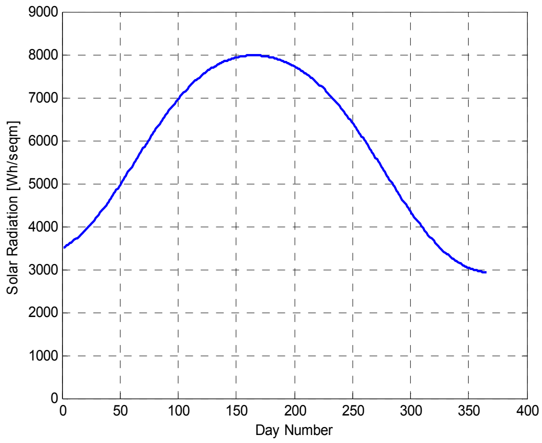

Fig. 4. Daily global SR intensity on horizontal surfaces at Kuwait area (Wh/m^2 –day).

In general, for daily SR on horizontal surfaces the maximum value (in summer solstice 21 June) is 7959 Wh/m^2, minimum value (in winter solstice 21 December) is 2902 Wh/m^2, while for the equinoxes (21 March and September) it is 6210 Wh/m^2-day and 5909 Wh/m^2, respectively. The monthly averaged global SR intensity on a horizontal surface at Kuwait area is also given and plotted in Fig. 5. Table 5 shows the results for monthly averaged SR intensity on a horizontal surface at Kuwait area in 22-year average as obtained from NASA website. The closeness of the obtained results and that from NASA is evident, which prove the validation of the developed mathematical model.

The results obtained for the hourly SR on horizontal surfaces is graphically shown in Fig. 6 to Fig. 8 for selected days in specific months of the year. The hourly SR is calculated every hour with a range according to the solar time t in hours from sunrise to sunset. It is clear to obvious that the hourly SR is increased from the sunrise hour H and reached its peak at solar noon and then decreased until the sunset hour. It can be easily noticed that the peak hourly SR always occurs at solar noon, 12:00 PM, according to the longitude, γ equals 47.5°, of Kuwait area where the sun at its highest altitude in sky during its daily path.

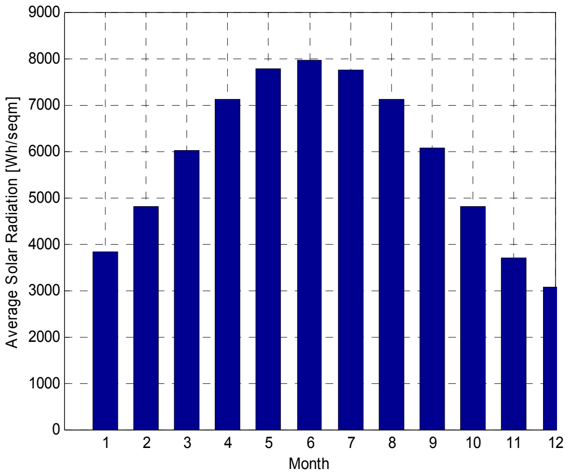

Fig. 5. Monthly averaged SR intensity on horizontal surfaces (Wh/m^2 –day).

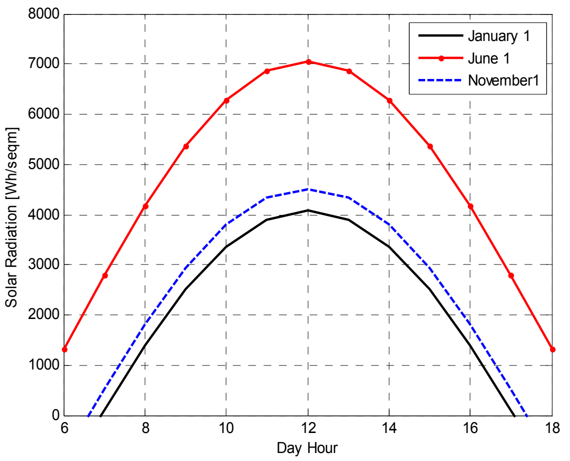

Fig. 6. Hourly global SR intensity on horizontal surfaces at Kuwait area in 1st of Jan., June and Nov.

Table 5: Monthly averaged insolation incident on horizontal surface at Kuwait area (kWh/m^2/day)

Latitude 29.33° Longitude 47.5°	**22-Year Average S_H**
January	3.89
February	4.96
March	6.09
April	6.91
May	7.80
June	8.16
July	7.76
August	7.29
September	6.28
October	5.05
November	3.82
December	3.26
Annual Average	**5.94**

Dividing (10) by solar time, it can be readily obtain the solar power received per unit area at the horizontal surface W/m^2 that can be delivered to the solar photovoltaic surface at cloudless weather as shown in Fig. 9 and Table 6.

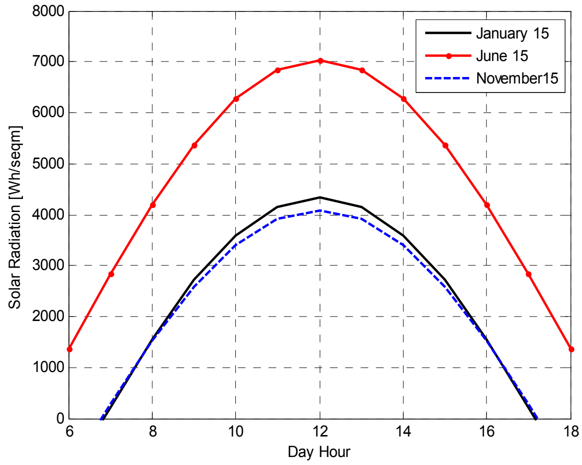

Fig. 7. Hourly global SR intensity on horizontal surface at Kuwait area in 15th of Jan., June and Nov.

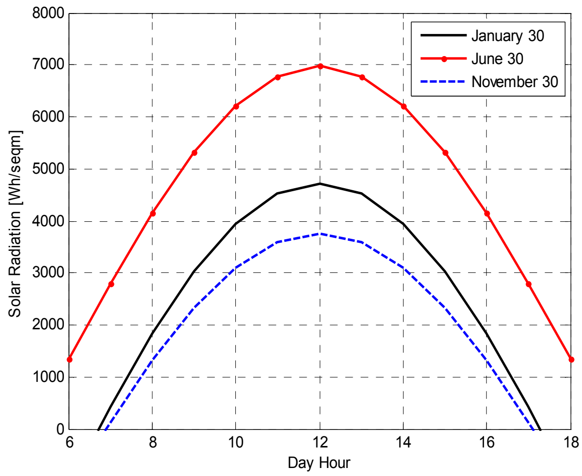

Fig. 8. Hourly global SR intensity on horizontal surface at Kuwait area in 30th of Jan., June and Nov.

The knowledge of the SR data is essential for design and sizing the PV system. Manufacturers always provide performance data of the PV cells under specific operating conditions. There are many types of such cells in the international market; the best of which is the silicon mono semi-crystalline PV type. The maximum power of this module is 300 W according to SR in Kuwait and its area is 2.427 m^2. If we divide the whole area of Kuwait by the area of this module and multiply the result by 300 W we will end up with the total output power from the whole area of Kuwait. But, practically we can't make such arrays for this area. So, we will take only 16 km^2 from the area of Kuwait and we obtained 1.9778 GW of power and divided this amount of power by the power consumed in Kuwait in year 2010 (see Fig. 2) resulted in 16.5% of total power generated from the PV arrays according to SR in Kuwait to the total power consumption in Kuwait. Also, Fig. 2, Fig. 5 and Fig. 9 showed that the peak load matches the maximum incident

SR and its relative averaged electrical power and these results are very promising capabilities for Kuwait to use solar energy in electrical power generation.

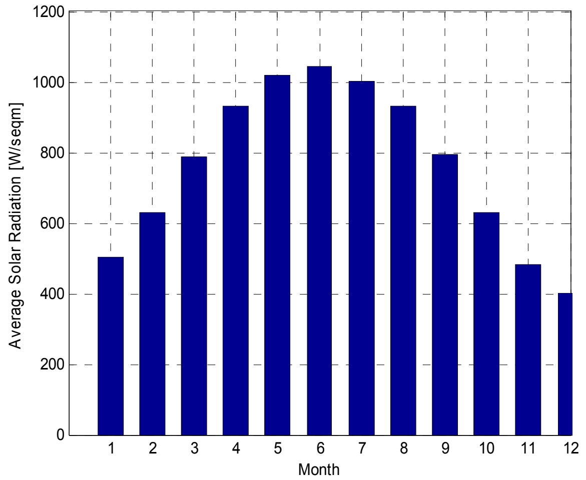

Fig. 9. Monthly averaged clear sky SR incident on horizontal surfaces at Kuwait area in (W/m^2)

Table 6: Monthly averaged SR incident on horizontal surfaces at Kuwait Area (W/m^2/day)

Month	S_H (W/m^2)
January	501.90
February	628.17
March	787.80
April	931.71
May	1017.63
June	1042.70
July	1000.61
August	930.86
September	794.48
October	628.84
November	483.63
December	401.02

VII. Conclusions

Production and consumption of Kuwait electrical energy, installed capacity and peak loads have been presented and discussed in this paper.

The visibility and the potential of solar energy in Kuwait have been identified and analyzed in this paper. The obtained results prove that Kuwait has an abundance of solar energy capability in terms of almost cloudless atmosphere for nine months and twelve hours solar time a day over the year. The daily global and monthly averaged solar intensity on horizontal surface at Kuwait is ranging from 3 Wh/m^2 in winter to 8 kWh/m^2 in summer. Monthly averaged clear sky solar radiation on horizontal surfaces at Kuwait area is ranging from 500 W/m^2/day to 1042 W/m^2/day.

Using the solar energy as an alternative energy source in Kuwait is expected to contribute to the development and improvement of Kuwait grid and this will be the subject of the future work.

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