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# Environmental Impacts of Grid Connected Photovoltaic System Adapted for Peak Load Reduction in Kuwait

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Peak loads in Kuwait occur in summer afternoons because of the extensive use of air conditioners. Peak loads are more expensive to satisfy than other loads. The main objective of the present work is to minimize the peak and total electrical load in Kuwait using grid connected PV systems. It was found that the peak load matches the maximum incident solar radiation which would emphasize the role of using PV stations to reduce the electrical load demand. In addition, significant reduction in peak load can be achieved with grid connected PV systems. To assess the environmental impacts of grid connected PV systems, the recovered energy from PV system is assumed to satisfy the needs of a family in a Kuwaiti house from electricity consumption. Different array areas and slopes were studied to maximize the annual energy generated by grid connected PV systems. The maximum energy generation from the grid connected PV systems corresponds to PV slope of 26° and facing south. An annual avoided $CO_2$ emission of 1.2 t/y is achieved due to the use of PV systems. These results explicitly confirm the environmental impacts of the grid connected PV systems in Kuwait climate.

## 1. Introduction

In this paper, grid connected photovoltaic systems have been proposed to minimize the peak and total load in Kuwait. A variety of grid-connected PV systems have been installed and working successfully throughout the world (Shugar, 1990 and Chokmaviroj et al., 2006). These systems can potentially reduce electrical line losses, and improve distribution system reliability (Byrne et al., 1996). Optimum PV inverter sizing ratios for grid-connected PV systems in selected European locations were determined in terms of total system output by Mondol et al. (2006). It is found that the PV inverter cost ratio and the PV and inverter lifetimes have significant impact on the optimum PV inverter sizing ratio. Jung Hun So et al. (2007) evaluated the performance of four 3 kW grid-connected photovoltaic (PV) generations in Korea. Their results indicate that it is highly imperative to develop evaluation, analysis and application technology for PV systems. Hamrouni et al. (2008) studied the performances of a grid-connected photovoltaic plant. The simulation and the experimental results showed the control performance and dynamic behaviour of grid-connected PV system in normal and disturbances modes. The four parameter model (Townsend, 1989) is a widely used model for determining the characteristic curves of solar cells. The four parameters appearing in the IV equation are the light current, the series resistance, and two theoretical diode characteristics. In the present work, the five parameter model (Ghoneim et al. 2002) which adds the shunt resistance to the four-parameter model is implemented for simulating the characteristics of solar modules. Adding this parameter makes this model applicable to both crystalline and amorphous PV solar cells. The transient simulation program (Klein et al., 2011) is used to determine the characteristics of grid connected PV systems in Kuwait climate.

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A new electrical power generation plants are installed continuously in Kuwait. This indicates the urgent need for alternative sources to satisfy a significant part of the total load especially in peak periods. This work evaluates the role of PV grid connected in reducing the total and peak load demand in Kuwait. Different solar array areas and slopes are studied to maximize the annual energy generated. In addition, the annual avoided $CO_2$ emission at the optimum conditions is calculated to assess the environmental impacts of grid connected PV system. The recovered heat energy from the PV system is assumed to satisfy the needs of a family in a typical Kuwaiti house from domestic hot water load and electricity consumption. Different photovoltaic areas and slopes are studied to maximize the annual energy generated by the PV system. Finally, the annual avoided $CO_2$ emission at the optimum conditions is calculated to assess the environmental impacts of the grid connected PV system.

## 2. Analysis of Hourly Load Data

The weather data for Kuwait used in this study have been measured and collected for a period over twenty years in Kuwait Institute for Scientific Research (KISR, 2011). The weather data used are monthly average values of daily radiation on horizontal surface and ambient temperature. So, the weather data measured was analyzed to reveal hourly solar radiation patterns on a tilted surface ($I_T$ ) for a typical day in each month of the year using the following equation (Duffie and Beckman, 2006):

$$I_T = I_{bh} R_b + (\frac{1}{2}) I_{dh} (1 + \cos\beta) + (\frac{1}{2})(I_{bh} + I_{dh}) \rho (1 - \cos\beta) \quad (1)$$

where $I_{bh}$ is the beam radiation on horizontal surface, $I_{dh}$ is the diffuse radiation on horizontal surface, $\beta$ is the tilt angle, $\rho$ is the ground reflectance and $R_b$ is the ratio of beam radiation on titled surface to that on horizontal surface. It is found that the maximum global radiation corresponds to a tilt angle of 30°.

The total installed power generation capacity in Kuwait has increased very rapidly from 70 MW in 1960 to 12400 MW in 2010. Consequently, the power station generation of electrical energy has increased from about 1000 M kWh in 1960 to 51749 M kWh in 2010 (MOE, Kuwait, 2011. In addition, the peak load has greatly increased from 2100 MW in 1980 to about 12500 MW in 2010. It is found that the installed capacity is always larger than the peak load for every year from 1960 to 2010. Generally, it is found that a sharp increase in the energy generation in each year is noticed during the hot months. This is mainly due to the increased demand of AC systems that represent the main load during summer months. Generally for most of the years, it is found that more than 60 % of the peak loads are due to AC loads during the relatively hot months (April-November), and only about 10 % of the peak loads are due to heating loads during the relatively cool months (December-February).

## 3. Methodology

PV systems require other components in addition to the PV modules. In addition to DC to AC conversion, most stand-alone and all utility-interactive inverters incorporate some level of system control. The proposed system is a utility interactive system where utility service is already available. The main objective of this work is to address the photovoltaic ability to reduce total and peak load demand. The reduction in load demand depends on PV system performance as well as instant match between the peak load and PV output. The PV output is simulated using measured weather data and hourly electrical loads for the period from 1960 to 2005. The five parameter photovoltaic model (Ghoneim et al., 2002), is used to determine the performance of the solar arrays. Transient simulation program (Klein et al., 2011) is used to calculate the PV system hourly energy output using the radiation incident on the array surface and the ambient temperature. The incident radiation on photovoltaic module is a function of the incidence angle ($\theta$). At large incidence angles, a great portion of incident radiation is reflected. The incidence angle modifier (i) is given by (King et al., 1994):

$$i = 1 - (1.098 \times 10^{-4})\theta - (6.267 \times 10^{-6})\theta^2 + (6.583 \times 10^{-7})\theta^3 - (1.427 \times 10^{-8})\theta^4 \quad (2)$$

Each simulation has a length of one year period and employing monocrystalline solar cell rated at 100 Wp and facing south.

## 4. Environmental Life Cycle Assessment

Replacing a higher $CO_2$ emitting plant with a lower or non $CO_2$ emitting plant results in decreased $CO_2$ addition to the environment. The $CO_2$ emission avoided is generally defined as the difference between emissions generated by conventional systems and emissions generated in the production of the PV system over the life time of the system (25 years). An inventory of greenhouse gas emissions from various economic sectors in Lebanon was conducted by Fadel et al. (2003). Spiegel et al. (2005) assessed the pollutant emission offset potential of distributed grid-connected PV power systems. The GHG emission reduction potentials are addressed by Delarue et al. (2008) for several Western European countries. They concluded that the global GHG emission reduction in the electricity generating sector could amount to 19 %. In the present work, a theoretical model is developed to calculate the $CO_2$ avoided emission achieved by using grid connected PV system to satisfy the needs of a family in a typical Kuwaiti house from electricity consumption load (lighting and household appliances). Emissions generated in the production of the PV system are much less than the emissions generated by conventional systems and can be neglected (Hill and Baumann, 1993). To perform $CO_2$ emission reduction analysis for PV system, one needs to define the baseline electricity system. Often this will simply imply defining a conventional system and its associated fuel (oil, natural gas, coal).

## 5. Results and Discussions

The proposed grid connected photovoltaic system is assumed to deliver the load demand and does not back feed power to the utility grid. In all the simulation runs, it is assured that the PV output never exceeds the load demand. The annual match between PV output and the load demand is important. To achieve that, the simulated PV output was correlated with load data on an hourly basis. The PV system parameters were varied until getting the required match between the load data and the corresponding PV output throughout the year. Figure 1 shows an example for the result of this procedure for the day of maximum load in year 2008 (July 27) with PV capacity of 2,500 MW.

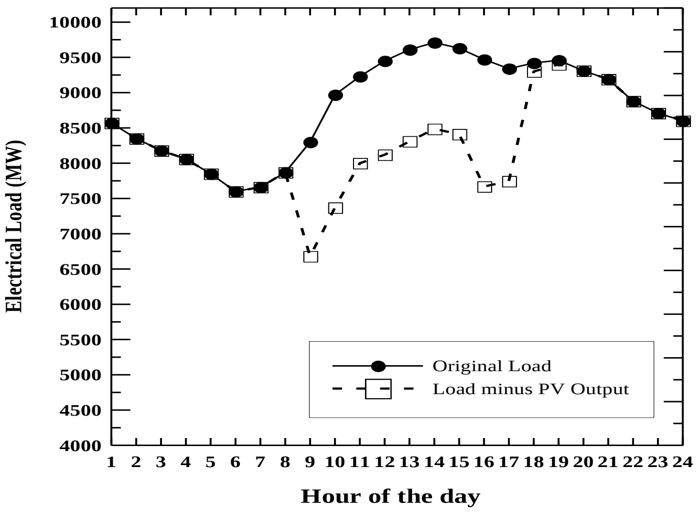


*Figure 1. PV Output shaves the electrical load in July 27, 2008*

PV output shaves the peak load, which indicates that there is an excellent match between the hourly electrical load and PV output. This means that the PV system can reduce the peak loads throughout the day with PV output never exceeding the load.

Figure 2 shows the maximum electrical energy demand by month for the year 2008 for PV system sizes of 0 MW, 2,500 MW, and 5,000 MW. The peak load for the year 2008 (9,710 MW) occurs in July 27. As shown from the figure, a 2,500 MW fixed PV system can reduce the peak load throughout the entire year, summer as well as winter. This photovoltaic system capacity can reduce the peak load in July 27 by about 21 % (1,995 MW) with PV output never exceeding the load.

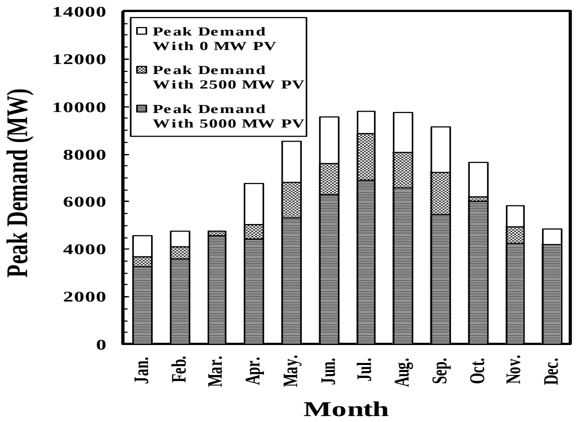


*Figure 2. Monthly peak demand for different PV system sizes*

Another method to assess the potential of photovoltaic system is to calculate the individual impact on demand reduction. The total reduction in load demand can then be evaluated by summing all the individual impacts. Load demand reduction is the average monthly demand reduction at any time of the day during all months of the year. Figure 3 shows the variation of the ratio of average monthly demand reduction with PV system capacity.

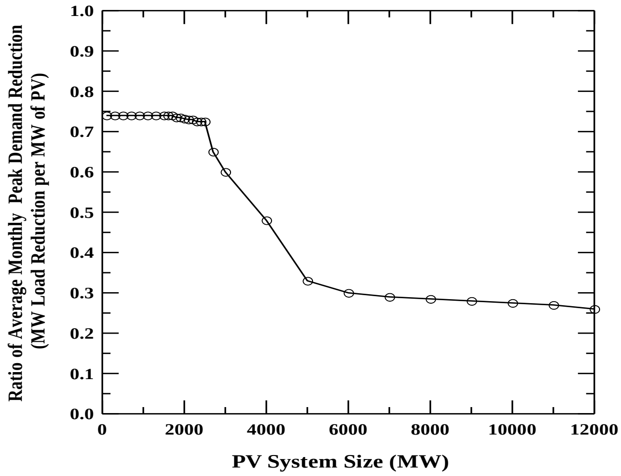


*Figure 3. Ratio of demand reduction versus PV system size*

The ratio of average monthly demand reduction is defined as the average monthly demand reduction in MW for each 1 MW PV output. The ratio of average monthly demand reduction is constant up to PV system capacity of 2,500 MW and is approximately equal to 0.74. As PV system capacity increases, the ratio of the average monthly demand reduction decreases. Consequently, the impact of PV system on load reduction begins to be less significant especially at PV system sizes higher than 6,000 MW.
The variation of total annual energy savings at different PV system sizes has been studied. Figure 4 shows the variation of total annual energy savings at different PV system sizes. The reduction in total annual energy consumption is found to be significant up to 2,500 MW, then the savings in energy consumption become less significant especially at values higher than 5000 MW. Using a 2,500 MW grid connected PV system can reduce the total energy consumption by approximately 21 %. This means that using PV systems can greatly enhance the performance of conventional utility grid system.

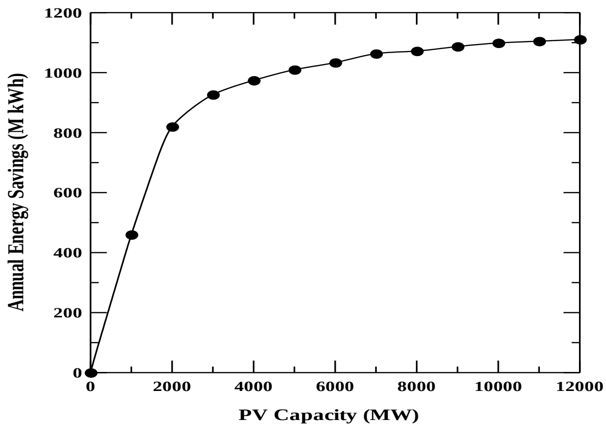


*Figure 4. Annual energy savings at different PV system capacity*

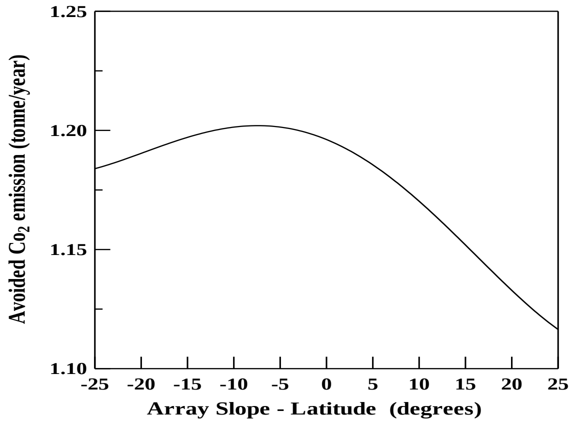


*Figure 5. Avoided $CO_2$ emission variation with array slope (azimuth angle=0)*

The recovered heat energy from the grid connected PV system is assumed to satisfy the needs of a family in a typical Kuwaiti house from domestic hot water load and electricity consumption (lighting and household appliances). Assuming a figure of 40 L/person/d, the hot water demand is about 250 L/d. The computer program is provided with an estimate of typical loads encountered in the house. The two-story house consists of two living rooms, six bedrooms, dining room, two kitchens and a set of household appliances. An hourly load schedule, which repeats each day, is written to a file to be called during calculation. The program is provided with an estimation of the number of hours that the load is used during a typical day for each household appliance. Different PV array slopes and azimuth angle were studied to maximize the annual energy generated. The maximum energy generation from the PV system corresponds to a collector slope of 26° (Kuwait latitude-4°) and facing south (azimuth angle=0°). Maximum energy production at angles less than location latitude is coincident with the fact that more solar energy is available in summer than in winter in Kuwait. The accurate analysis of the total avoided emissions for PV systems, should take into account the emission generated in the fabrication phase of the PV system components. The $CO_2$ emission rate from PV systems is much lower than the $CO_2$ emission rate from conventional utility and can be neglected.

The variation of annual avoided $CO_2$ emission with tilt angle is presented in Figure 5. The figure again illustrates that the optimum tilt angle which maximizes the avoided $CO_2$ emission is 26°. At this optimum angle, the avoided $CO_2$ emission approximately equals to 1.2 t/y. These results explicitly confirm the environmental impacts of the grid connected PV system in Kuwait climate.

## 6. Conclusions

This paper has evaluated the technical impact of PV systems on peak load consumption as well as the environmental impact of grid connected PV system in Kuwait climate. Based on the present results, the following conclusions can be drawn out:

- Grid connected PV system greatly reduce the energy and peak demand load.
- A 2500 MW fixed PV system can reduce the peak load by about 21%.
- The average monthly peak load is decreased by approximately 0.74 MW for each 1 MW PV output up to 2500 MW.
- A 21 % reduction in the total annual energy consumption is achieved when using a PV system with 2500 MW capacity.
- Maximum energy generation from grid connected PV system corresponds to array slope of 26° (Kuwait latitude-5°) and facing south (azimuth angle = 0°).
- At the optimum conditions, the avoided $CO_2$ emission is about 1.2 t/y.
- The present results obviously confirm the environmental impacts of the PV system in Kuwait climate.

### References


Byrne J., Letendre S., Govindarajalu C., Wang Y., 1996, Evaluating the economics of photovoltaics in demand-side management role, Energy Policy 24, 177-185.

Chokmaviroj S., Wattanapong R., Suchart Y., 2006, Performance of a 500 $kW_P$ grid connected photovoltaic system at Mae Hong Son Province, Thailand, Renewable Energy 31, 19-28.

Delarue E., D'haeseleer W., 2008, Greenhouse gas emission reduction by means of fuel switching in electricity generation: Addressing the potentials, Energy Conversion and Management 49, 843-853.

El-Fadel M., Chedid R., Zeinati M., Hmaidan W., 2003, Mitigating energy-related GHG emissions through renewable energy, Renewable Energy 28, 1257-1276.

Ghoneim A.A., Al-Hasan A.Y., Abdullah A.H., 2002, Economic analysis of photovoltaic powered solar domestic hot water systems at Kuwait, Renewable Energy 25, 81-100.

Goldstein L., Mortensen J., Trickett D., 1999, Grid-connected renewable electric policies in the European Union, NREL Report NREL/TP.620.26247.

Hamrouni N., Jraidi M., Chérif A., 2008, New control strategy for 2-stage grid-connected photovoltaic power system, Renewable Energy 33, 2212-2221.

Hill R., Baumann A.E., 1993, Environmental costs of photovoltaics, IEE Proceedings 140, 76-80.

King D.L., 1994, Measuring the solar spectral and angle of incidence effects on photovoltaic modules and irradiance sensors, Proceedings of the IEEE Photovoltaic Specialists Conference, 1113-1116.

Klein S.A., Beckman W.A., Mitchell J.W., Duffie J.A., 2004, TRNSYS, A Transient Simulation Program, University of Wisconsin-Madison, USA.

Kuwait Institute for Scientific Research (KISR). 2011, Personal Communication.

Ministry of Electricity & Water, Kuwait, 2011, Statistical Year Book.

Mondol J., Yohanis Y.G., Norton B., 2006, Optimal sizing of array and inverter for grid-connected photovoltaic systems, Solar Energy 80, 1517-1539.

Shugar D.S., 1990, Photovoltaics in the utility distribution system: The evaluation of system and distributed benefits, Proceedings of the 21st IEEE PV Specialists Conference, Kissimmee, Florida 2, 836 – 843.

So J., Jung Y., Yu G., Choi J., 2007, Performance results and analysis of 3 kW grid-connected PV systems, Renewable Energy 32, 1858-1872.

Spiegel R.J., Leadbetter M.R., Chamú F., 2005, Distributed grid-connected photovoltaic power system emission offset assessment: statistical test of simulated and measured-based data, Solar Energy 78, 717-726.

Swezey B., Bird L., 2001, Utility green pricing programs: What defines success?, NREL Report No. NREL/TP.620.29831.

Townsend T.U., 1989, A method for estimating the long term performance of direct coupled photovoltaic systems, M.Sc. Thesis, Mech. Eng., Univ. of Wisconsin- Madison, USA.