Investigation of Solar Cells for Households in Gulf Cooperation Council (GCC) Countries

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ABSTRACT

The Gulf Cooperation Council (GCC) countries are blessed with several natural resources, such as oil and natural gas. Currently, 17% of these countries oil and gas production is being used to produce electricity. Now, the GCC countries have the opportunity to decrease their CO_2 emissions to encourage using renewable energies, most importantly solar energy. Using solar energy could be a possible alternative to reduce the oil consumption rates and cease some sources of CO_2 emission, thus decreasing global warming.

The objective of this paper is to equip a house in residential areas with solar cells in the GCC countries, therefore substituting its energy source with solar power. The household design includes designing of a DC/DC converter with different output voltage ranges. The design will also include a DC/AC inverter that produces a high power AC output to operate the appliances and Heat, Ventilation, and Air Conditions (HVAC). A charge controller and batteries functioning as a backup power supply will be designed and installed as well.

INTRODUCTION

Solar energy is one type of a renewable energy that can be converted easily and directly to electric energy by photovoltaic converters, without any environmental effects. In addition, solar energy can last for a long time, and it can produce small power (watt) to large power (Mega-watt) scales [1].

In fact, a photovoltaic converter is an energy converter with advantageous features such as relevant design and installation, silent energy conversion, long life time with less maintenance requirements, easy transportation and light weight. Nonetheless, in comparison with other types of energy converters like diesel generators, photovoltaic converters are not expensive.

The process of non-movable mechanisms converting solar energy into electric energy is called photovoltaic (PV) phenomena whereas the conversion device is called solar cell [2]. Solar cells convert the energy of light's photons to electric energy with efficiency between 5 to 25 percent, without using thermodynamic cycle or active fluid. "The maximum efficiency a solar cell made from a single material can achieve in converting light to electrical power is about 30 percent; the best efficiency actually achieved is about 25 percent. " [11], [1-3] Solar cells can be direct light collectors or can use light concentrators, like mirrors or convex lenses that can help highlight the aesthetic features of the design.

Since the solar arrays have low efficiency, which is a disadvantage, it would be better to install them in a movable manner. The movable installation of the solar arrays will help absorb the maximum electric energy from the PV-array and will add an inventive value to the design of the building. [5]

ENVIRONMENTAL CONCERNS ABOUT USING SOLAR ENERGY

Since the GCC countries, in general, and Qatar in especial are going through a vast development in terms of producing gas and oil products, it has been brought to their concern that those products are affecting their environment. Therefore, a great deal of research is currently underway in the topic of renewable energies that are not only environmental friendly but also provide a longer lasting energy resource.

Solar cells have been proven to be good energy sources, as they produce fewer pollutants than conventional fossil fuel technologies. There are concerns that producing solar cells would add to the region some serious pollutants like lead, mercury and cadmiums producing carbon dioxide which contributes to global warming. However, a study conducted and published by the ACS (American Chemical Society) Environmental Science & Technology showed that air emissions data from 13 solar cell manufacturers in Europe and the United States from 2004-2006 were collected, and it was found that "producing electricity from solar cells reduces air pollutants by about 90 percent compare to using conventional fossil fuel technologies" [12].

SOLAR CELL DESIGN AND SIMULATION

Implementing solar panels on building requires finding fixed solar arrays. There are several types of these arrays: flush mounts, universal roof/ground, and pole mounts. Those mounts are used to support the solar panels to be installed almost everywhere, finding the best angle of installation. For maximum design strength, Aluminum could be considered as an element to be used in manufacturing the frames of the solar panels. Also, there are several parameters that should be considered for designing the mounts of the solar panels [1-3], [13]. These parameters are as follows:

Weight and height of the solar panels;
Air resistance;
Humidity and temperature of the region;
Stress on the solar mount support;

The flush mount can be implemented on buildings; however it requires a space underneath it to keep it cool. The minimum required space would be between 2 to 4 inches and if this space is eliminated, then the life time of the solar panel will be greatly affected due to overheating.

The floor-roof mount is a type of mount that provides more flexibility during the installation process. Figure 1 shows the adjustable floor-roof mount. The system can be placed higher by adding poles or concrete blocks at the ground of the mounts. Moreover, the height can be placed at any desired inclination by adding screws to support the beams at any desired position [14].

Figure 1: Adjustable Floor-Roof Mount

Pole mounts can be easily installed. It requires a pole to be fitted on and it can be installed on the top of the pole or on the side of the pole. It might require, though, some physical stress depending on the size, and weight of the solar panel. Table 1 shows the specification of solar cell model ND-216u1F [14].

Maximum Power (Pmax)	216 W	Series Fuse Rating	15 A
Tolerance of Pmax	+10%/-5%	NOCT	47.5°C
Type of Cell	Polycrystalline silicon	Temperature Coefficient (Pmax)	-0.485%/°C
Cell Configuration	60 in series	Temperature Coefficient (Voc)	-0.36%/°C
Open Circuit Voltage (Voc)	36.5 V	Temperature Coefficient (lsc)	0.053%/°C
Maximum Power Voltage (Vpm)	28.9 V	Maximum System(DC) Voltage	600V
Short Circuit Current (Isc)	8.10 A	Maximum Power (Pmax)	216Watt
Maximum Power Current (Ipm)	7.48 A	Module Effi ciency (%)	13.3%

Table 1: Specifications of Solar Cell ND-216u1F [14]

Regarding the simulation, Figure 2 simulates the equivalent circuit of the solar cell and the following formula (1) measures the total current *I* in the simulated circuit:

$$I = qA\left(\frac{D_h}{L_h}P_{N0} + \frac{D_e}{L_e}n_{P0}\right)\left(e^{\frac{qV}{K_BT}} - 1\right) - qAG(L_{h+}L_e) \qquad (1)$$

Formula (1) shows I which is the load current (amperes), q is the charge of the electron (coulombs), A is the area of the diode (cm^2), D_h is the diffusion constant for the hole, L_h is the diffusion length for the hole (cm), P_{N0} is the density of holes (g/cm^3), D_e is the diffusion constant for the electrons, L_e is the diffusion length for the electrons (cm), n_{P0} is the density of electrons (g/cm^3), V is the voltage (volts), K_B is Boltzmann's constant, T is the transmission coefficient of coupler in coherent receiver, and G is the generation rate for carriers. The output voltage of the solar cell can be calculated using:

$$V_{oc} = \frac{k_BT}{q}\ln\left[\frac{L_h + L_e}{\frac{D_h}{L_h}P_{N0} + \frac{D_e}{L_e}n_{P0}}G + 1\right] \qquad (2)$$

Formula (2) shows V_{oc} which is the maximum voltage obtainable at the load under open-circuit conditions of the household (volts)[4].

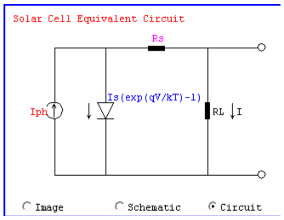

Figure 2: Equivalent Circuit of the Solar Panel

DC/DC CONVERTER DESIGN AND SIMULATION

A DC/DC converter will be used in the design. Since the input would be changed accordingly with the intensity of the sun light, a DC/DC converter will supply electric energy to the load, and also it will be used to charge the batteries from the output voltage of the photovoltaic arrays which will help maintain a constant DC output voltage.

There are three main types of converters that could be used in solar panels: buck, boost, and buck-boost converters. The main advantage of the Step Up (boost) converter is that the output voltage will be higher than the input voltage. On the other hand, the Step Down (buck) converter will have a lower voltage for the output compared with the input voltage. However, the buck-boost converter has the flexibility of working as a Step Up or a Step Down converter. Therefore, preferably the Buck-Boost converter will be used since the sun intensity is not constant over the year.

Figure 3 shows a graph that summarizes the performance of the three DC/DC converters, where a linear relationship has been monitored between the three types. This proportional relationship helps provide a Step Up and Step Down conversions in the buck-boost converter, making it the most suitable converter for the household design.

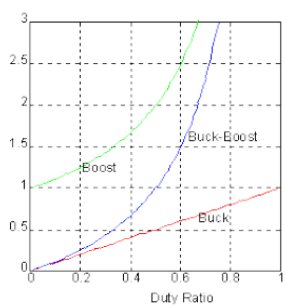

Figure 3: Comparison of Voltage Ratio for DC Converter

Figure 4 illustrates an equivalent circuit of the buck-boost converter.

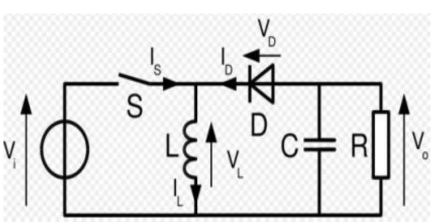

Figure 4: Buck-Boost Converter Circuit

Figure 5 shows a simulation indicating how a buck-boost converter can maintain the same pattern of voltage output.

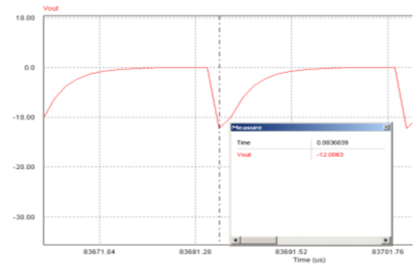

Figure 5: Voltage versus Time across DC/DC Converter Using PSim

After doing this simulation, the study was directed towards using technology and according to the available solar cell specifications; a DC/DC converter with digital or analog control of a custom fit for the designed circuits will be used. This converter was chosen because it allows us to control the power, current and most importantly the voltage. It can also maintain a constant voltage which is just what is needed to stabilize the input voltage entering the inverter. The input voltage is intended to be 12 V.

The specifications of the DC/DC converter for this design are as follows:

Input voltage: 0-48 V
Output Voltage: 120 V
Output Power: Depending on the design of loads

Since the DC converter chosen is very flexible and supports a wide range of input voltages, 0 to 48 V range was chosen because the open circuit voltage (Voc), the solar cell model has a maximum voltage of 36.5 V with full efficiency.

DC/AC INVERTER AND SIMULATION

DC/AC Inverter is crucial for having a household operating on energy obtained from solar panels. DC to AC inverters converts the DC current generated by a solar panel into AC current that can be used to supply power to different appliances and HVAC. Figure 6 represents a schematic diagram for the AC inverter.

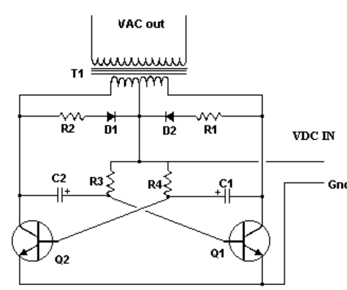

Figure 6: 12V DC-120V AC Step Up Inverter [15]

The design suggests getting more output power, larger transformers and more powerful transistors that can substitute T1, Q1 and Q2.

An inverter produces a pure sine wave output power which helps the appliances run efficiently and keeps their circuit out of damage. The following figure shows simulation of input voltage vs. the output voltage of the inverter.

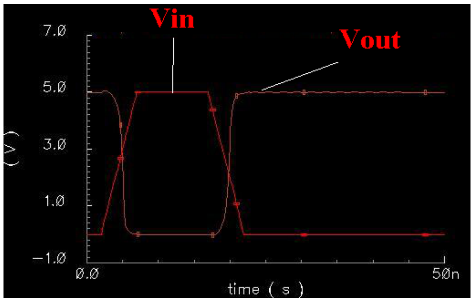

Figure 7: Comparison between the Input Voltage and Output Voltage for a DC/AC inverter [16]

Therefore, according to output voltage from the converter, it is suggested to use a voltage of 220 V with high power output around 8000 W. The inverter will function on 48 V DC with model 8000WPowerJack[16].

CHARGE CONTROLLER DESIGN

A charge controller will be used to control the overflow of the charges in the battery. Batteries, used as a backup plan to maintain power supply, will be charged and discharged depending on the sun's intensity. The charge controller would be installed to prevent an overcharge or unexpected discharge of these batteries.

In fact, there are two main categories for charge controllers: the stand-alone charge controllers and the integrated charge controller circuitry. The circuit of a charge controller is composed of resistors, diodes, and transistors. Each circuit element plays a different role in the functionality of the charge controllers. Resistors are used to drop the incoming voltage to suit the battery condition and diodes are used to prevent any extra charge coming from the solar panels. Figure 6 demonstrates the circuit composition of a solar charge controller.

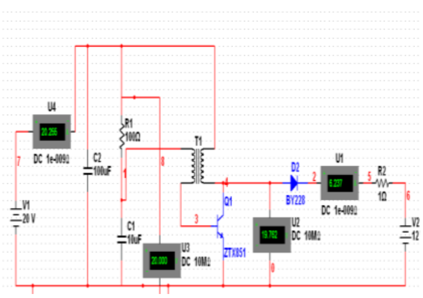

Figure 8: Solar Charge Controller Circuit

BACKUP BATTERIES

Adding an inverter to the design of the solar household will help operate appliances much better than having only a DC-DC converter. The current I is :

$$I = \frac{P}{V \cos\theta} \qquad (3)$$

Where P is the total power in watts, V is the voltage in volts and $\cos\theta$ is the total power factor of the loads that will be taken around 0.9 with $I = 40.40$ A.

To support this energy continuously, two batteries of UB8D model are required for power supply backup. Figure 9 shows the characteristics of UB8D's voltage while operating on 25 A load for a period of 500 minutes17].

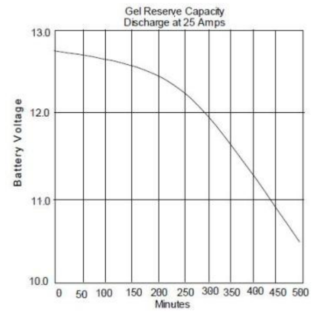

Figure 9: Voltage vs. Time of UB8D's Batteries with 25 A Load [17]

CONSTRAINTS OF SOLAR CELLS IN GCC COUNTRIES

Research done by Adel A. Hegazy [6] relates the dust on solar cells to their power output. In his research, the dust accumulation on glass plates with different tilt angles and associated reductions in solar power output were investigated for one year under the climate conditions of the Minia region in Egypt. This region has similar weather conditions as the GCC's. [6]. The glass plates were never cleaned for one month so that dust could accumulate. The results clearly showed that the solar power strongly depends on dust deposition in conjunction with plate tilt angle, as well as on the exposure period and site climate conditions. The research recommends weekly cleaning of the glass covers of the solar panels as part of the maintenance routine and also immediately after a dust storm to retain the operating efficiency. Figure 10 shows how the dust level is related to the solar power for the days of exposure.

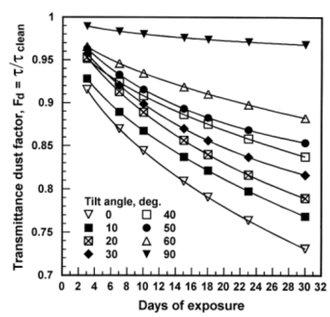

Figure 10: Dust Factor versus Days of Exposure [6]

Another factor that has to be considered is the excessive heat in GCC countries. All PV systems are affected by heat; the more heat there is, the less power produced. Reuk, a company in the UK, conducted an experiment to show the effect of heat. For this purpose, 6V, 250mA solar panels were used for simulation. In order to reproduce heat levels that solar panels experience in hot climates, a 150 Watt halogen office lamp was used at a distance of 55 mm from the solar panel as a sun substitute. This guaranteed that a constant level of light would be incident upon the solar panel, ensuring the quality of the results collected.

“The experiment shows relationship between temperature in degrees Celsius and the solar panel power output measured in milliwatts. Because of the way the halogen lamp took one minute to reach full brightness the results from 25-30 degrees Celsius should be ignored.” [7] Figure 11 illustrates the relationship between the measured temperatures and the solar panel power output.

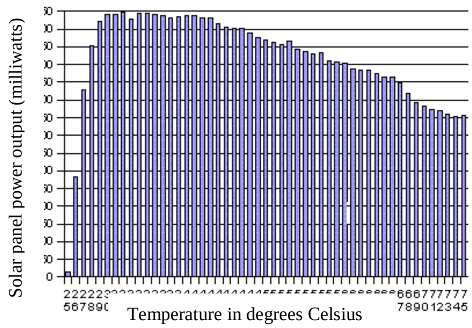

Figure 11: The Effect of Temperature on the Solar Panel Power Output

“Between 30 and 42 degrees there was only a small drop in power output from a peak of 749 mW down to 730 mW. After that there was a consistent drop in power output of around 8.3mW (1.1% of peak output) per degree rise in temperature. Voltage under load went from a peak of 6.21V at 0.12 Amps down to just below 5V at 0.09 Amps.

The total power loss due to the increase in temperature was from around 750 mW down to just 458 mW - a fall of almost 40%! Had the solar panel been pre-cooled in the fridge before the experiment was started the peak power output would certainly have been even higher.” [7]

These results prove that solar cells will be affected by the heat in GCC countries which can reach up to 55 degrees Celsius in summer. Therefore, the solar cells should be cooled in the summer in order to obtain maximum power output.

DESIGN OF SOLAR HOUSEHOLD AND SOLAR PANEL FOR ENERGY CONSUMPTION

Different parts of the house consume different electric energy. Nevertheless, there is a general trend that has been recognized in most of the houses. According to a survey conducted in 2001, the following percentages have been set in Figure 12:

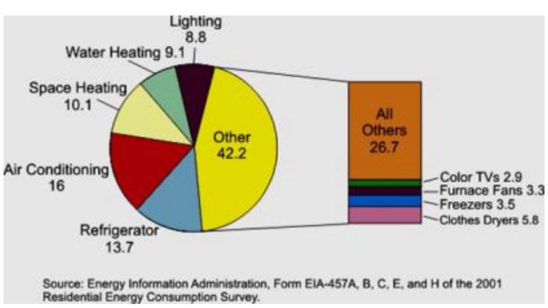

Figure 12: Percentile of Energy in Household [9]

Table 2 shows different appliances of the house with the relative energy consumption.

Heating		**Lighting**	
Elec. furnace, 2000sf, cold climate	26,500 watts	60-watt light bulb (incandescent)	60 watts
Elec. furnace, 1000sf, warm climate	7941 watts	CFL light bulb (60-watt equivalent)	18 watts
Electric space heater (high)	1440 watts	Night light	5 watts
Electric space heater (medium)	900 watts	LED night light	0.5 watts
Electric space heater (low)	600 watts	**Computers**	
Gas furnace (for the blower)	750 watts	Desktop Computer	150-340 watts
Cooling		17" LCD monitor	40 watts
Central Air Conditioner (2.5 tons)	3500 watts	Laptop computer	45 watts
Window unit AC, huge	1440 watts	**Others**	
Window unit AC, medium	900 watts	Microwave oven or 4-slot Toaster	1440 watts
Tiny-ass window unit AC	500 watts	Coffee maker	900 watts
Central AC fan (no cooling)	750 watts	Range burner	800 watts
Major appliances			
Clothes dryer (electric)	4400 watts	Refrigerator (compressor)	200-700 watts
Electric oven	4400 watts	Refrigerator (average)	57-160 watts
Water heater (electric)	3800 watts	Dishwasher (washer heats water)	3600 watts

Table 2: The Required Power for Several House Applications [9]

A normal household power usage will be estimated through a design of hypothetical house supplied with the following appliances in Table 3.

Equipments Used	Power Consumption (W)
2-Electric space heater	2x900=1800
6-Window unit AC	6x900=4500
1- Clothes dryer	1x4400=4400
1-Microwave oven	1x1440=1440
1-Coffee maker	1x900=900
2-Refrigerator (compressor)	2x550=1100
1-Dishwasher	1x3600=3600
12-CFL light bulb	12x18=216
6-60-Watt light bulb	6x60=360
3-Laptop computer	3x240=720
Total Possible Maximum Power Usage	**17,236**

Table 3: A Sample of Possible House Applications [9]

The total estimated amount of energy consumed is 17,236 watts**.** So for the specific suggested model, ND-216u1F, 80 solar cells has to be installed to maintain the household requirements.

There are many parameters that need to be considered when designing a solar household. There is the question whether to use DC or AC (alternating current) equipments. If AC equipments are used throughout the whole house, it is possible to use the power grid as a backup system. However, in this case it is necessary to convert the DC voltage to AC voltage and the energy would be dissipated in this process.

On the other hand, it is possible to design the whole household for DC equipments. In this case, the energy, does not need to be converted to AC voltage thus energy is conserved. However, as the current is not constant, it needs to be stored in a battery. The other problem is that if there is no sunlight for a while or during night, the main grid cannot be used. Some alternatives would include a backup generator.

Since most of the equipments, in the Gulf region, work on 110 to 220 volts, this paper favored using a digital DC/DC converter with an output of 48 V. This means that the voltage is stabilized. Thus, by adding an DC/AC inverter to the whole design of the solar household, the power output will reach a value of 8 kilo-watts enabling the household users of operating many high power-consumption appliances (e.g.: Electrical oven and electrical furnace). Also, with the inverter installation, the voltage can reach a value up to 220 volts and the system can have a frequency of 50-60 Hz.

GCC COUNTRIES ACHIEVEMENTS IN TERMS OF FINDING MORE SUSTAINABLE ARCHITECTURE

Since global warming and CO_2 emission is becoming a major problem everywhere in the world, the Arabian Gulf region can play a great role in this aspect. Several studies have been done to save the region from this future environmental disaster. Most of the countries in the world are taking steps towards finding a green environment by using sustainable resources. That is why a few of GCC countries (e.g. State of Qatar and the Kingdom of Saudi Arabia) were encouraged to find a healthier living environment in the educational campuses.

Qatar Foundation, in State of Qatar, is willing to give students the chance to live in zero-waste residence halls, offering them a great lesson in terms of responsible living by conserving the surrounding environment and utilizing the available technology. These new residential halls will maximize energy efficiency and water use by utilizing wind turbines, photovoltaic cells and a bio mass wall for filtering gray water. Figure 10 shows a design of the new residential halls in Qatar Foundation in Doha, Qatar. [8]

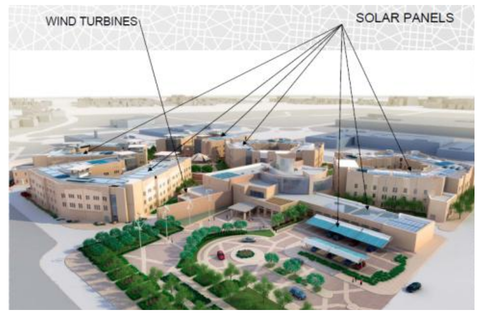

Figure 13: Design of Future Residential Halls in Qatar Foundation [8]

There would be 976 solar panels and 4 wind turbines, providing about 12.5% of the current power usage of energy per year. This would be considered a big jump towards finding a healthier environment and would give the students the chance to interact with the modern technology. All these panels would be computerized and observed by specialized staff. Access for engineering students who are willing to improve the solar system by obtaining data or studying the behavior of the solar and wind turbines systems will also be provided.

Kingdom of Saudi Arabia (one of the GCC countries) is implementing sustainable designs where renewable energy sources can be used. For example, in the future project of King Abdullah University of Science and Technology (KAUST), currently performed in the Red Sea area, solar panels have been installed. The KAUST campus will incorporate multiple strategies to reduce the overall energy demand for campus buildings. The strategies included both the architectural design of the buildings and the selection of the appropriate mechanical systems. There would be renewable solar photovoltaic energy and solar towers to provide natural ventilation for the pedestrian spine. The courtyard areas would use natural day-lighting strategies for outdoor spaces and select the interior space to reduce lighting demands. [10]

Since this paper is dealing with the solar panels implementations, a study has been done by KAUST which shows that solar panels play a great role in terms of providing energy to buildings. Figure 14 and 15 show how successful was the implementation of the solar panels in the GCC region. This would help the rest GCC countries start implementing the solar panels' strategies.

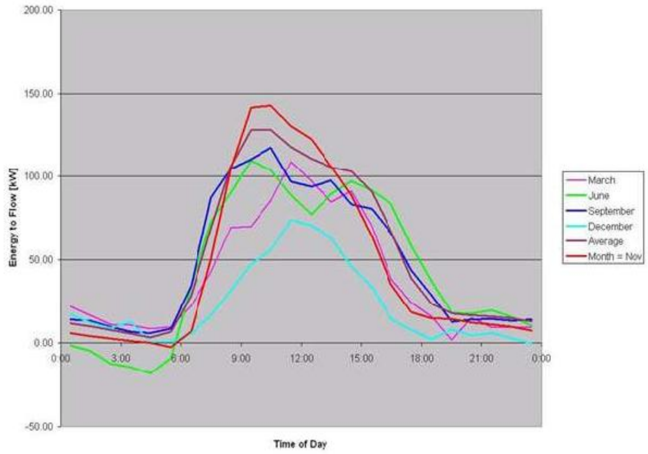

Figure 14: Potential Energy Release by Photovoltaic Solar Panels Located at KAUST [10]

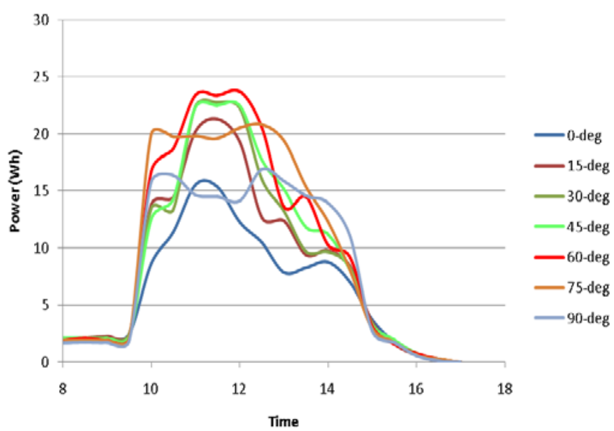

Figure 15: Solar Panel Power versus Time at Different Angles for November 8 [1]

CONCLUSION

Although oil and gas are common energy resources in GCC countries, they are not renewable and are limited to a certain period of time. Many efforts have been taken to find alternative resources that are renewable, long-lasting and environmental friendly. The solar energy can become the most reliable clean energy source. Since the GCC countries have hot and sunny weather, this qualifies them to greatly seize the opportunity and efficiently use solar energy. Heat, humidity level and dust intensity are factors that affect the study and application of solar energy. Due to various constraints that should be considered, a lot of research has been conducted in Europe and America and less in the Middle East.

In this paper, it has been found that the most suitable design for a solar household consist of a DC/DC converter, DC/AC inverter, charge controller and backup batteries. The DC/DC converter has an input voltage range of 0 to 48 V, an output voltage of 120 V and an output power depending on the design and loads. The DC/AC inverter is used in the solar household design to generate high power output of 8000 watts. According to the design, the inverter will function on 120 V generated by the DC/DC converter. Furthermore, the charge controller will be used to prevent any overflow of the charges or any sudden discharge of the battery. Finally, two batteries of UB8D model is required to have a backup power supply.

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