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# Assessment of Utilizing PV System in the West Region of Saudi Arabia

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**Abstract-This work aims at studying the potential of utilizing the solar energy togenerate electricity for small house surrounded by palm trees farm lies in the west region of Saudi Arabiawhere this area is not supplied by conventional power sources. Based on the load calculations for the location and using the soft code prepared by Saudi Electricity Company, the PV system has been designed. A detailed study has been carried out toinvestigate the potential of running the air conditioning unit byutilizing the PV, because air conditioning system is almost a must in every building in Saudi Arabia where the outside temperature in summer higher than 45°C. The input powers for the system as well as the coefficient of performance (COP) for the system under west region Climatical conditions were measured along the day. The results of the analysis showed that using PV systems at current electricity tariff is economically feasible for the house and this will become shine and more efficient for the house owners if the electricity tariff increased as it was expected during the coming years. Cost analysis demonstrated that the proposed system is economically viable in compare to traditional system where the initial cost for this system based on Saudi electricity statistical about 618000 SR compared with 124311 SR for PV system in addition to safe and clean energy source.**
**Keywords: Performance; PV; COP; Remote Areas; Climatic Conditions.**

## I. INTRODUCTION

Kingdom of Saudi Arabia is one of the modern country who has witnessed a sharp rise in energy demand through the last ten years and the need for energy grow too fast in this country due to high rate of the population growth. Additionally, a great development of civilisation, and a growth of different commercial sectors noticed in Saudi Arabia recently, in the same time a high birth rate has been recorded in the country; the population reached 32 million in 2017 [1]. AlMadinah AlMunawwarah one of the big cities in the west region of the kingdom witnessed waves of visitors from the Islamic and neighbouring countries to perform Umrah and Hajj, which increased the demand of power supplied to the city and the surrounded area to the city. Figure 1 shows the development of total fuel consumed by the power plants to generate electricity [1]. From this figure, it is clear the impacts of fuel burning on the environment, which contributed in the global warming and the climatic change, and the quantities of fuel consumed for the purpose of electrical generation will increase consequently. The west region especially AlMadinah AlMunawwarah is blessed with an abundance of solar energy, which is evident in figure. From this figure, the average daily solar irradiance about 6800 W/m2, which is one of the highest in the area. In the northern and western part far from the city center, there are many palm trees farms suffer from the availability of electricity because of poor road links with the city centres due to the nature of area geography, and far away from the national electrical transmission grid. In addition, these remote areas suffer from the non-easy access to fuel resources and low demand as well as population. However, these areas considered a promising station for the PV as a source for electricity generation. In spite of the availability of solar irradiation which is abundant and free in comparison with other energy sources, Saudi Arabia utilization for solar energy still low as shown in figure 3 which display the relative contribution of solar PV from the total energy delivered in the kingdom in 2014. Therefore, solar PV utilization to generate electricity identified as a key strategy to face the peak load in the main cities in Saudi Arabia and can be an optimum solution for the remote areas to provide the necessary power required for lighting, irrigation, cooling and other aspect of life. Generally, the higher power consumption occurs at the period of availability of maximum daily solar energy in the year where the PV system is working at its best conditions, this will make the utilization of PV systems very advantageous especially in higher power consumption devices like air conditioning systems because energy consumption for cooling has increased dramatically in Saudi Arabia and can be considered as the most significant costs to Saudi Arabia households during summer. In remoteSaudi'sareas far from the city centre and hence from the main grid, electric energy is usually supplied by conventional diesel generators which is very expensive in addition to bad impact aspects. Usually, the farmers who live in these areas seek for an alternative solution to the diesel generators and think seriously for using a renewable energy and specifically the solar energy. In this work we will focus on the potential of utilizing the solar PV system as a power source to provide electricity to the remote area and investigate the feasibility to provide electricity for small family house surrounded by the palm trees farm, this house used as living rooms for this family where they used diesel generator for electricity generation. Feasibility study of PV electricity generation for operating the pumps, lighting, air conditioning, refrigerator and

other domestic equipment used by the family will be conducted and the economic assessment andanalysiswill be conducted based on load calculation and equipment prices.

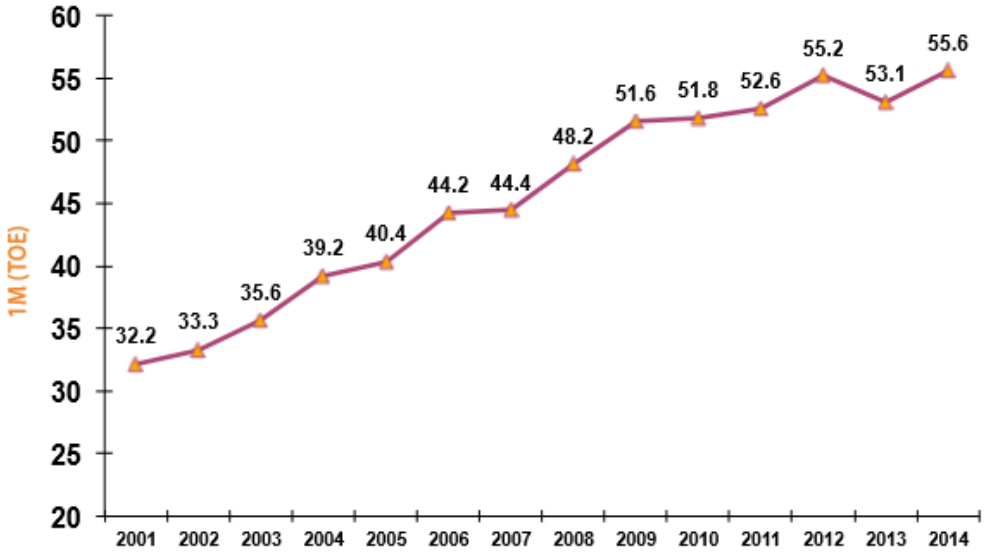


Figure 1. Development of total fuel consumed for Saudi Arabia power plants

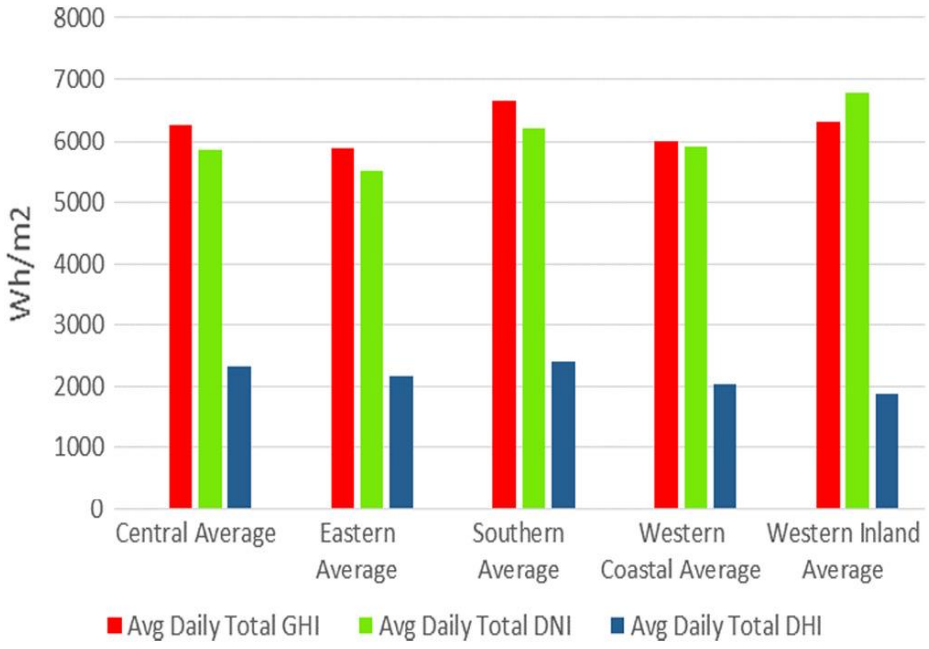


Figure2. Solar irradiance summary by region in Saudi Arabia

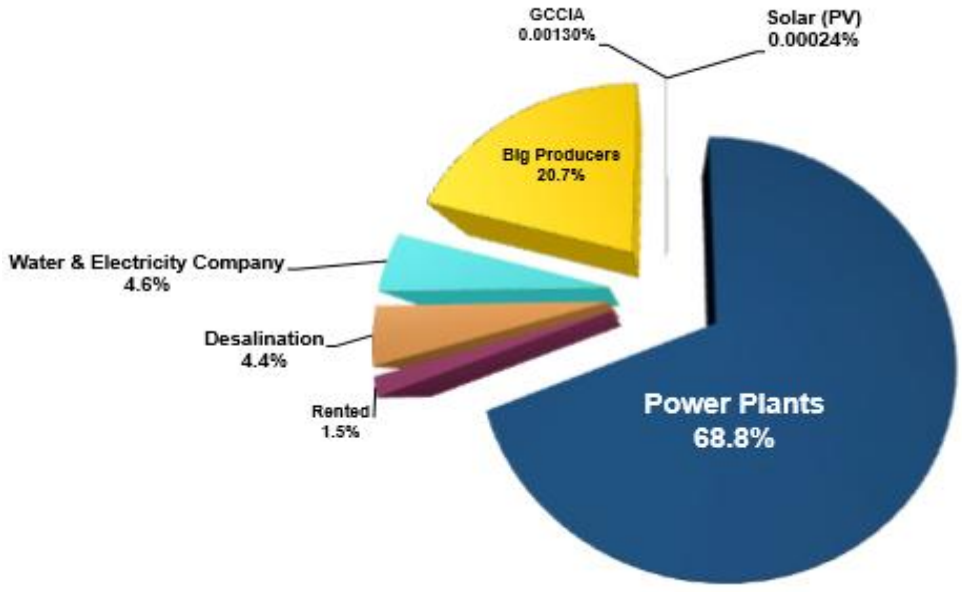


Figure 3. Relative Contribution Energy delivery to Network in 2014

The techno-economic evaluation of utilizing of the PV system is being conducted by many researchers, the most previous work that conducted the techno – economic studies of solar energy used for domestic applications has been conducted by: [3] R. Heinzen, 2006 investigated the potential and simulation of solar assisted Climatisation plants in single family houses. [4] Balaras etal, 2007 reviewed the solar air conditioning in Europe [5] Madrose andSayigh, 2007 conducted the theoretical behaviour of thermal parameters and their interaction in absorption cooling systems powered with solar energy. [6] Shaahid and Elhadidy, 2008 analysed the long-term solar radiation data of Dhahran to assess the techno-economic feasibility of utilizing hybrid PV–diesel–battery power systems to meet the load of a typical residential building. [7] Paula Naukkarinen, 2009 discussed the solar air conditioning and its role in alleviating the energy crisis of the Mediterranean hotels. [8] Al-Salaymeh et al, 2009, the feasibility of utilizing the photovoltaic solar cells in an apartment in Amman city is studied and economic analysis of the system is performed. [9] Shaahid and El-Amin, 2009 analysed solar radiation data of Rafha, K.S.A., to assess the techno-economic feasibility of hybrid PV-diesel-battery power systems to meet the load requirements of a typical remote village Rawdhat Bin Habbas) with annual electrical energy demand of 15,943 MW. [10] Shafiqua Rahman and Al-Hadrami studied a PV–diesel hybrid power system with battery backup for a village being fed with diesel generated electricity to displace part of the diesel by solar. [11] Lavinia and Mario, 2012 investigated the solar heating and air-conditioning by GSHP coupled to PV system for a cost effective high energy performance building. [12] Grandjean, and Adnot, 2012 analysed the residential electric load curve models. [13] Blackledge, etal, 2012 conducted a techno-economic analysis of photovoltaic system design applied to commercial buildings in Ireland. [14] Dan et al, 2012 the potential applications and advantages of powering solar air-conditioning systems using concentrator augmented solar collector. [15] Gang Liu et al, 2012, investigated the economic, technical and environmental performance of residential PV system running under the Queensland (Australia) climatic conditions, and optimize the size and slope of PV array in the system. [16] Abolfazl etal, 2013 investigated the techno-economic analysis of stand-alone hybrid photovoltaic–diesel–battery systems for rural electrification in eastern part of Iran. [17] Ch. Li et al, 2013 conducted a techno-economic feasibility study of autonomous hybrid wind/PV/battery power system for a household in Urumqi, China. [18] Gobind, 2014 presented a comparative assessment of the near term economic benefits of grid-connected residential PV systems. Case studies from the UK and India are taken as examples, as they vary significantly in solar resource, customer demands, electricity prices and financial support mechanisms.

Deep review to the previous work showed thatvery limited research has been done or conducted the potential of PV system in western areas of Saudi Arabia to be used as a main source of power. So this can be considered as starting point to conduct the techno-economic and feasibility to utilize the solar PV to generate electricity in western remote areas.

## II. METHOD

Figure2 shows the average amount of solar energy hitting the west region where our case study lies in this region. Using the soft code prepared by Saudi Electricity company, the daily power consumption has been estimated for the appliances used in this house in addition to water pumps used for irrigation and water supply and for the other domestic appliances as it shown in figure 4. Practical test performed to measure the performance of one of the air conditioners used for cooling this house. The air conditioning system represent important impacts upon the electricity network affect especially in summer's days, where the electricity grid exposed to overload due to air conditioner use, which would cause essential service disruption and severe economic impact. One of the few solutions that provides power to the air conditioning system with low environmental impacts is the solar energy. After the daily load estimation, a detailed monthly consumption and the bills estimated using the soft code shown in figure 5 and based on the data collected from figures 4 and 5, intensive work has been done to size the PV system required to supply electricity for this house.

To evaluate the performance of air conditioning system, experimental investigation has been conducted to estimate the total cooling load. The first step in this investigation is data collection such as design temperatures, humidity, tilt angle, daily and annual values of solar radiation for the site and the number of working hours for all equipment because toestimate the capacity of air conditioning system it is essential to calculate the cooling load. The selected space is the room of 16m2 area cooled 8 hours daily. Hourly Analysis Program (HAP) used to estimate the cooling load by specifying the inside, outside design temperature, relative humidity, thickness and type of insulation materials used in addition to the building structure.

The design temperatures are 46◦C as a maximum temperature during summer and the comfort temperature or the inside temperature is 22 ◦C and the relative humidity of 50% [20]. Figure 6 display the maximum and minimum cooling load for this room. The maximum cooling load estimated in this work in July 2017is about3.4 kW. Based on the results obtained from the (HAP) program, the specifications of the air conditioning unit have been selected as the unit capacity 3.52 kW or 12000 BTU, which is equivalent one-ton refrigeration (1TR). Unitary split unit air conditioning system is used in this investigation with 220V and input power 1.374 kW.

| Type | Watt | number | Hours work daily |
|---|---|---|---|
| Blub | 60 W | 2 | 4 |

| Consumption | Residential - Commercial | Period | 1 |
|---|---|---|---|
| Capacity | 100 | Season | Summer |

| c | Item | Power | Count | Hours work | Daily Consumption (kW) |
|---|---|---|---|---|---|
| ✕ | Neon blub | 60 W | 16 | 8 | 7.68 |
| ✕ | Neon blub | 40 W | 4 | 4 | 0.64 |
| ✕ | Neon blub | 60 W | 2 | 4 | 0.48 |
| ✕ | Blub | 60 W | 2 | 4 | 0.48 |
| ✕ | Blub | 100 W | 20 | 8 | 16 |
| ✕ | Refrigerator | 100 W | 1 | 24 | 1.68 |
| ✕ | Water Heater | 500 W | 2 | 4 | 3 |
| ✕ | Air Conditioner | 2TR | 1 | 4 | 12.8 |
| ✕ | Air Conditioner | 1TR | 3 | 12 | 48 |
| ✕ | Water pump | 3000 | 1 | 5 | 15 |
| ✕ | Water Pump | 400 | 2 | 5 | 4 |
| ✕ | Extra loads | - | - | - | 10 |

Calculate

Figure 4. Daily power consumption for all appliances

| Consumption class | Residential | Consumption Period (Day) | 30 |
|---|---|---|---|
| Capacity | 100 A | Total Consumption (kW) | 119.76 |
| Season | Summer | Total of Consumption Period | 3485.16 |
| Total (SR) | | 274.28 | |

| | Slide Number | Consumption Type | Daily By Consumption Type | Total of bill period by Consumption |
|---|---|---|---|---|
| 1 | 0.05 | 33.33 | 1000 | 50.00 |
| 2 | 0.05 | 33.33 | 1000 | 50.00 |
| 3 | 0.1 | 33.33 | 1000 | 100.00 |
| 4 | 0.1 | 19.76 | 592.8 | 59.28 |
| 5 | 0.12 | 0.00 | 0 | 0.00 |
| 6 | 0.12 | 0.00 | 0 | 0.00 |
| 7 | 0.15 | 0.00 | 0 | 0.00 |
| 8 | 0.2 | 0.00 | 0 | 0.00 |
| 9 | 0.22 | 0.00 | 0 | 0.00 |
| 10 | 0.24 | 0.00 | 0 | 0.00 |
| 11 | 0.26 | 0.00 | 0 | 0.00 |
| المجموع | | 119.76 | 3592.8 | 259.28 SR |

Back

Figure 5. Monthly power consumption and bill details

As shown in figure 4 and based on the house daily load estimated for the appliances and air conditioners, the PV system specifications can be selected and design. From figure 5, the total daily load is 119.76 kWh. The required air conditioning load represents 50.76 % from the total load for the house. Based on the climatic conditions data available for the location, the solar PV effective for 8 hours. Taking the simultaneous load changes and safety factor, roughly estimated 42 PV panels with 310W each will be adequate to supply the house with daily electricity needs [21]. The charge controllers used to regulate the current from the PV module to prevent the batteries from overcharging and to sense when the batteries are fully charged and to stop, or decrease, the amount of current flowing to the battery [22] As the electrical energy coming from the PV module is in DC, inverter will convert it into AC as the compressor needs AC to operate. The electricity provided by the panel array and battery is DC at a fixed voltage. The charge controller specification is 12 V and rate charging control 24Amp [22]. A battery bank is added to allow electricity storage, wiring connections enable the operation of the air conditioning unit by both AC and DC current. Therefore, the system can be connected to PV panels, and solar electricity can be stored during the day and used later [22]. Using the invertor will make it possible to reach higher efficiencies, and subsequently, direct current lighting, fans, pumps and other equipment can be connected to the battery bank. The yearly average tilt panel is 23.5° which nearly corresponding to the latitude of Madinah site 24.5° [23]. This angle should be selected in order to let the system work efficiently. Finally the system accessories for the PV panels, batteries, charge controller and inverter, wires and connections,the frame which will hold the system has been designed at an optimum tilt angle, cabinets to protect the batteries from a high temperature issue, the system installed to provide power to one air conditioning unit under investigation to check if this system will work efficiently under the climatic conditions of the selected area.

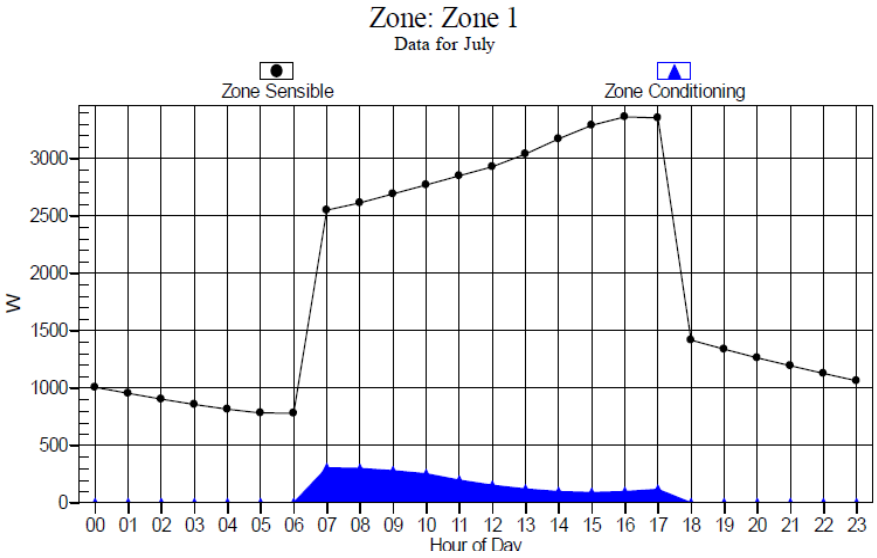


Figure 6. Maximum cooling load estimated in July 2017

## III. RESULTS AND DISCUSSION

Using the data available in figures 4, 5 and 6, it can be seen that the total load needs about 42 PV solar panels with capacity of approximately 310 W each, the number of batteries that can be used to store electricity about 32. The number of charge controllers needed for this work about eight as well as eight investors in addition to the connection lines and the other accessories. It was found that the air conditioning consumed 50.76% of the total load of the building.The air conditioning driven by electricity consumes large amounts of electrical energy and increases the peak load demand for electricity. In Saudi Arabia, the cost for the electricity supplying in additional to the cost of generating and maintenance of the power equipment systems necessary to supply this electricity make a big challenge to the company and for the government. The experiment test performed to evaluate the performance of one of the air conditioning units available in this house with capacity of 3.52 kW (1TR). Measurements for the temperatures at each component in the air conditioning cycle compressor, evaporator and condenser were recorded and transferred to the data logging system through thermocouples, this data logging system connected to the computer where a lot of data recorded a long the day. The main properties for the working fluid which are; temperature, pressure, enthalpy and entropy must be reported in addition to the coefficient of performance (COP). Figure7 represents the variation of COP with time during last July, it can be seen that the higher value of measured in the morning where the outside temperature still low and the system is fully charged. The coefficient of performance is a function of compressor input power and the absorbed heat at low temperature, the higher values indicated that the cooling capacity is at its optimum values during the first hours then the compressor needs more input which leads to reduction in the system performance. Monitoring the coefficient of performance along the day show that normal operation and acceptable performance which is equivalent to thesame system operating under conventional power systems in addition to that, the PV system is clean, safe and reliable system in spite of the high cost. The variation of temperatures with time in the afternoon from 1pm to 4pm at the beginning of July where the outside temperature greater than 40 °C, the compressor usually switches off by the control system when in the temperature of the space 23°C, small deviation between the inlet of compressor and evaporator temperature during this test as a result of the continuous door opening for the room from the occupants and ventilation process. Because any air conditioning unit used to cool the small family house will consume large amount of electrical energy when these air-conditioning units run together concurrently on hot days, this will lead to what is called ‘peak load’ scenario. So the PV is the best and the promising solution for air conditioning at an economically competitive level and could reduce electricity costs for residential and small commercial customers. From the results obtained using solar energy as a power source it can be seenthat the solar PV panels used to run most of the equipment available like pumps used for irrigation and other accessories in the house and farm. This will the best way to reduce the demand for electricity. Therefore, this work focuses in the design and construction of solar PV system to provide electricity for remote area. Generally, the maximum output of PV solar system can be obtained around solar noon, while peak load occurs before this time which leads to incompatibility between the power supply and the power

demand. Batteries system is the only possible solution for the energy storage to match between the power supply and the peak load. The initial cost of batteries is high and need a regular replacement.

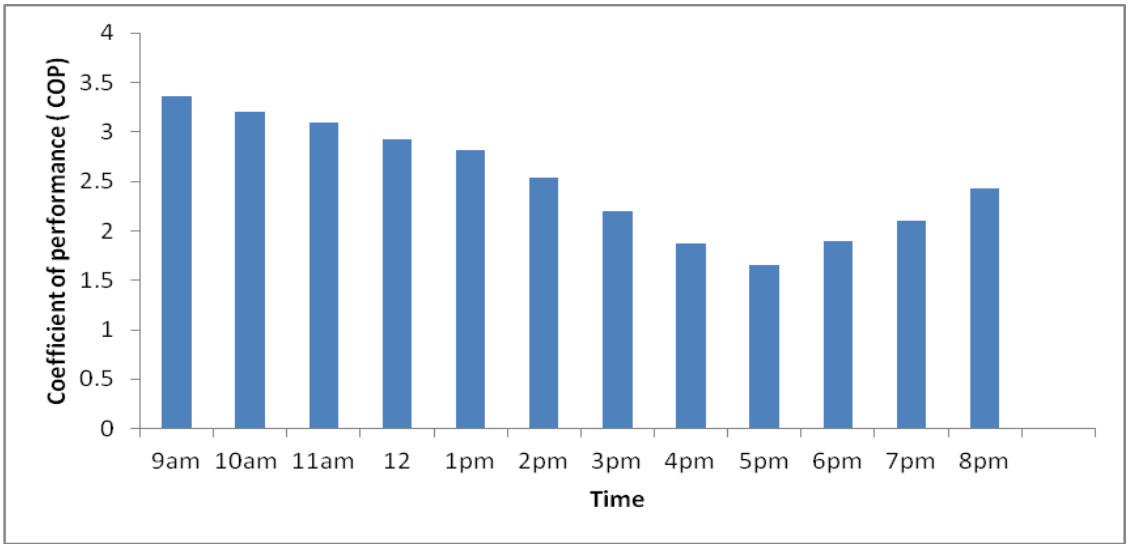


Figure 7. Variation of the coefficient of performance during summer days

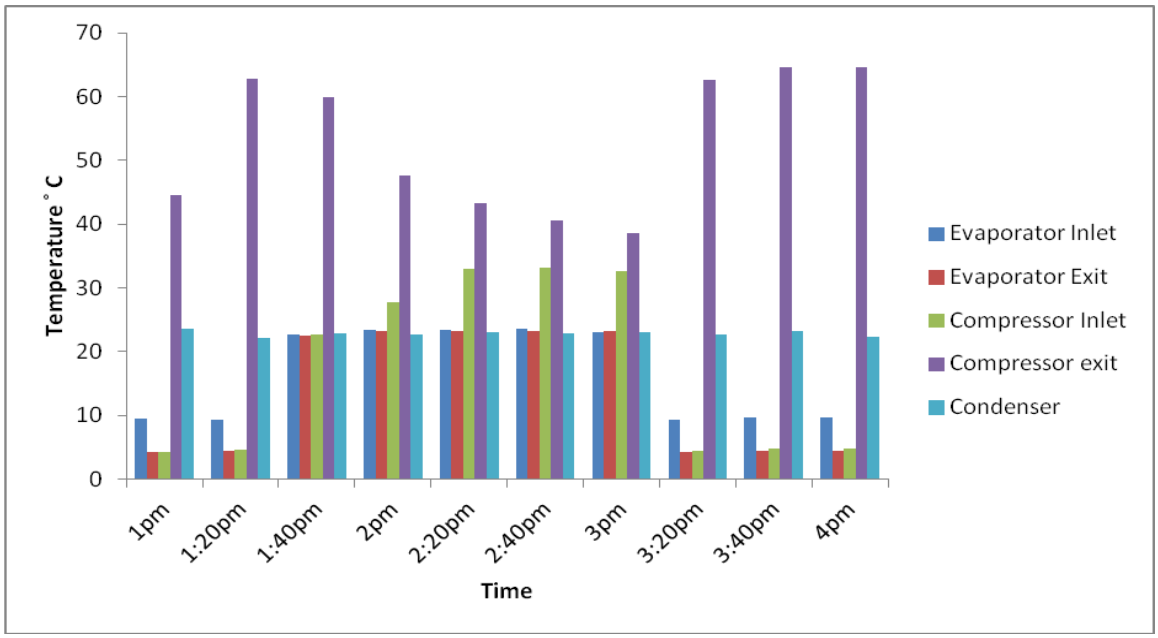


Figure 8. Temperatutre variations from 1:00 pm to 4:00 pm during July,2017.

## IV. ECONOMIC ASSESSMENT

The essential PV system equipment have been selected and tabulated in table 1 with the approximate prices for these equipment. The total cost for the system powered by solar energy including system installation, construction work and the present worth for the batteries, the total cost about 124311 SR.

The present worth (PW) for the batteries can be estimated using the formula

$$PW = \frac{(1+i)^{N-1}}{(1+d)^{N}} [8]$$

Where A=Present value and suppose the inflation rate $i$ = 6%, N: number of years, d= discount rate=10%. For the first 10 years is $PW = \frac{11520(1+0.06)^{9}}{(1+0.1)^{10}} = 7503.75$ [8] and for the next 10 years will be 4887.7 SR. The total annual cost for electricity supplied by the Saudi Electricity company is 3291 SR in 2017. Now this value increased by 20% in 2018. The longer payback for the PV system is 33.7 years, this high payback period refers to the low electricity price in 2017.But it is expected that these prices will be increased because of oil fluctuating prices. If the electricity prices increased by 10% during the next 10 years as it is expected, the payback period will be reduced to 5.6 years as shown in figure 9. This variation of payback period can be consider promising and will becomes lower than this as it is expected if the PV prices decreased as a results of more competition and new technology of PV manufacturing and production.Usually, PV module manufacturers provide performance warranties of 30 years, with maximum power loss of no more than 20 % at the end of the 30 years. Because of the effects that climatic conditions on the performance of PV.

Table1: Summary of PV system total cost

| Item | No off | Unit price (SR) | Total (SR) |
|---|---|---|---|
| Solar PV Panels | 42 | 1500 | 63000 |
| Battery | 32 | 360 | 11520 |
| Charge controller | 8 | 900 | 7200 |
| DC-AC Inverter | 8 | 2400 | 19200 |
| Construction work | 1 | 6000 | 6000 |
| Cables and connections | 1 | 2000 | 2000 |
| Labour rate | 1 | 3000 | 3000 |
| Batteries Present worth | 1 | 12391 | 12391 |
| Total | | | 124311 |

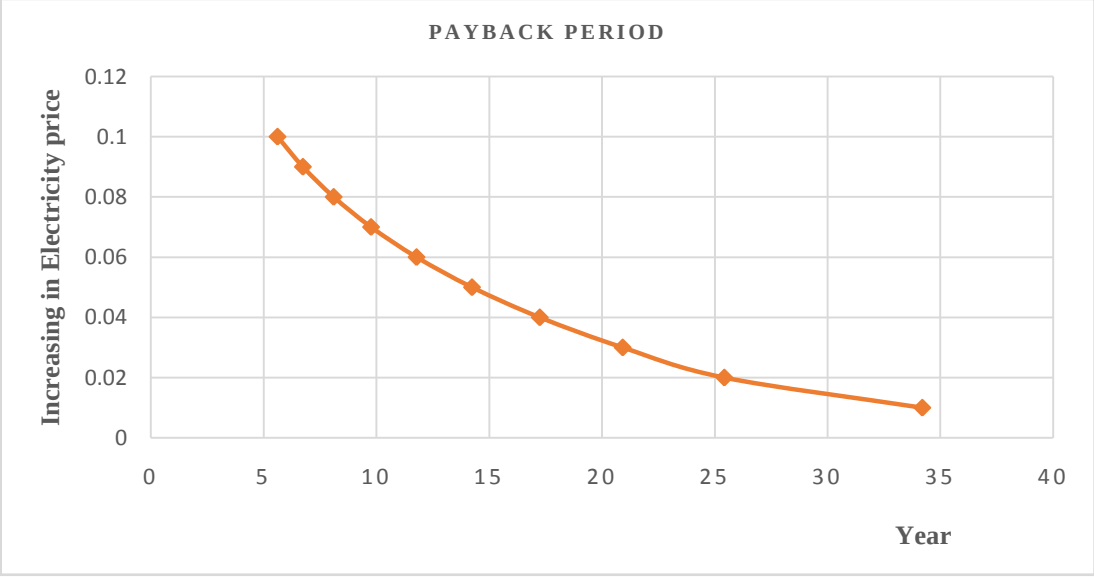


Figure 9. Variation of payback period with inflation of electricity prices

From the presented figures and results, it can be seen that solar energy at an economically competitive level to provide electricity for residential and small buildings and decrease the peak electric demand. More than 60% of power used in Saudi Arabia during summer time goes into air conditioning (according to Saudi Electricity Company statistical). The approximate cost can be considered high when we compare it with electricity price in Saudi Arabia. Recent price drops of PV panels however have changed so the system can be utilized efficiently in remote areas

where the electricity generation becomes more cost. In spite of the high cost and long payback period. This investigation verifies that solar energy, as a power source in remote areas is one of the few solutions that provides to overcome the summer high demand and addresses peak loading. On the hot summer's days, the electricity grid increasingly faces the danger of overload due to air conditionersand cooling devices used in addition to its advantages as a clean and safe energy. Providing the house with electricity generated by Saudi Electricity Company is one of the alternative solutions but the initial cost for this system is too expensive; because of the high cost of columns, poles, transformers and other expenses needed. The approximate cost to provide the house with electricity by installation power stationwill cost about 618000 SR [1].In addition, this station needs extra cost for maintenance and operation. Therefore, Saudi Arabia government encourage the people to use alternative energy sources like solar and wind energy. Finally, the solar PV prices is rather high until this day, however these prices will bedropped withincoming years, and probably the overall price will drop at least 30% during the next 5 years based on the fast improvement for PV modules designing and it becomes shine to supply electricity to the remote areas by utilizing the PV panels.

## V. CONCLUSIONS

This study discusses the potential of utilizing solar energy to reduce the dependency on the conventional grids. The existing house not connected to the grid and lies within the remote areas of AlMadinah region. The chosen option was a PV connected system. The electricity delivered by the grid is the cheapest but the PV scenario becomes shine because Saudi Arabia has solar radiation reaching7kWh/m2/day. Evaluation for the air conditioning investigation has been carried out as a case study in this work and the results obtained indicated that the PV solar systemto power air conditioners in remote areas is suitable technically and economically. The investigated proposed by this study shows that using PV systems at current electricity tariff is not economically feasible for the house and the proposed plant in this study shows that using PV systems becomes economically feasible when electricity tariff increased by 10% or more.Photovoltaic (PV) powered has been investigated in this study. The results of this work indicate a promising and encouraging potential for electricity power generation in the west region of Saudi Arabia. An economic analysis show reveals that the system has sufficient amount of saving due to the renewable source of energy, which is free, and lower maintenance cost. One more major advantage of the proposed model is its longer lifetime that might reach up to 30 years.

## VI. ACKNOWLEDGEMENT

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