Experimental analysis of an off-grid solar powered split-type air conditioner

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Abstract

A significant portion of energy is used for air conditioning in buildings. Solar energy generally is high during cooling period. So, the required energy for air conditioners that meet the cooling can be supplied by solar energy. In this study, the performance analysis of a split type air conditioner powered by an off-grid PV system is carried out at climatic conditions of Şanlıurfa. The split type air conditioner is installed in an office room and run during working hours. Off grid PV system consists of PV panels, a battery group, a charge controller and an inverter. The charging time of batteries is measured without any load. Discharging time of the batteries and electrical parameters are also measured when the air conditioner is on. In addition to all, the electrical and thermal parameter measurements on the split type air conditioner and the off-grid PV system were done when charging and discharging occur in the same time. Solar radiation incident on PV panels, current and voltage of PV panels, current and voltage of split type air conditioner, temperatures of inlet and outlet air of indoor unit of the air conditioner and indoor and outdoor air temperatures were measured and recorded with a data logger. It is seen that charging time gets longer when solar radiation is low and discharging time becomes shorter when the outdoor air temperature is high. It is determined that the air conditioner can operate during working hours without a problem when charging and discharging occur in the same time. It is concluded that the off-grid PV system can ensure the required energy to a split type air conditioner and thermal comfort conditions can be achieved with using these two system together. The proposed and handled system can be developed.

Keywords: Off-grid, split-type air conditioner, solar energy, PV panel, charging, discharging

1. Introduction

The energy systems based on fossil fuels causes environmental and economic problems. Because fossil fuels have negative impact on environment and their cost is rising. The current energy systems largely depends on fossil fuels and world energy demand is rising. The renewable energy sources such as solar, wind and biomass can help to cut this dependency.

The rising living standards and the need for more comfort conditions with reduced prices leads a fast demand of using air conditioning systems. But this results more energy consumption. Because a significant portion of energy is used for air conditioning systems in building sector. Providing cooling by utilizing renewable energy such as solar energy is a key solution to the energy and environmental issues [1].

The use of solar energy for cooling has the advantage of the synchronization between solar irradiation and cold demand. The two main components of a solar cooling plant are the solar collector and the chiller, where the overall system efficiency depends on the coupling between these two components [2].

Solar air conditioning or cooling refers to any air conditioning or cooling system that uses solar power. This can be done through solar thermal energy conversion and photovoltaic conversion. The power of the cooling systems is offered by solar collectors-based thermally driven cycles and photovoltaic (PV)-based electrical cooling systems. Table 1 provides the systems and applications of solar cooling. The literature provides a detailed review of different solar refrigeration, technologies and cooling methods [1, 3, 4]. According to the study carried out by Noro and Lazzarin, the specific cost of PV is by far lower than solar thermal due to the fast reduction of the PV cost during the last two years and to the improvement of their efficiency. PV solar cooling solutions actually allow definitely better economic results than thermally driven solar cooling and are in direct competition with the traditional solutions even without any economic support [5].

Table 1. The systems and applications of solar cooling.

Conversion	**Solar PV (Electrical)**	**Solar Thermal**
Cooling Systems	Vapor Compression Thermoelectric	Ejector (Steam Jet) Absorption Adsorption
Collector	PV Panels	Flat plate Evacuated tube Concentrated
Applications	Air conditioning, Individual cooling	Air conditioning, Process industries, Food preservation

Photovoltaics (PV) is a method of generating electrical power by converting sunlight into direct current electricity using semiconducting materials that exhibit the photovoltaic effect. A photovoltaic system employs solar panels composed of a number of solar cells to supply usable solar power. Photovoltaics can provide the power for any type of electrically powered cooling be it conventional compressor-based or adsorption/absorption-based, though the most common implementation is with compressors. For small residential and small commercial cooling (less than 5 MWh/a) PV-powered cooling has been the most frequently implemented solar cooling technology. The reason for this is debated, but commonly suggested reasons include incentive structuring, lack of residential-sized equipment for other solar-cooling technologies, the advent of more efficient electrical coolers, or ease of installation compared to other solar-cooling technologies [6].

While the output of a PV cell is typically direct current (DC) electricity, most domestic and industrial electrical appliances use alternating current (AC). Therefore, a complete PV cooling system typically consists of four basic components: photovoltaic panels, a battery, an inverter circuit and a vapor compression air conditioning unit [7].

The most common residential split type air conditioner is an air conditioning unit made up of two units-an outdoor unit, the compressor, and an inside air outlet from indoor unit, usually referred to as the “wall hung head unit”. The two units are connected by pipes that carry refrigerant. An alternative to the standard unit is the multi-split system, which has multiple indoor units connected to a single outdoor unit.

Split type air conditioners are generally used in residential and commercial buildings for cooling and heating thanks to their simplicity and flexibility. The split type air conditioners have many advantages such as easy installation, easy maintenance, simple control, attractive and efficient design, and quiet operation and low cost when compared to central systems. So, the use of split-type air-conditioners in residential and official buildings is popular. But split type air conditioners account for significant power consumption and these systems, covering approximately 31% of the refrigeration and air conditioning sector, have noticeably increased their market share since 90's [8].

The main aim of this study is to carry out the performance analysis of a split type air conditioner powered by an off-grid PV system at climatic conditions of Şanlıurfa which has high potential of solar energy.

2. Material and Methods

A typical split type air conditioner powered by an off-grid PV system is shown in Figure 1 schematically. The system consists of five components. (1) The PV panels produce electricity by converting light energy (from the sun) into DC electrical energy. (2) The battery is used for storing DC voltages at a charging mode when sunlight is available and supplying DC electrical energy in a discharging mode in the absence of daylight. (3) A battery charge regulator can be used to protect the battery form overcharging. (4) The inverter is an electrical circuit that converts the DC electrical power into AC and then delivers the electrical energy to the AC loads. (5) The vapor compression air conditioner unit is actually a conventional cooling or refrigeration system that is run by the power received from the inverter.

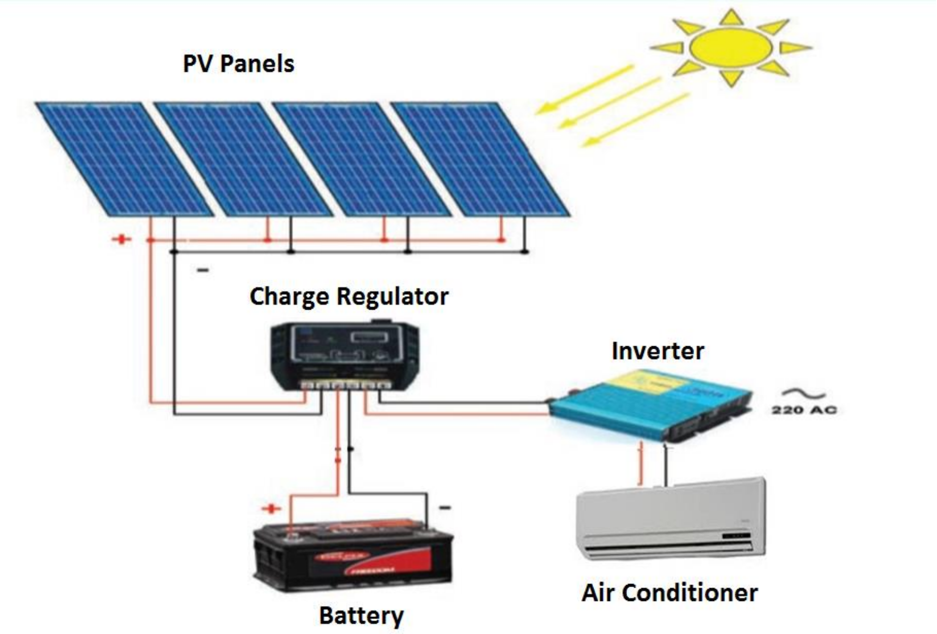
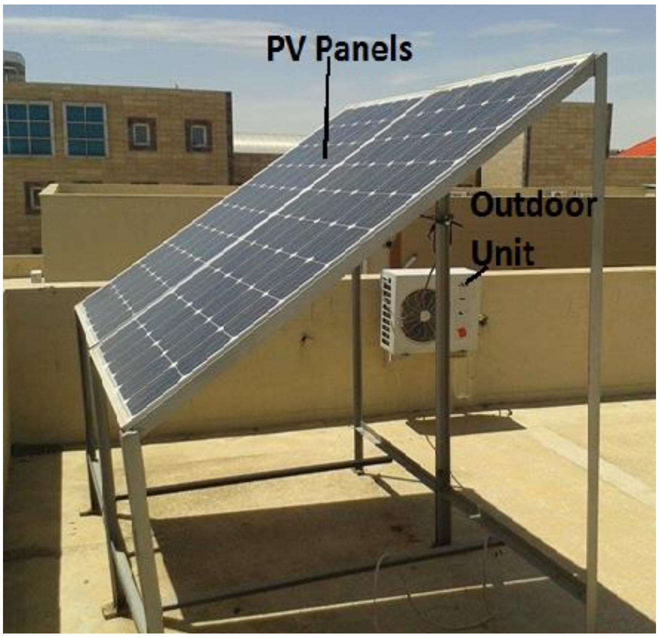
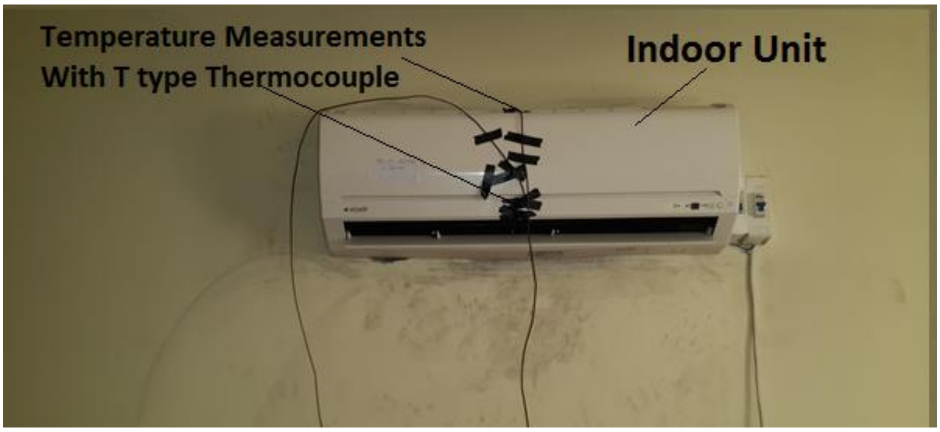


Figure 1. A typical split type air conditioner powered by an off-grid PV system

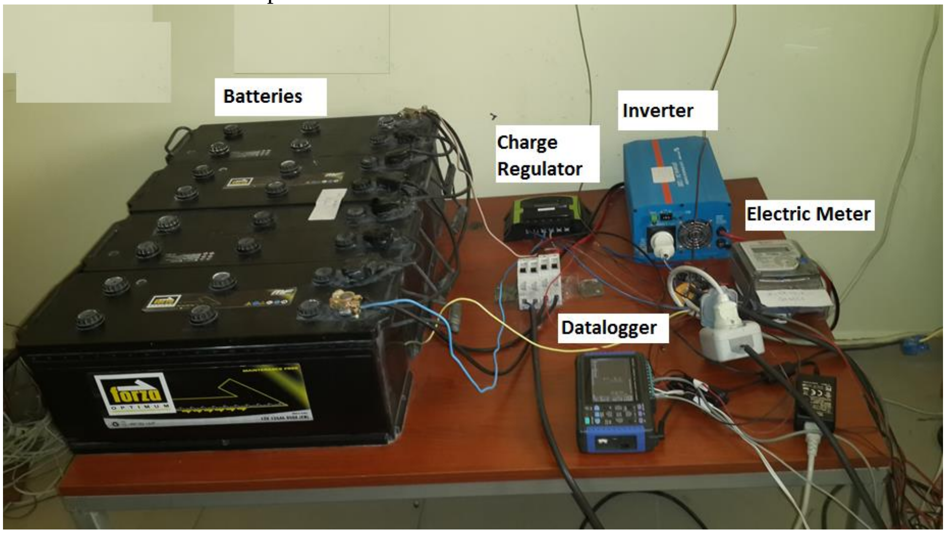
The measurement equipment and components of the split type air conditioner powered by an off-grid PV system studied in this study is shown in Figure 2. The technical properties of components are given in Table 2. Figure 3 shows the schema of electrical connection of the experimental setup.



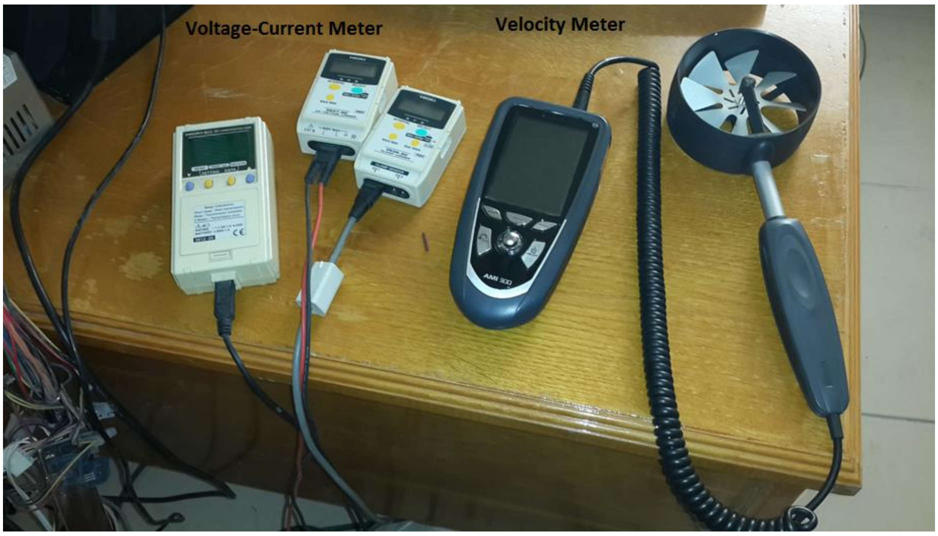
(a) PV panels and outdoor unit of split type air conditioner



(b) Indoor unit of split type air conditioner and temperature measurements points with thermocouples



(c) Battery group, charge regulator, inverter, data logger and electric meter



(d) Voltage-current meter and velocity meter

Figure 2. The components and measurement equipment of the experimental setup studied in this study.

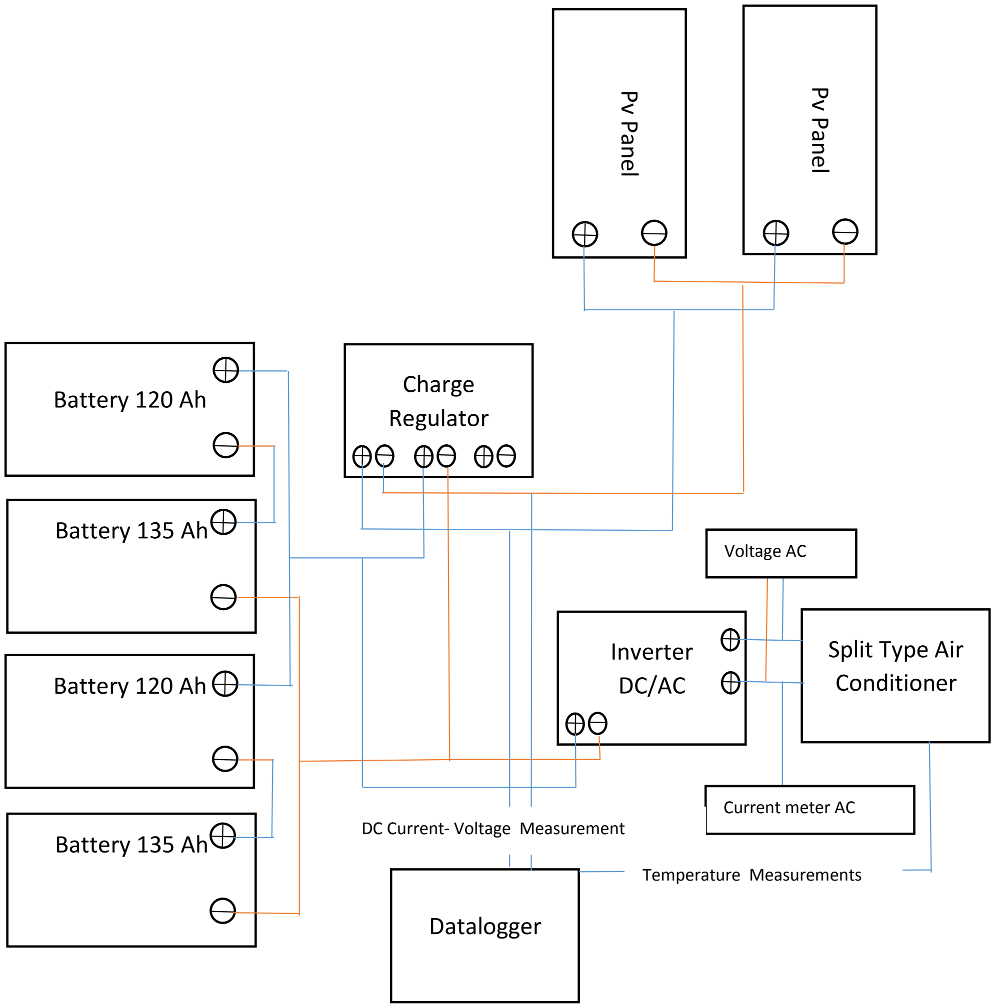


Figure 3. The schema of electrical connection of the experimental system

The split type air conditioner is installed in an office room and run during working hours from 08:00 to 17:00. Off grid PV system consists of PV panels (2 x 230 W), a battery group, a charge controller and an inverter. The office room dimensions (LxWxH) are 5.6 m x 2.7 m x 2.7 m. The room has a door (0.9 m x2.10 m) and a window (0.75 m x 1.05 m).

Table 2. The technical properties of the experimental setup

Component	**Properties**
PV panel	Mono-crystalline, 24 V, 2 items, power 230 W, parallel connection
Battery group	Flooded Lead Acid type, 120Ah/12 V (2 items) and 135 Ah/12 V (2 items): 2 serials and parallel connection: 255 Ah/24 V
Charge controller	12 V/24 V, Max. Current: 30 A
Inverter	Input Voltage: 24 V, Output Voltage: 220 V, Max. Power: 1200 W
Air Conditioner	Spit type, Heat pump, Cooling Capacity: 7300 BTU/h, Power Consumption: 665 W, Voltage 220 V, Current : 3.1 A

Solar radiation incident on PV panels titled 42° oriented to South, current and voltage of PV panels, current and voltage of split type air conditioner, temperatures of inlet and outlet air of indoor unit of the air conditioner and indoor and outdoor air temperatures were measured and recorded with a data logger. Solar radiation was measured by a pyranometer (Figure 4). Temperatures were measured with T type thermocouples. Outlet air velocity of indoor unit were measured with fan type velocity meter (Figure 2-d). The charging time of batteries is recorded without any load. Discharging time of the batteries and electrical parameters are also measured when the air conditioner is on.

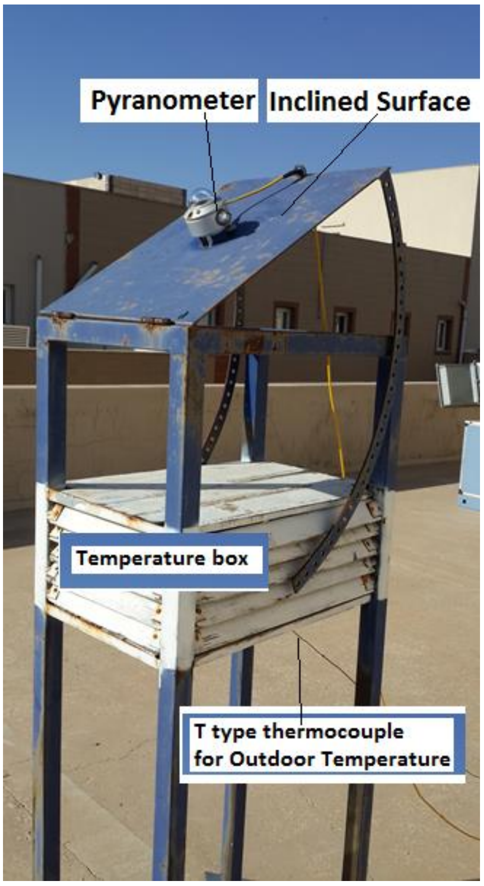


Figure 4. Solar radiation measurement by a pyranometer.

Cooling Coefficient of Performance (COP) of air conditioner is calculated with equation 1.

$$COP = \frac{Q_c}{W_c} \quad (1)$$

Where Q_c is cooling capacity of indoor unit and W_c is power consumption of compressor.

$$Q_c = \rho A V C_p (T_i - T_o) \quad (2)$$

Where ρ is density of air (1.2 kg/m^3), A is cross sectional area of outlet air in indoor unit (0.0456 m^2), V is outlet velocity air, C_p is specific heat value of air (1.005 kJ/kg ^{o}C), T_i and T_o are input and output air temperatures in indoor unit.

The efficiency of PV panel is found from equation 3.

$$\eta = \frac{P}{IA_p} \quad (3)$$

Where P is solar power generated from PV panels (W), I is solar radiation incident on PV panels titled 42^o oriented to South (W/m^2) and A_p is total surface area of PV panels (3.2736 m^2).

3. Results and Discussion

Charging time and performance of PV panels were determined. Figure 4 and 5 shows the voltage of battery, solar radiation and power produced by PV panels during charging. As seen in figures, fluctuation in solar radiation effects produced power and battery voltage. The charging time depends on solar radiation and it is approximately 200 minutes.

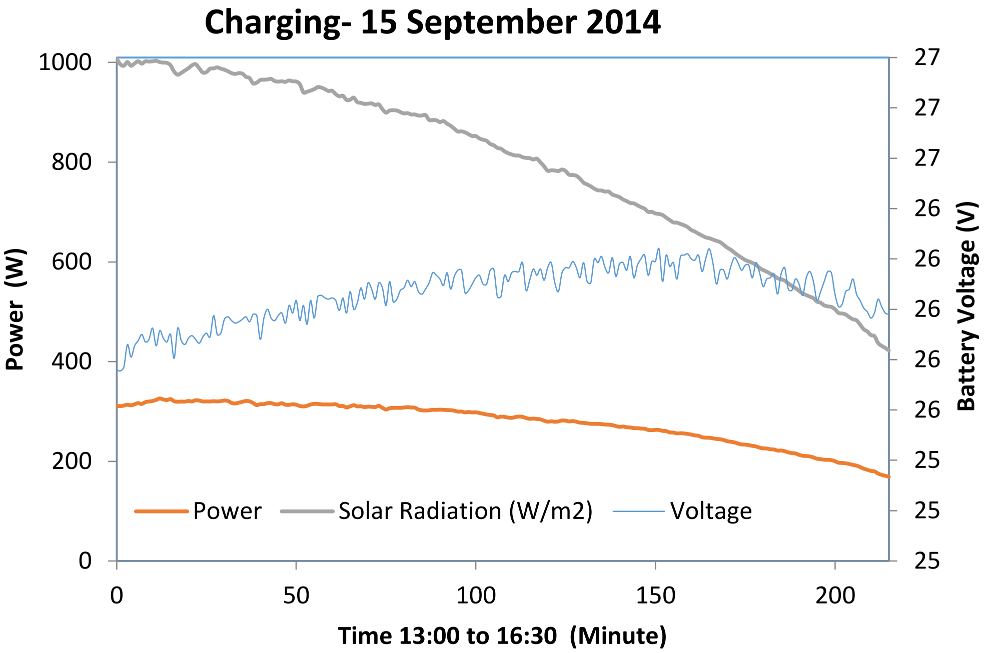


Figure 4. The variation of produced power from PV panels, solar radiation and battery voltage with time during charging

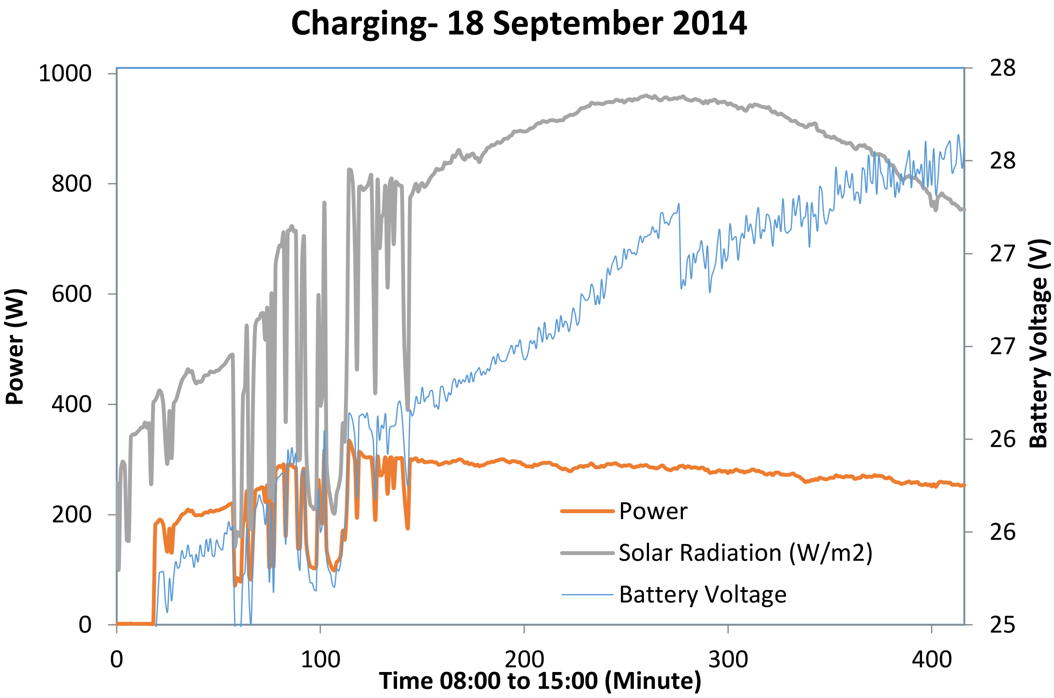


Figure 5. The variation of produced power from PV panels, solar radiation and battery voltage with time during charging

Figure 6 and 7 show the variation of the parameters during charging and discharging period on 17 September 2014. As seen from Figure 6, when the air conditioner is on, the battery voltage declines and fluctuations occurs. It is seen from Figure 7 that the indoor air temperature falls sharply with starting the air conditioner and stops with reaching set point 25 ^{o}C.

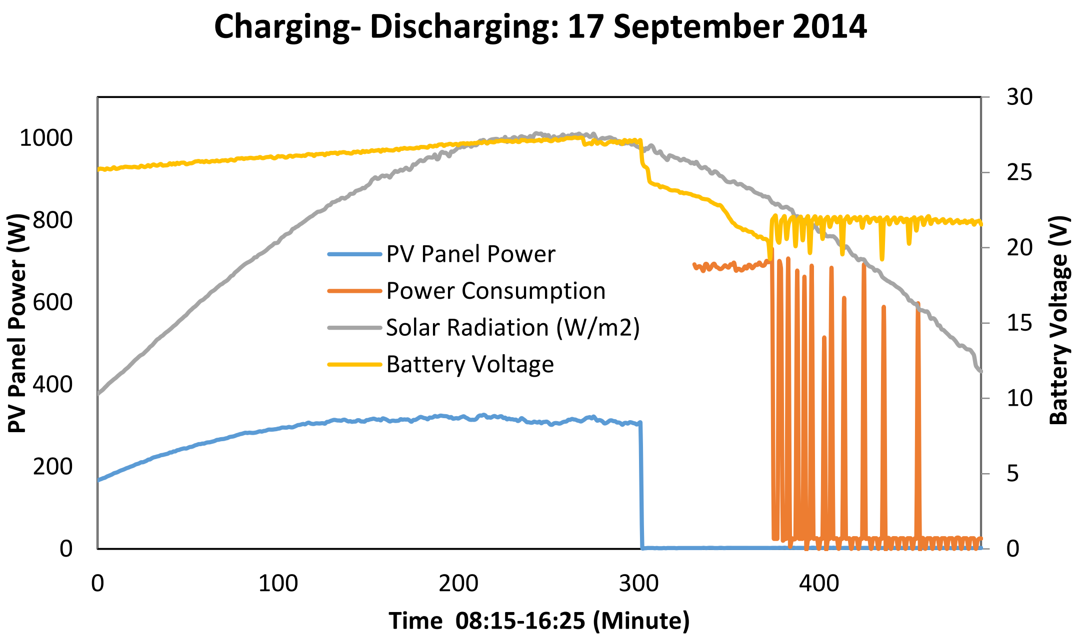


Figure 6. Charging and discharging of the battery group

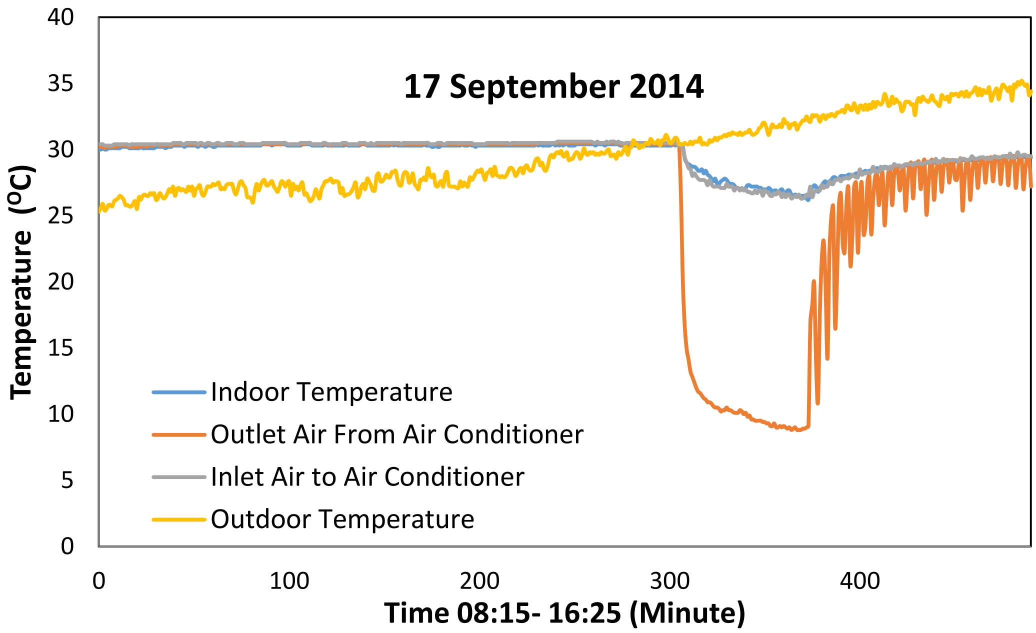


Figure 7. Variation of temperatures during charging and discharging of system

Figure 8 show the variation of power produced from PV panel, power consumption of air conditioner, solar radiation and battery voltage with time when charging and discharging occur at the same time. As seen from Figure 8, the system meets the demand power. During the day, it runs primarily on solar power. The variation of temperatures shown in Figure 9. The fluctuations are the results of the air conditioner's on/off. The indoor air temperature is kept at set point temperature 25 ºC. The variation of PV panel efficiency with outdoor temperature is shown in Figure 10. When solar radiation is high, the PV panel efficiency decreases.

The average efficiency of PV Panels is calculated as 10.5 %. The maximum value of efficiency is found as 13.42 %. The mean of COP values is 2.42 and the maximum COP value is 5.13 when the compressor of air conditioner is on. When the compressor is off and only circulation fan runs, the mean of COP is 52 and the maximum COP value reaches to 279.

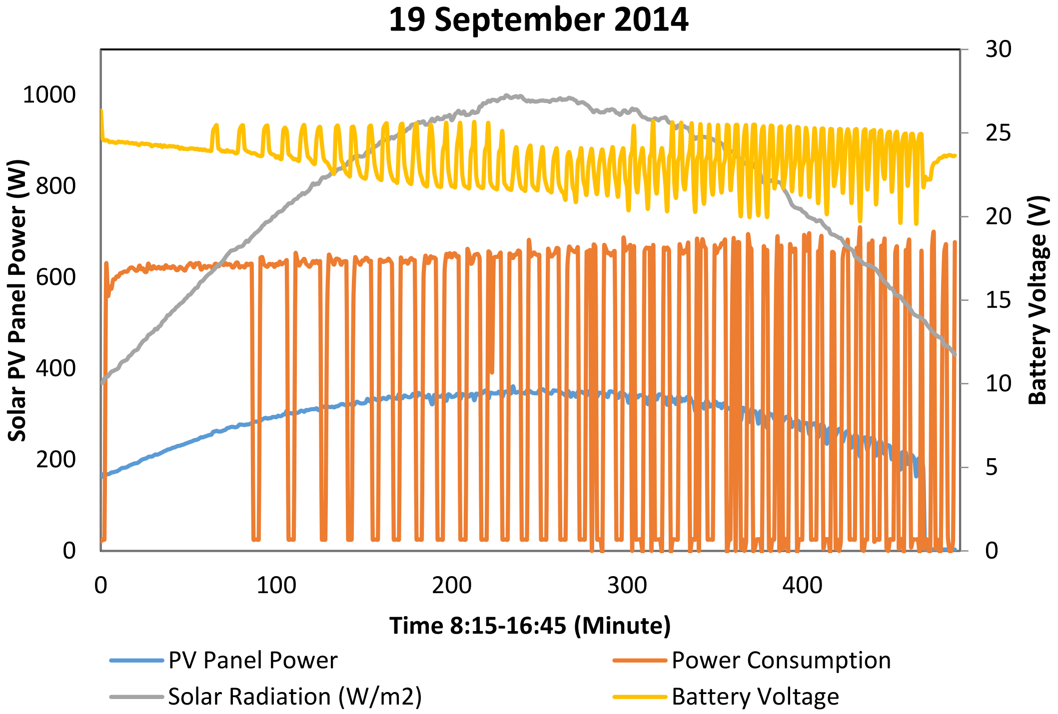


Figure 8. Variation of power produced from PV panel, power consumption of air conditioner, solar radiation and battery voltage with time.

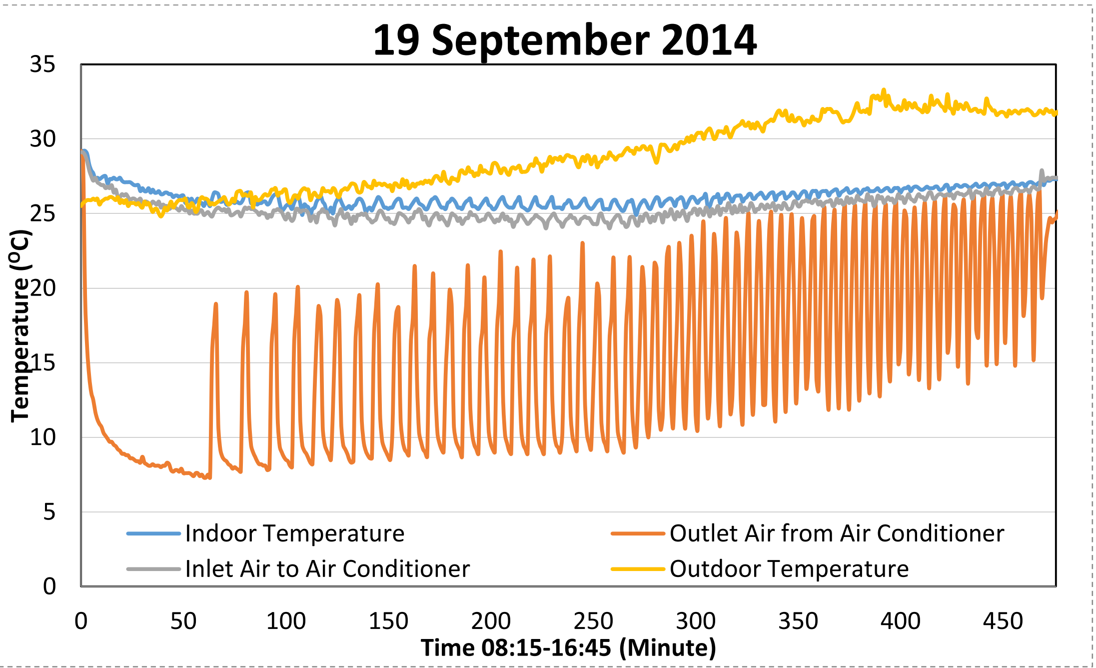


Figure 9. Variation of temperatures with time

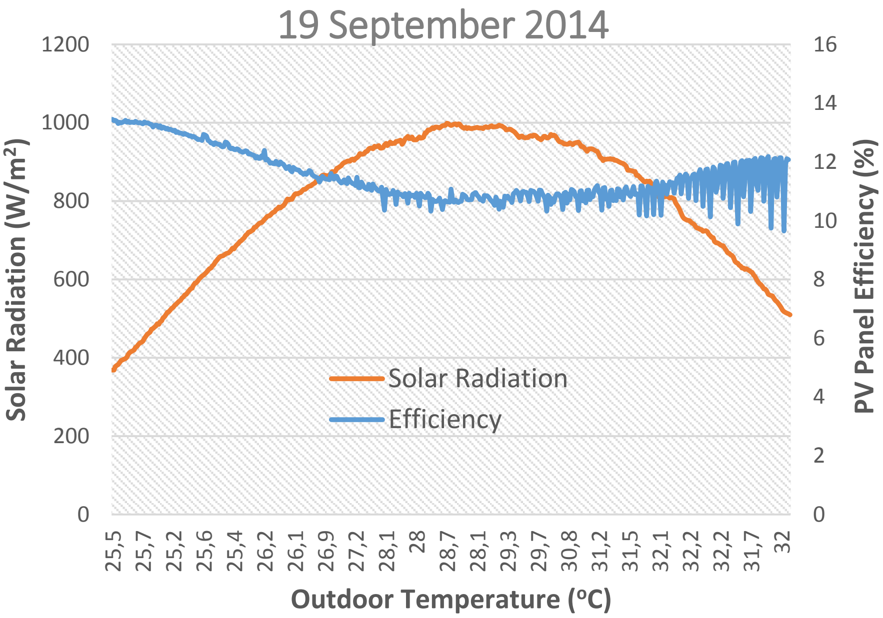


Figure 10. Variation of PV panels with outdoor temperature.

4. Conclusion and Recommendations

The performance analysis of split type air conditioner powered by an off-grid PV system is carried out at climatic conditions of Şanlıurfa experimentally. Thermal and electrical parameters were measured on the experimental setup. The charging time change between 2.5 hours and 4 hours according to solar radiation. It is seen that during the day, the split type air conditioner can run primarily on solar power produced from PV panel and storage to batteries. It is observed that charging time gets longer when solar radiation is low and discharging time becomes shorter when the outdoor air temperature is high. It is determined that the air conditioner can operate during working hours without problem when charging and discharging occur in the same time. It is concluded that the off-grid PV system can ensure the required energy to a split type air conditioner and thermal comfort conditions can be achieved with using these two system together.

The proposed and handled system can be developed. The more PV panels should be installed for quick charging. The capacity of batteries should be increased for night usage of the system. The experimental analysis of air conditioner can be done for heating mode with off-grid PV system. AC/DC hybrid operation can be arranged on the control system. The air conditioner should be inverter type for energy efficiency.

References

1. Sarbu, I. and Sebarchievici, C. 2013. Review of solar refrigeration and cooling systems. Energy and Buildings, Vol. 67, pp 286–297.
2. Bermejo, P., Pino, F.J. and Rosa, F. 2010. Solar absorption cooling plant in Seville. Solar Energy. Vol. 84, pp 1503–1512.
3. Anand, S., Gupta, A. and Tyagi, S.K. 2015. Solar cooling systems for climate change mitigation: A review, Renewable and Sustainable Energy Reviews. Vol. 41, pp 143-161.
4. Kim, D.S., Ferreira , C.A. I. 2008. Solar refrigeration options – a state-of-the-art review, International Journal of Refrigeration. Vol. 31(1), pp 3–15.
5. Noro, M. and Lazzarin, R.M. 2014. Solar cooling between thermal and photovoltaic: An energy and economic comparative study in the Mediterranean conditions. Energy. Vol. 73, pp 453-464.
6. http://en.wikipedia.org, http://en.wikipedia.org/wiki/Solar_air_conditioning).
7. Otanicar, T., Taylor, R.A. and Phelan, P.E. 2012. Prospects for solar cooling – an economic and environmental assessment. Solar Energy. Vol. 86, pp 1287–1299.
8. Sogut, M. Z. 2012. Exergetic and environmental assessment of room air conditioners in Turkish market. Energy. Vol. 46(1), pp 32–41.