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Technical and Economic Feasibility of Solar Powered Air Conditioners in Brunei Darussalam

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Abstract

On daily basis, a huge amount of fossil fuel is being burnt which results in a substantial amount of greenhouse gasses being released into the atmosphere. Air conditioners are becoming more common and are a major strain on energy demands especially in tropical climate countries like Brunei Darussalam. The photovoltaic electricity is a clean and sustainable. In this paper, we present a techno-economic feasibility study for solar powered air conditioning system in Brunei Darussalam. Four alternatives are investigated, 1) the PV system supplies 50% of the loads, 2) the PV system supplies 75% of the loads, 3) the PV system supplies 100% of the loads, and finally 4) the PV system supplies 125% of the loads. Where in the last two case the excess electricity is sold to the grid. With 0.3$ feed-in tariff. The best alternative is the grid-connected PV system with 125% capacity factor which was chosen due to its short payback time period as well as high profit rate over the lifetime of the project.

Keywords: *Air Conditioner; Feasibility, PV System, Solar Energy.*

1. Introduction

The demand on the electricity is escalating worldwide. Up to 50% of a building energy comes from air conditioning in subtropical regions [1-2]. This large electricity demand leads to an increase in the peak electric load, which can be a major cause of power system instability and system failure. The increased energy demands and the negative environmental effects of the fossil fuel have been boosting the development, investigation and application of renewable energy sources such as wind, solar, hydro or tidal power for over the decades. Moreover, the combination of the renewable sources is getting more attention in renewable energy applications. In recent years, the application of Photovoltaic (PV) systems has increased dramatically. PV system is considered as a clean and sustainable source of electricity. PV systems are very attractive for air conditioner application because the peak demand for cooling coincides with the period of the high solar radiation [3]. Furthermore, the operation cost is very low compared with other energy sources and the average lifetime for PV solar equipment varies from 20 to 30 years.

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Solar PV technology is one of the alternatives to conventional energy sources with great potential contribution to solving energy issues. Even the combination of fossil power plants with renewable energy applications, (e.g. PV system), mitigate the adverse effect of fossil fuels on the environment. The need to reduce CO_2 emissions has affected the price of photovoltaic systems, and solar modules in particular, making application of photovoltaic more profitable.

Since Brunei, the location of the research, has high level of solar radiation, the development of solar energy sector including solar thermal, solar photovoltaic and solar water pumps is of a great interest. Using PV solar system to power the air conditioning system is productive proposition since Brunei is hot country and air conditioning systems consume huge amount of the electricity. Total dependence on gas for electricity generation may affect the country's economy especially electricity is subsidized by the government in Brunei. PV system can be provided as a long-term strategic plan for electric power consumption which will help to cut down the operation cost of conventional power plants as well as reduce CO_2 emissions. In Brunei, the government buildings are the second highest consumer of electricity making up 29% of the total energy consumption. Therefore, air conditioners are recorded as having the largest portion of the monthly electricity consumption with an average operation of 14 hours per day, and an air conditioner takes up about 76% of Bruneian household’s monthly electricity cost [1].

Air conditioning system can be operated with different technologies such as electric-vapor compression refrigeration (SE-VCR). Goswami [4], has investigated solar SE-VCR where the study is carried out in Adana city in Turkey. Minimum photovoltaic panel surface area and maximum compressor power consumption are obtained and, it was found that the SE-VCR system could be used for home/office-cooling purposes during the day. Inverter air conditioner is one of the new technologies that provides more efficient as well as less power consumption. Aroon et al [5] have presented the application of the inverter air conditioner using the back-to-back converter. The main aim of this technique is to provide the reactive power during the steady-state operation. In this study, a 3-phase has been used for the experimental setup to support the reactive power back to the utility grid system. The results show that remained power rating during steady state can be used to compensate the reactive power as a function of smart home which can be applied with home energy management system.

Compressor in air conditioner can be powered with DC motor drive or AC motor drive. DC compressor requires high DC current which can be provided by PV solar system. In reference [6], solar PV power has proven to be reliable to drive DC motor for air conditioning system. In this design, it is recommended to supply high DC voltage from the PV panels which can be done by connecting them in series with respect of quintiles of PV panels. As a result, there is not risk with using two types of energy modes of mutual interference either in analysis or experiments.

DC inverter air conditioning system is considered as one of the best technologies for saving power in air conditioning system. Waleed et al [7] have investigated two air conditioning systems in order to cut down the peak load and its risks in summer. DC inverter air conditioning system has been recommended in this study in Bahrain because it is cost effective. Air conditioning equipment using DC

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power supply system was discussed in reference [8]. Air conditioner load is significantly affected by the temperature along with characteristics of randomness, distribution, diversity, and intermittence.

In air conditioner applications, the conventional single-phase induction motors have been widely used as fan or compressor motors for a long time. However, its efficiency and power density are quite low and the motor speed is not adjustable. According to [9], brushless DC (BLDC) motor is considered rather than induction motor in efficiency, structure, and power density. Thus, it is used in air conditioner applications. Experimental results showed as well as the implementing of system has been successfully.

Recently, many solar air-conditioning systems have been developed and tested including solar-absorption, solar adsorption and solar-vapor compression systems. Solar-absorption and adsorption systems are powered mainly through solar thermal energy system. Two different technologies of solar air-conditioning have been discussed in reference [10]. They are solar thermal absorption refrigeration and PV vapor compression. This study concludes that PV vapor compression air-conditioning systems are more convenient due to smaller surface area as well as higher coefficient which were compared with solar thermal absorption refrigeration systems.

In recent years, the world has put a significant effort to cut down the electrical energy consumption which is one of the major causes of climate change and global warming. Applications of solar air conditioning assisted systems in Sub-Saharan Africa for residential buildings in reference [11]. Here, the demonstration of the possibility to implement an air conditioning system powered by solar. Refrigerant with low Ozone was used which could reduce depletion potential and global warming potential risks. In [12], a design of six air conditioners systems is investigated. The proposed system is stand-alone PV system where the batteries are used to compensate the deficit in the electricity generation. The batteries can provide the independence of the system, however, they form around 40% of the total system cost which approximately doubles the cost. Additionally, batteries need to be replaced after few years. In [13], the performance of solar powered air conditioner system in hot and cold weather is investigated. The location of the system is Shanghai, China. The system works steadily in hot and cold weather. A techno-economic analysis for a hybrid solar powered air conditioner system in Ghana is presented in [14]. The proposed system has achieved a potential savings compared to the grid electricity.

In this paper we present a design of air conditioning grid-connected PV system for a building at Universiti Teknologi Brunei in Brunei Darussalam. Four alternatives are considered; 1) the PV system supplies 50% of the loads, 2) the PV system supplies 75% of the loads, 3) the PV system supplies 100% of the loads, and finally 4) the PV system supplies 125% of the loads.

2. Solar Energy Resource In Brunei

Brunei has high potential of solar energy. The solar radiation in Brunei Darussalam is shown in Figure 1. The solar radiation is in the range between 4.7 to 5.8 kWh/m2 per day, which is considered as high range level globally. The irradiation is obtained using different sources such as NASA, estimation using Angstrom method, and measured data. The estimated values are higher than the measured and NASA data, whereas both the measured and the data

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from NASA are approximately equal. However, all data values are realistic since they are within the reasonable global rang of the irradiation. In this paper, the NASA data has been used to design the PV system due to its reliability and its regular updates as well as the flexibility to access the irradiation history.

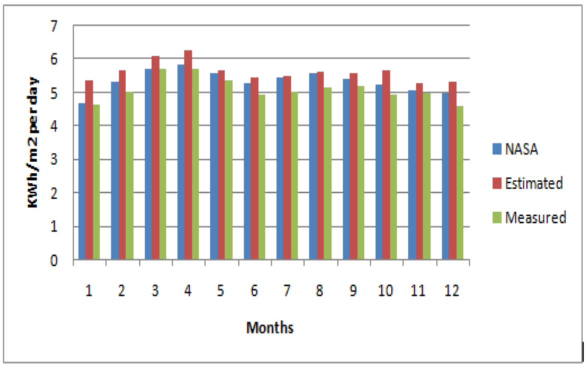

Figure 1: The Solar Radiation in Brunei

3. The Electricity Consumption of the Air Conditioning System

This study is targeting the government's building especially the air conditioning systems' equipment items. As a sample, the school of the design at UTB where the system is proposed to be implemented is chosen to provide the test-bed. The school of design at UTB uses split air conditioners that cool all rooms inside the building. There are different capacities of the air conditioners used in the building and each one consumes different electricity. However, the time that the air conditioners run per day is equal, which is 8.5 hours per day (08:00 AM- 04:30 PM). During Fridays and Sundays, the air conditioning system is kept turned off which will not be considered in the estimation of the electricity consumption. The air conditioners are based on inverter technology. In order to find the electricity consumption per day/week/month, it is required to find in Watt the rating of all devices and the operation duration in hours with respect to the devices quantities. The input rating power of the air conditioner is determined from the data sheet of the air conditioners. The details of the electricity consumption of the air conditioning system in School of design at UTB is listed in Table 1. The energy consumption of the School of design at UTB is 305.03 kWh per day as shown in Figure 2.

An inverter air conditioner's compressor is controlled by integrated controller which can adjust the speed and the frequency of the compressor's motor according to the temperature required in the room. This technology plays a role in the energy consumption which decreases the duration of the compressor working time. In this paper, the ratio of the compressor working time needs to be considered since all the air conditioners used, are an inverter technology which means that the compressor does not run all the time. In order to measure the exact energy consumed, it is required to use special equipment that can measure the electricity consumed in a certain electrical appliance. In this paper, POW R2 energy monitor is used to measure the energy consumption of one air conditioner in order to determine the ratio of the compressor working time. POW R2 is connected to the air conditioner for 8.5 hours to investigate its energy consumption and to find the ratio of the compressor working time. The energy monitor POW R2 is connected to mobile application via Wi-Fi, the POW R2 is shown in Figure 3.

Table 1: The electricity consumption of the air conditioning system

Item	*Rating* (Watt)	Hours	Quantity	CONSUMP (kWh/day)	CONSUMP (kWh/week)	CONSUMP (kWh/month)
Carrier inverter R410A 2.0HP	2750	8.5	15	210.375	1051.875	4207.5
Carrier inverter R410A 2.5HP	4400	8.5	4	89.76	448.8	1795.2
Carrier inverter R410A 1HP	960	8.5	1	4.896	24.48	97.92
Total	8110		20	305.031	1525.155	6100.62

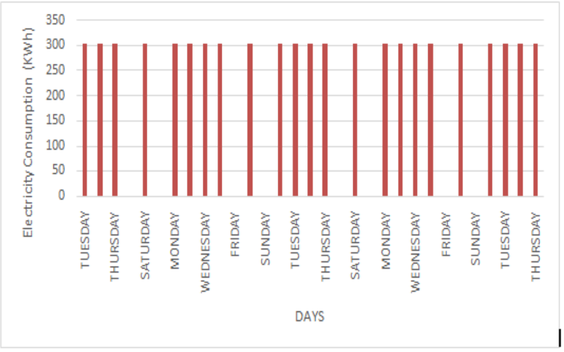

Figure 2: The energy consumption for January 2019

Figure 3: The POW R2

4. The Design of the Pv System

Sizing of the PV system is the main part of the system design. In this section, different parameters of solar PV system will be calculated and optimized such as the electricity generated, the electricity consumed, and the electricity feed into the grid. The feed-in tariff is the price that the electrical company will pay to the costumers who have PV systems installed at their houses. In the recent years the feed-in tariff policies have contributed to the expansion of the PV technology. The maximum output power is totally based on the peak-sun hour. The amount of solar radiation, or insolation, delivered by the sun varies throughout the day, based on the sun's position in the sky, clouds, and other atmospheric conditions. The peak-sun hour was already obtained from the previous section in the solar irradiation data. The maximum output power equation is described by:

$$P_{\max} = \frac{E_{per-day}}{peak-sun\_hour(h)} C_{sys}\eta_{sys} \qquad \textbf{(1)}$$

Where: P_{max} is the maximum output power generated by PV system in kW. $E_{per-day}$ is the electricity consumption per day. C_{sys} is the capacity of the system and η_{sys} is the efficiency of the system. Here in this paper, the capacity of the system is changing from 50% to 125%. The total efficiency η_{sys} was estimated as 85% where all the losses have been considered. The losses that included are the inverter losses (2%), The temperature losses (6%), DC cables losses

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(2%), AC cables losses (2%), and shading weak irradiation (3%). The total losses are estimated to be 15 % so the efficiency of the system equals to 85% as it shown in Figure 4.

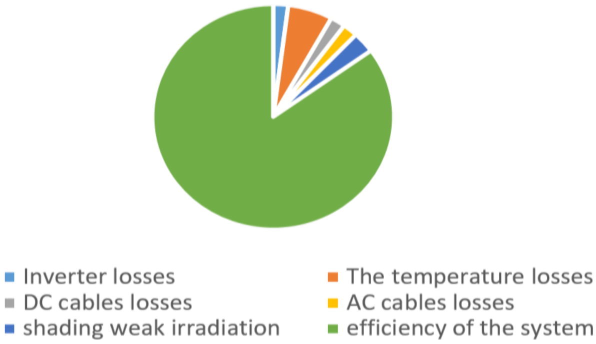

Figure: 4 The total losses in the system

Sketch Up Skelion is a tool that can be used to design solar thermal or solar PV systems starting from a 3D model. It can simulate the sunny area in a certain location for studying the shading effects. It has a feature to export the report of the capability of the system by using PVsys and Google Earth. The shading can be also simulated in order to obtain the suitable area for installing the PV modules in order to reduce the shading losses. In this paper, the area of the project on the top of the roof of School of Design UTB has been simulated by SketchUp, Skelion for studying the available area that is not affected by the shadow. In addition, the sun path chart was created based on the latitude and longitude of the project's location. The location of this project was determined by the Google earth tool so the sun position is accurate. The shading of the nearby buildings was considered as well, and the simulation has indicated the area that not effected by the nearby buildings shading. Therefore, the shading between the PV panels that is created by the tilt angle was avoided by calculating the minimum distance between each PV panel. The simulation model for the area and shadow calculation is shown in Figures 5. From the figure the available area is 760 m^2.

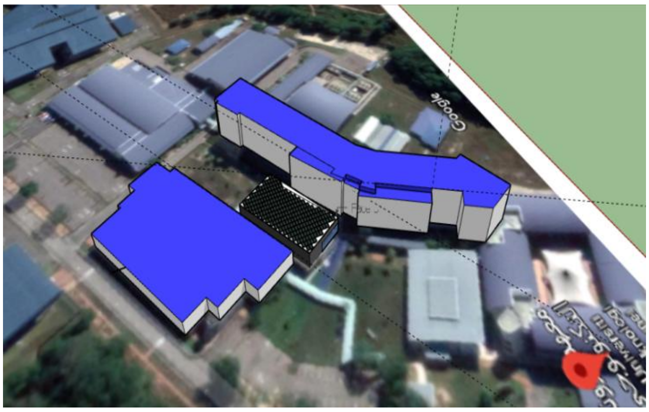

Figure 5: The Top View of Simulated Project Location with Nearby Buildings

5. The Economic Analysis

An economical evaluation is made to evaluate the cost-benefit of different configured PV systems. Some economical terms to consider are payback time, net present value (NPV), internal rate of return (IRR), feed in tariff, and cash flow return rate. Besides, the cost of the PV system components. The NPV method is used to calculate the present value of the future cash flows and is a common way of evaluating PV systems. A project is considered profitable if the NPV > 0. The payback time shows how long it will take to make the invested money back, while NPV shows the profit one can expect at the end of the investment period. The NPV present is calculated by:

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{Revenue_t - Costs_t}{(1+r)^t} \quad (2)$$

Where t is the year of operation, C_t is the net cash flow, T is the lifetime of the system, r is the discount rate, Revenue is the cash inflow and Costs is the cash outflow. IRR is the interest rate at which the net present value of all the cash flows (both positive and negative) from a project or investment equal zero. Internal rate of return is used to evaluate the attractiveness of a project or investment. If the IRR of a new

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project exceeds a company's required rate of return, that project is desirable. If IRR falls below the required rate of return, the project should be rejected. In order to calculate IRR using the formula of NPV, one would set NPV equal to zero and solve for the discount rate (r), which is the IRR. Because of the nature of the formula, however, IRR cannot be calculated analytically and must instead be calculated either through trial-and-error or using software programmed to calculate IRR.

When using feed-in-tariffs (FiTs), electricity generated by the PV system can be sold to the grid utility for a fixed price. A smart meter or two analogue electricity meters are required for this system. In a net feed-in-tariff only the surplus electricity is sold to the grid. In Brunei, selling the electricity to the grid by PV system grid-connected still under consideration although the feed in tariff was estimated to be equal to 30 cent Bruneian dollars per KWh [15]. This estimation was done based on the levelized cost of the conventional electricity generation. This study therefore recommends starting with the feed-in tariff scheme as the key policy framework to stimulate private investments and to scale-up deployment of renewable energy technologies. In the future, once tariff reforms are introduced and coupled with declining technology costs, and once solar PV power generation would achieve or approach close to grid parity, net metering could be introduced [15].

6. Results and Discussion

Four alternatives are considered; 1) the PV system supplies 50% of the loads, 2) the PV system supplies 75% of the loads, 3) the PV system supplies 100% of the loads, and finally 4) the PV system supplies 125% of the loads. The parameters of the system used in this paper are given in Table 2. The overall output results of the system are the output parameters that are required for the installation such as the number of the modules and required area. Additionally, the economical parameters such as the payback time, the capital cost and IRR. The output results are shown in Table 3. The change in the inputs will be accrued in the cost of the inverter, cost of the installing of the system, and O&M cost and the rest inputs will remain constant. The PV production, electricity consumption and the electricity feed-in for the four alternatives are shown in Figures 6-8. The cash flow for the four alternatives are shown in Figures 9-11.

As it clearly shown in Figure 6, the electricity exported into the grid is negative because in this case the system depends on the grid where the grid is supplying the building with 50% of the required electricity. In this case, no monthly income from the system but the users need to pay half of the electricity with no PV system implemented. In the case of 100% capacity the net cash flow has increased and there is amount of incoming profit from the system. However, the discount cash flow is less than cash flow without discount rate which is assumed to be 5%. The profit of this system in this case is estimated to be equal to 87,880 BND over the lifetime of the project.

The output power of the system with 125% capacity equals to 69 KWp. The payback time has decreased to 7.8 years which shows this alternative is profitable. The net cash flow in this case has increased. However, the discount cash flow is less that cash flow without discount rate which is assumed as 5%. The profit of this system in this case was estimated to be 245,819 BND over the lifetime of the project. Whereas the profit with the discount rate can reach 95,497 BND.

Table 2: The input parameters of the system

System Parameter	Value	System Parameter	Value
The daily power consumption	305.031 kWh	Cost of the inverter	30,000 $
The efficiency of the system	85%	System Capacity	50% - 125%
Available Area	760 m^2	Feed in tariff	0.3 $
Max output power of the PV panel	300 W	Discount rate	5%
Area of each panel	1.9 m^2	Depreciation	0.05%
The cost of PV panel	180 $	Electricity tariff	0.1 $
Cost of the system	30,000 $	O&M cost per year	O&M cost per year

Table 3: The output parameters of the system

System Parameter	Value	System Parameter	Value
The system output capacity	66.245 kWp	The system total income	12983.34 $
No of PV modules	221	The payment back time	8.6 years
The area needed for the system	420 m^2	The cash flow return rate	11.7%
Total cost of the system	112247.12 S	The net present value	$106,924.69
The life time	25 years	The internal rate of return	6.36%

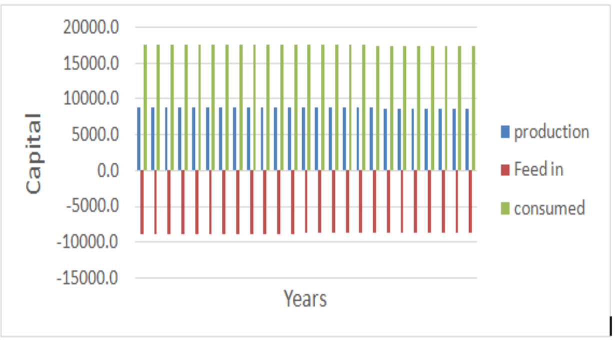

Figure 6: The PV production, the electricity consumption and the electricity feed-in with 50% capacity

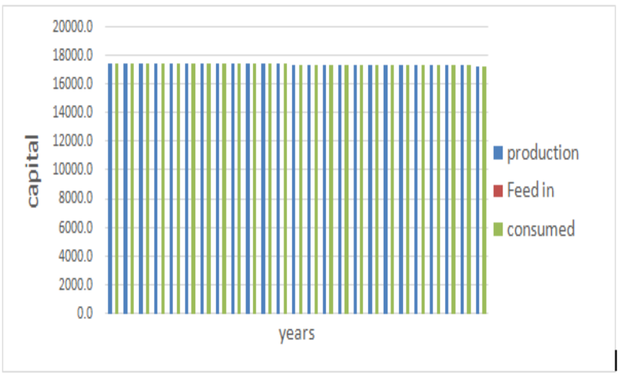

Figure 7: The PV production, the electricity consumption and the electricity feed-in with 100% capacity

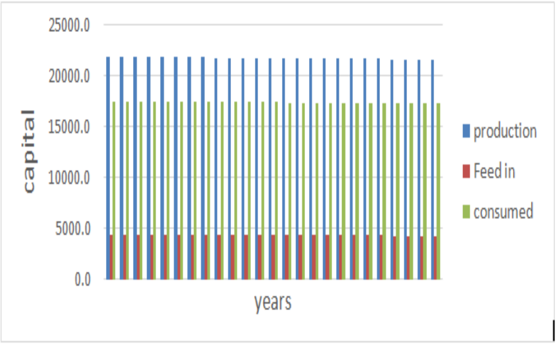

Figure 8: The PV production, the electricity consumption and the electricity feed-in with 125% capacity

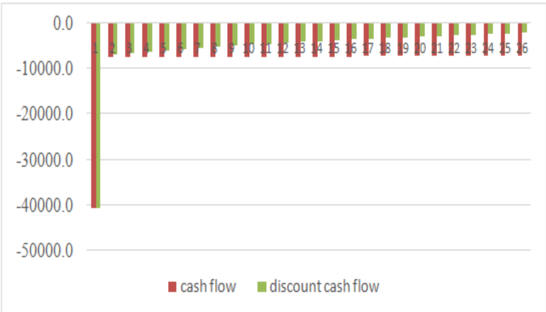

Figure 9: The cash flow with 50% capacity

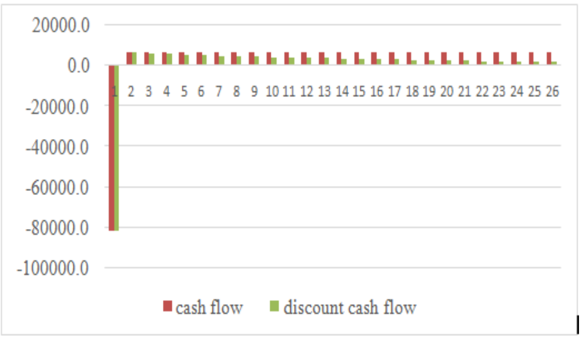

Figure 10: The cash flow with 100% capacity.

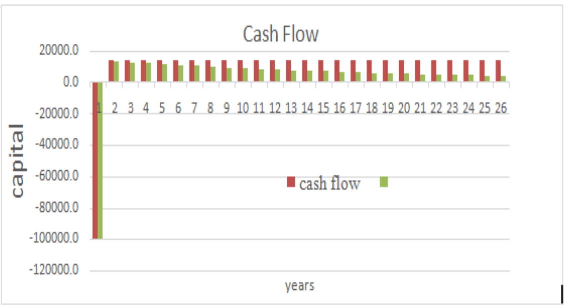

Figure 11: The cash flow with 125% capacity.

7. Conclusion

Four alternatives have been investigated for a PV powered air conditioning system in Brunei Darussalam. The capacity of the system ranges from 50% to 125%. The main purpose of this study is to find weather the solar powered PV system is techno-economic feasible or not. It was found that the most cost effective option is the PV system with capacity rate of 125%, which has the highest profit over the lifetime of the project and the shortest payback time with 7.8 years. In addition, the 50-100% capacity rates can be considered as suitable solation for limited budget. The feed in tariff in Brunei is assumed to be 0.3 cents as proposed in some previous research. In this study the feed-in tariff, the interest rate and the inflation rate are assumed to be constant.

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