

## Simulation Study of Stand-Alone Photovoltaic System Design with Battery and Supercapacitor

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DOI: <https://doi.org/10.30880/eeee.2022.03.02.046>

Received 01 July 2022; Accepted 19 September 2022; Available online 30 October 2022

**Abstract:** Nowadays PV system has been used in many countries around the world. A PV system is composed of one or more solar panels combined with an inverter and other electrical and mechanical hardware that use energy from the sun to generate electricity. There are many types of photovoltaic solar system designs and can be listed into three types, on-grid, off-grid, and hybrid-grid. In this project, an off-grid photovoltaic solar system design is chosen. However, since solar photovoltaic systems are fully dependent on the weather and temperature, this might interrupt the continuous supply of electricity to the household. To alleviate the uncertainty of photovoltaic systems the home appliance, this study will implement hybrid energy storage by utilizing the application of a battery and supercapacitor. Hybrid energy storage will improve the efficiency of grid-connected photovoltaic systems. They are used to improve the quality of output power from the photovoltaic system. The variation of output power depends heavily on weather conditions, leading to adversely affecting the power system's stability. Battery and supercapacitor are the best work together since the battery has high energy density while the supercapacitor has high power density. The supercapacitor is introduced in this paper to extend battery performance, and lifetime and reduce maintenance costs. The results are tested and analyzed for a battery system with supercapacitors integrated.

**Keywords:** Stand-Alone, Photovoltaic System, Energy Storage, Supercapacitor, MatLab Simulink.

### 1. Introduction

Solar energy is becoming increasingly important in the power supply systems throughout the world striving to build their economies. Amid the Covid-19 pandemic, the installed capacity of renewable energy sources throughout the world was still expanding in 2020 [1]. Along with its accessibility and long-term sustainability, solar energy is regarded as one of the most promising sources of energy. The PV system is the most efficient way to utilize solar energy. PV is the process of converting sunlight directly into electricity using solar cells. PV power generation is the most promising, readily available, and necessary renewable energy. Off-grid photovoltaic (PV) solar system is one of the solar system

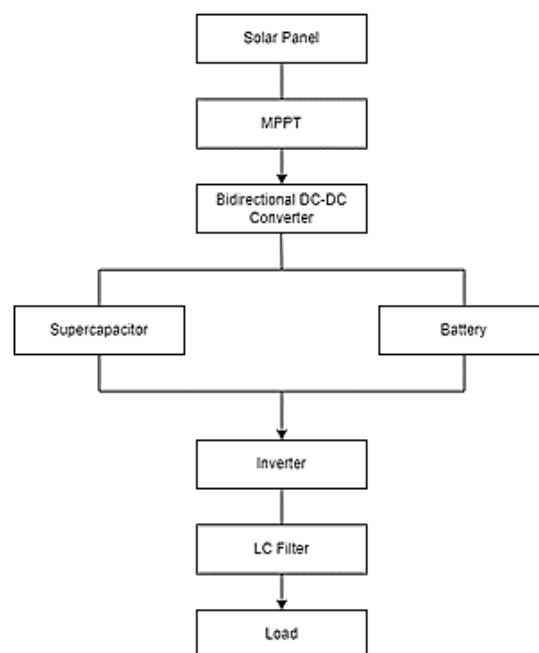
designs that is most used in rural residential. The consumer will gain access to electricity from the solar panel. However, due to the unpredictable nature of solar irradiation and the monsoon season in Malaysia, energy storage is crucial for tackling this issue. Thus, the implementation of battery and supercapacitor together as energy storage in the PV solar system will allow the consumers to get full accessibility to electricity from the PV solar system. Hybridization of energy storage technologies could also come with a variety of applications in a system that would otherwise be impossible with single storage technology. Supercapacitors can help prolong the life of batteries by reducing stress in storage [2].

This research work embarks on the following objectives: to design a simulation of the off-grid photovoltaic system for residential by using Matlab software, and to implement battery and supercapacitor in PV circuit as energy storage system.

## 2. Methodology

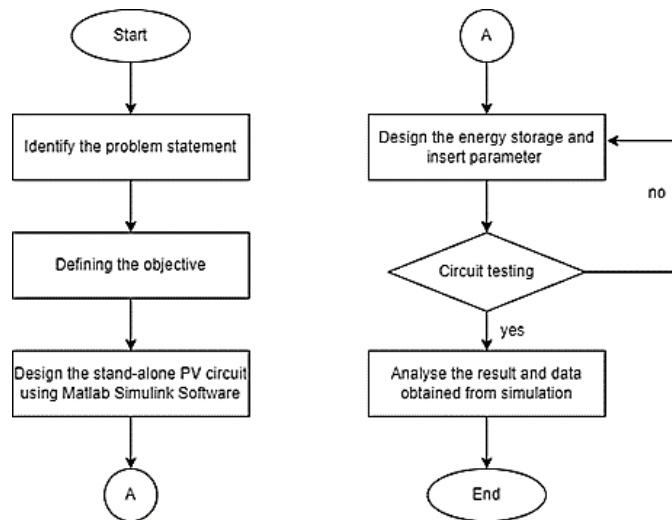
The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

Figure 1 depicts the block diagram of the simulation. The voltage output from the solar panel is sent to the MPPT to maximize the output power from the solar panel since the output is dependent on the irradiance and the temperature. Next, the excess power produced will enter the energy storage system to be stored and delivered. The energy storage system is a battery and supercapacitor which work together to optimize and prolong the energy storage lifetime. After that, the voltage will be inverted through a DC-AC inverter since home appliances and grids are AC loads.



**Figure 1: Block Diagram of the project**

The flow work of this study starts with identifying the problem in the application of renewable solar energy which is energy storage management. Secondly, the objectives are defined after finding and research are done regarding the title. The third step is to start designing and drafting an on-grid PV solar system with a battery and supercapacitor. Next, the circuit is built and tested using Matlab Simulink software. If the circuit is functioning, the outcome from simulation and waveform is analyzed and discussions are made. Figure 2 shows the flowchart of this project.



**Figure 2: Process Flowchart of the Project**

The battery and supercapacitor will act as energy storage in this photovoltaic system. The lithium-ion battery has been chosen since it has many advantages compared to the other type of batteries. The battery will store and supply energy to the load. The supercapacitor acts as energy storage alongside the battery. Supercapacitors will reduce the battery’s current stress and lower the battery’s depth of charging. Thus, it will improve energy density and prolong the battery lifetime. Tables 1 and 2 tabulated the parameter of energy storage that used in this simulation.

**Table 1: Parameter of Battery**

Specification	Value
Nominal Voltage (V)	148V
Rated Capacity (Ah)	700 Ah
Initial SOC (%)	80%
Battery Response Time (s)	30/10

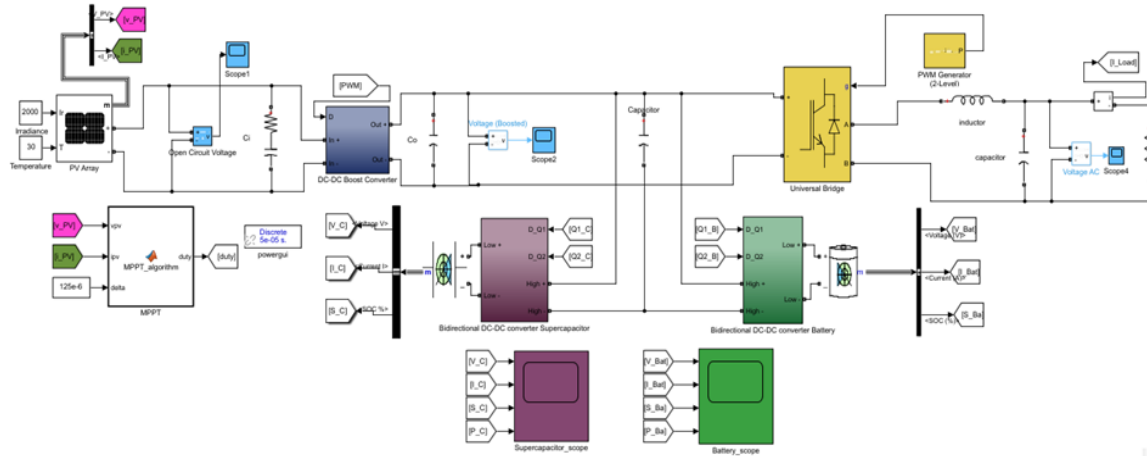
**Table 2: Parameter of Supercapacitor**

Specification	Value
Rated Capacitance (F)	29F
Rated Voltage (V)	32V
Operating Temperature (°C)	25 °C
Initial Voltage (V)	32V

### 3. Results and Discussion

The results and discussion section presents data and analysis of the study. This section presents three subtopics which are photovoltaic analysis, energy storage analysis and overview of the circuit. We will discuss the result of the study. The circuit is tested and built using Matlab Simulink software. The waveforms from the circuit are shown and discussed.

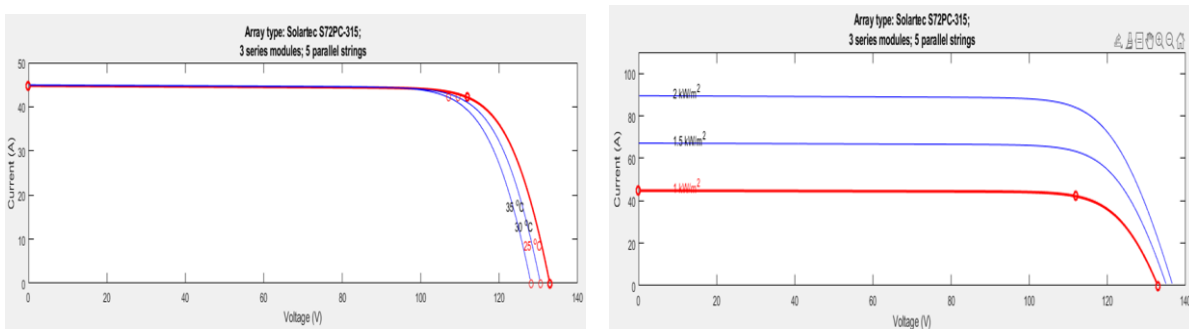
Figure 3 shows the circuit of the PV solar system using Matlab software for this project. The component used in the simulation is the PV array with an irradiance of 1500 and temperature of 25 °C. The PV array is connected to the DC-DC boost converter to increase the output voltage from the PV array. After that, energy storage is connected consisting of a bidirectional DC-DC converter with battery and supercapacitor. A universal bridge is used as an inverter to convert the DC voltage to AC voltage. Next, the resistor acts as a load. Scopes are connected to the PV array, boost converter and inverter. Scope for battery and supercapacitor is connected to obtain the waveform.



**Figure 3: Stand Alone Photovoltaic Solar Circuit**

**3.1 Photovoltaic Analysis: Difference Irradiance with Constant Temperature**

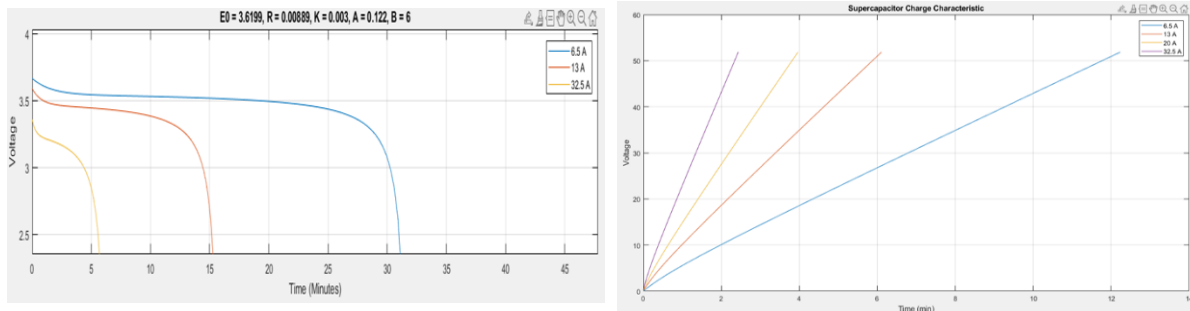
Different irradiance may affect the performance of the PV array. The value of irradiance is varying from 1, 1.5 and 2 kW/m<sup>2</sup> while the temperature is constant at 25°C. The higher the value of irradiance, the higher the value of current. Thus, a higher voltage output will be obtained. While I-V curve for different temperatures with constant solar irradiance for 25, 30 and 30°C with constant solar irradiance of 1000 W/m<sup>2</sup> When the temperature is increasing, the output voltage is decreased, and this will have decreased the output power too. The current will stay constant at a certain point until it drops to zero voltage as shown in Figure 4.



**Figure 4: Graph for PV Analysis**

**3.2 Energy Storage Analysis**

For energy storage, the curve of discharging rate of battery and supercapacitor charge are obtained and discussed. The rate of battery discharging at a current of 6.5A, 13A and 32.5A. The discharging rate of the battery will go constant for a certain period of time before the rate become zero. The discharging rate of the battery change with the change of current where the higher the value of current, the less time for the battery to fully discharge. The supercapacitor charge characteristic with the current of 6.5A, 13A, 20A and 32. The voltage of the supercapacitor is directly proportional to time. The higher the magnitude of the current, the longer it takes for the supercapacitor to charge. For I = 6.5A it takes the shortest time to fully charge which is t=2.4min. While for the current 32.5A, it takes t=12.2min to charge. Figure 4 illustrates the graph for discharging rate of the battery and supercapacitor charge.



**Figure 4: Graph for Energy Storage**

#### 4. Conclusion

A simulation of an off-grid connected PV solar system with battery and supercapacitor as energy storage has been presented in this project. Matlab Simulink software was used to simulate the project. An off-grid connection was designed with output obtained. A comparison analysis was made for different temperatures and different solar irradiance with a reference graph. It can be concluded that the different input parameters produced different I-V curves. The energy storage of the battery and supercapacitor was connected to the main circuit. A graph of battery discharge, and charging characteristics of the supercapacitor were obtained and discussed.

#### Acknowledgement

The authors would also like to thank the Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia for its support.

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