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Supercapacitor Implementation to Prototype Energy Storage System Optimizer in PV System

Muhamad Zakaria[1], Abdul Multi[2], Agus Sofwan[3]
[1]National Institute of Science and Technology, Jakarta, Indonesia, email: muhzakaria336@gmail.com
[2]National Institute of Science and Technology, Jakarta, Indonesia, email: amulti@istn.ac.id
[3]National Institute of Science and Technology, Jakarta, Indonesia, email: asofwan@istn.ac.id

Corresponding Author: Muhamad Zakaria[1]

Abstract: This research aims to create a prototype of an energy storage optimizer in a PV system using a supercapacitor in combination with batteries. The purpose of adding supercapacitors in this prototype is to maintain battery usage when there is a change in irradiation with a loading source that refers to the amount of electrical current and voltage as a supply of energy. A sudden increase in load without an energy buffer component can affect battery endurance. This can result in a decrease in electrical energy supply. Based on experimental results, it has been found that the battery and supercapacitor complement each other. The battery works more statically while the supercapacitor works more dynamically. Thus, the power output to the load is more stable, and the battery can be more durable because when there are extreme changes in irradiation and load, they can be overcome by supercapacitors.

Keyword: PV System, Supercapacitor, Battery, Storage Energy System.

INTRODUCTION

The need for clean energy supplies such as solar panel systems is an energy source that is expected to solve the problem of future energy needs after various conventional energy sources are reduced in number and are not environmentally friendly.

In use, PV (photovoltaic) is affected by the intensity of sunlight, causing the output power to fluctuate. The power generated by the PV is then stored in the battery. The battery itself has storage state characteristics, namely state of charge (SOC) and depth of charge (DOD) (Aditya Setiadi Putra, 2018).

PV is not an ideal source for battery charging, the output generated is unreliable as it is highly dependent on weather conditions, therefore the charge-discharge cycle cannot be generated optimally, resulting in a weak battery state of charge.

Low battery state of charge leads to sulfation and stratification, both of which shorten battery life (M. E. Glavin, 2008).

Therefore, to support the shortcomings of batteries whose charging process takes a long time, it is necessary to add a capacitance component that can perform the charge-discharge energy process in a short time to keep the SOC value and battery power stable (Dewa Gde Santika, 2020).

One of the devices used to increase capacity is a supercapacitor. Supercapacitors have a higher power density than batteries, which allows supercapacitors to provide more power in a short period of time. Conversely, batteries have a much higher energy density than supercapacitors, allowing them to store more energy and release it over a longer period of time (M. E. Glavin, 2008).

Supercapacitor cannot store energy for a long time, so the combination of batteries and supercapacitors is expected to be able to bridge the gap between the two and make the capacity of the energy storage system more optimal and can be divided evenly when releasing power to the battery.

The existence of supercapacitor components is very important in developing new opportunities for optimizing the storage and use of electrical energy, which has also been studied by previous researchers with the aim of strengthening the availability of electrical energy sources.

METHODS

The system which is designed in this research uses six supercapacitors connected in series and then in parallel with the battery. This study examines the effect of the addition of supercapacitor on the level of battery resistance to the load with maximum sunlight condition.

The PV component used in this research experiment is a monocrystalline module with a capacity of 100 Wp.

The use of supercapacitors is intended to increase the durability and performance of the battery where the photovoltaic system has an unstable power output, so it is not an ideal source for battery charging.

Battery components have operating characteristics that allow them to work for a limited amount of time and to charge a certain amount of energy. The supercapacitor has a greater power density than the battery which allows to provide more power over a short period of time. Furthermore, supercapacitors must be able to operate under hybrid conditions and make the battery stable.

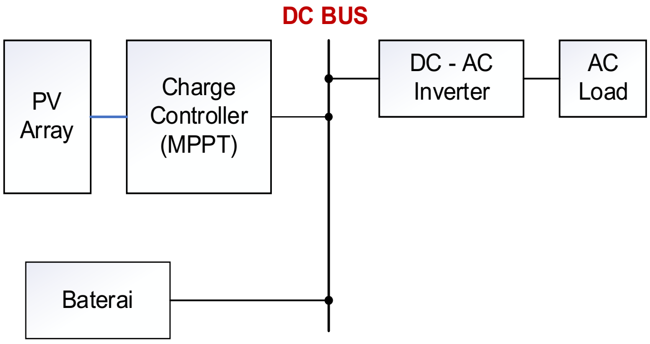
Model of Photovoltaic Battery Storage

Battery is one of the components used in photovoltaic (PV) systems that are designed to store the electrical energy generated by the solar panels in the form of direct current (DC). The energy stored in the battery is used as a backup when the solar panels are unable to generate electricity, for example at night or when it is cloudy.

The unit of energy capacity stored in the battery is ampere-hour (Ah), which is the maximum current that can be delivered by the battery for one hour. However, when discharging, the battery should not be discharged to its maximum point, this is so that the battery can last longer its life (lifespan), or at least not reduce the manufacturer's specified lifespan.

The battery discharge limit is often referred to as the Depth of Discharge (DOD), which is expressed in percentage units, the maximum DOD value is generally given as 80%.

The most common PV system configuration, shown in Picture 1, includes PV module, power converter, load, and battery storage. The energy produced by the PV panel is stored in the battery. The battery is used to supply the load when there is a difference between the available energy and the required energy.

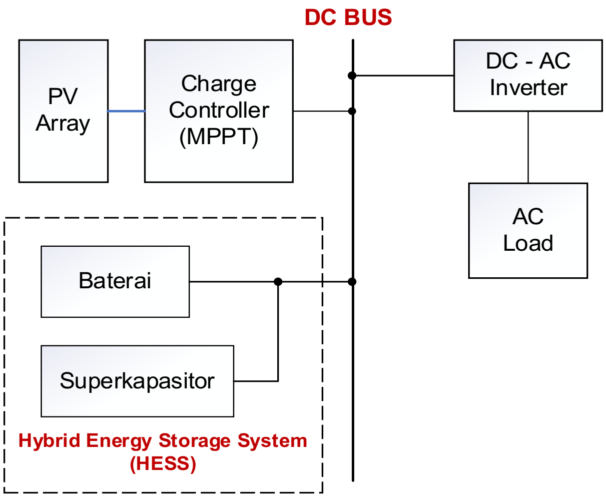


Picture 1. Photovoltaic Battery Storage Schematic Diagram

Model of Photovoltaic Battery Storage in Combination with Supercapacitor

The proposed energy storage model in this research is composed of a VRLA battery bank and a supercapacitor battery bank as shown in Picture 2.

The advantages of both technologies, the high-power density of the supercapacitor and the high energy density of the battery, are adopted by using both systems.



Picture 2. Photovoltaic Battery Storage with Supercapacitor Schematic Diagram

The schematic diagram above explains that the energy storage system in the PV system consists of several blocks, namely PV panels, MPPT, inverter, battery, and supercapacitor.

The available power from the photovoltaic panel is used for load power supply, and excess power is used for battery and supercapacitor charging. The MPPT captures the maximum amount of power available from the solar panel.

By using the supercapacitor as a battery buffer in PV energy storage systems, as shown in Picture 2, the size of the battery can be reduced, and higher state of charge (SOC) values can be maintained.

Supercapacitor has higher power density than battery, allowing supercapacitor to store and release more energy in short periods. Conversely, battery has a much higher energy density compared to supercapacitor, allowing the battery to store and release more energy over a longer period of time.

RESULT AND DISCUSSION

No Load Test Result and Discussion

The results of the design and development of the system model in this study is a type of conventional system without a controller component.

The circuit model is a passive hybrid system with the use of supercapacitor connected directly to the battery. The addition of supercapacitor to the energy storage optimizer in this PV system is as a battery buffer that aims to increase the absorption of electrical energy generated by the PV and stored in the battery, as shown in Picture 3 and 4.

Picture 3. Front View of The Energy Storage Optimizer

Picture 4. Inside of The Energy Storage Optimizer with PV Panel

The test is performed by pointing the PV directly into the sun and then measuring the PV output voltage to the solar charger. This test also measures sunlight intensity using a lux meter, where the measured light intensity value can later be used to illustrate the relationship between sunlight intensity and the output power produced by the PV.

The light intensity is measured by placing the lux meter parallel to the surface of the solar panel, as shown in Picture 5.

Picture 5. Testing The Intensity of The Sunlight

No load system operation is performed to determine the performance of PV in charging the battery with a system directly connected to the PV array. The result of measuring the sunlight intensity on the PV output power are shown in table 1.

Tabel 1. Sunlight Intensity Variation Test Results on Battery Charging

Time	Weather	Intensity (Lux)	Temperature (°C)	Battery Voltage (V)	Battery Curent (A)
9:00	Cerah	5132	32.3	10.03	1.7
9:30	Cerah	5568	32.5	10.30	2.3
10:00	Cerah	5572	32.6	10.63	2.7
10:30	Cerah	5912	32.9	11.02	2.8
11:00	Cerah	5920	33	11.38	3.1
11:30	Cerah	6008	33.1	11.46	3.1
12:00	Cerah	6025	33.2	11.87	3.1
12:30	Cerah	6091	33.3	12.00	3.4
13:00	Cerah	6113	33.4	12.28	3.4
13:30	Cerah	6121	33.4	12.48	3.4
14:00	Cerah	6143	33.5	12.64	3.4
14:30	Cerah	6160	33.6	13.89	3.7
15:00	Cerah	6213	33.6	13.03	3.7

From Table 1, we can see that the maximum voltage of the PV under the sunny condition is close to 13.03 V with a maximum current of 3.7 A. Then using the formula $P = V \times I$ we can calculate the amount of power absorbed by the battery of 48.21 W.

Then the addition of supercapacitor is performed to see the extent of optimization of the battery charging process by the PV system with the condition of the results shown in Table 2.

Tabel 2. Sunlight Intensity Variation Test Results on Battery Charging by Adding Superkapacitor

Time	Weather	Intensity (Lux)	Temperature (°C)	Battery Voltage (V)	Battery Curent (A)
9:00	Cerah	5132	32.3	10.81	1.7
9:30	Cerah	5568	32.5	11.8	2.3
10:00	Cerah	5572	32.6	11.10	2.7
10:30	Cerah	5912	32.9	12.10	2.8
11:00	Cerah	5920	33.0	12.38	3.4
11:30	Cerah	6008	33.1	12.46	3.4
12:00	Cerah	6025	33.2	12.61	3.4
12:30	Cerah	6091	33.3	12.96	4.1
13:00	Cerah	6113	33.4	13.07	4.1
13:30	Cerah	6121	33.4	13.16	4.1
14:00	Cerah	6143	33.5	13.21	4.6
14:30	Cerah	6160	33.6	13.35	4.6
15:00	Cerah	6213	33.6	13.38	4.6

From table 2 above, it can be seen that there is an increase in the maximum voltage of about 13.38 V and current of 4.6 A. We then recalculate the power absorbed by the battery using the formula $P = V \times I$, so that we obtain a power of 61.54 W. there is an increase of 27.5%.

Load Test Result And Discussion

The ability of batteries and supercapacitors to perform the process of discharging and recharging as desired makes it possible to maintain the power supply in the inverter even under irradiation conditions and changing load requirements.

A load test is conducted to determine the extent of the battery's ability to meet the inverter power requirements. The test was performed with a fan load of 50 W, with the results shown in table 3.

Table 3. Load Test Result Without Supercapacitor

Load Without Supercapacitor	
Battery Voltage	10.76 V
Battery Current	4.6 A

According to the above test data at the time of loading, the battery has a power of 49.50 W. The test was then continued with a 60 W fan load, but the voltage dropped drastically causing the inverter trip as shown in Picture 6.

Picture 6. Inverter Fault

The figure shows the state of the inverter trip, which is indicated by the red indicator light on and a voltage drop of 9 volt.

Then at the stage of adding six pieces of 2.7 V / 500 F supercapacitor made in series and then installed in parallel with the battery. By applying the same load condition treatment, the results can be seen in table 4.

Table 4. Load Test Result With Supercapacitor

Load With Supercapacitor 2.7 V / 500 F	
Battery Voltage	11.62 V
Battery Current	8.6 A

Adding supercapacitor at this stage gives significant result with nominal set. The amount of power in the battery is 99.93 W. Compared to condition without the addition of supercapacitor, this stage shows 9% increase in battery voltage and an 86% increase in battery current.

CONCLUSION

The use of supercapacitor in PV system provides result on battery that is able to be balanced by maintaining the voltage conditions on the battery connected with the load and provide charging current on the battery. With the addition of supercapacitor of 2.7 V / 500 F, there is an increase in power absorption in the battery, where at this stage there is an increase in voltage by 9% and current by 86%.

The use of loads can affect the performance of the battery as an energy storage. In this case, the battery voltage drops from 11 V to 8 V in a very short time during a load spike, causing the inverter triped.

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