Design of Battery Protection System from Over-Powering and Depth of Discharger in Off-Grid System Solar Power Plants Batteries

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Abstract. Renewable Energy (RE) is one of the energy sources widely used to meet the continuously increasing demand for electricity while reducing the use of depleting fossil fuels. Off-Grid Solar Power Plants (PLTS) are part of RE that utilizes solar energy as the primary energy source. In such systems, batteries often present a common issue, particularly due to damage caused by excessive power usage and Depth of Discharge (DoD) exceeding predetermined limits. Therefore, this study aims to design and build a battery protection system to prevent excessive power usage and manage DoD. The protection system allows for the regulation of power usage and DoD of the battery according to set parameters. Furthermore, in tests with incremental loads, the relay starts to activate at specific current and power levels. In the experiment with a 21.70-watt load, the relay remained off; however, when the power reached 70.86 watts with a larger load, the relay activated to protect the battery. Based on this research, the protection system can be applied to off-grid PLTS systems that use batteries as temporary storage for electrical energy generated from solar panels. The conclusion of the developed system is that this protection system successfully provides battery protection by cutting off the electrical flow when the power exceeds the set limit and the battery's DoD reaches the specified threshold. This system can be applied to off-grid PLTS to prevent battery damage due to excessive usage, extend battery life, and improve the reliability of RE systems. Thus, this system contributes to the development of more sustainable and efficient RE.

Keywords: Depth of Discharge (DoD), Off-Grid Solar Power Plant (PLTS), Power, Renewable Energy

1 Introduction

The increasing electricity consumption each year poses a challenge in Indonesia due to the reliance of many power plants on fossil energy sources such as coal, oil, and natural gas. This results in the diminishing availability of fossil energy sources each year, making it necessary to seek alternative energy sources such as renewable energy (RE)

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to meet the continuously rising energy demands. RE refers to energy sources that come from natural resources that can be replenished sustainably. It includes various forms of energy, such as solar energy, wind, water, biomass, and geothermal energy [1].

There are several types of power plants that utilize renewable energy sources, one of which is the solar power plant (PLTS). PLTS is an electricity generation facility that uses sunlight as its primary energy source [2]. Based on the system, PLTS is divided into three types: the ON-Grid system, which does not use batteries as a storage medium, but is directly connected to the PLN (State Electricity Company) source through an Exsim KWh meter; the Off-Grid system, which requires batteries to store the electrical energy generated from solar panels; and finally, the Hybrid system, which also requires batteries for energy storage while being connected to the PLN source [3].

Among the three types of PLTS systems mentioned, this research focuses on the Off-Grid system, as this system often encounters issues, particularly with batteries. Common problems with batteries can arise from several factors, including excessive power usage due to the absence of a control system to regulate power consumption, leading to depletion of energy in the batteries and a lack of backup energy sources for use at night. Furthermore, another frequent issue with batteries is excessive energy discharge, or the use of battery energy beyond its lower limit (depth of discharge), which affects the battery's lifespan. The greater the Depth of Discharge, the shorter the battery cycle life becomes [4, 5].

To address these issues, a control system is needed to manage power usage and the Depth of Discharge (DoD) of batteries in Off-Grid solar power systems. By utilizing current technology, microcontrollers serve as control tools that can help resolve the aforementioned problems. With the implementation of a power and DoD control system for batteries in Off-Grid solar power systems, it is expected to prevent damage to the solar power batteries in the future. Thus, the use of alternative energy sources, such as renewable energy, can reduce dependence on non-renewable energy sources.

2 Materials and Methods

Every time research is conducted, tools and materials are needed to support the research activities. Additionally, there are methods that need to be implemented in this study. The tools, materials, and methods used in conducting this research are as follows.

2.1 Tools and Materials

In the research conducted, several tools were used in the development of the protection system. The tools used are listed in Table 1 below.

Table 1. Device

No	Equipment	Amount(s)
1	Screwdriver	1
2	Solder	1
3	Cutter knife	1

No	Equipment	Amount(s)
4	Pliers	1
5	Multimeter	1
6	Power Supply Variabel	1
7	Electric drill	1

This research utilizes several components in the development of the protection system, with the main component being the ATMEGA 328p, which serves as the microcontroller in the protection system, along with several other supporting components. The materials used are listed in Table 2 below

Table 2. Materials

No	Equipment	Amount(s)	Specifications
1	Atmega328p	1	- Operating Voltage 5 V - Input Voltage (Recommended) 7-12 V - Digital I/O Pins 14 (which 6 provide PWM output) - Analog Input Pins 6
2	Voltage Sensor	1	- Input Voltage 7-30 Volt
3	Current Sensor (ACS758LCB-050B)	2	- Maximum: ±50A (DC atau AC) - Operational voltage 3.0V - 5.5V (usually set on 5V)
4	IC LM7805	1	- Output Current up to 1A - Output Voltage 5 Volt - Thermal Overload Protection
5	Transistor 2N1711	2	- Tipe NPN - Collector-base voltage 70 V - Collector-emitter voltage 50 V
6	Relay	2	- Coil voltage 5 Volt - Contact voltage 250 VAC/10 A dan 30 VDC /10 A
7	LCD 20x4	1	-
8	Conductor terminal	6	-
9	Push Button	4	-
10	Elco	4	Adjust the system
11	Resistor	8	Adjust the system
12	Crystal Oscillator	1	16 MHz
13	Diode	3	Adjust the system

In the research conducted on the Off-Grid solar power system, solar panels with a capacity of 50 Wp were used. The complete specifications of the panels utilized can be seen in the table below.

Table 3. Specifications of the Solar Panel

Specifications	Nominal
Max.Power (Pmax)	50 Wp
Power Voltage (Vmp)	18.9 V
Max. Power Current (Imp)	2,83 A
Open Circuit Voltage (Voc)	22,3 V
Short Curcuit Current (Isc)	3,03 A
Nominal Operating Cell Temp	45±2°C
Weight	3 kg
Deminsion	606 x 450 x 35 mm

In the Off-Grid solar power system, batteries are required as storage for the electrical energy generated from the solar panels. In this research, the battery used is a lead-acid type with a capacity of 40 Ah. The complete specifications of the battery can be seen in the table below.

Table 4. Specifications of the Solar Panel

Parameter	Specification
Battery Type	Lead Acid (conventional/AGM)
Capacity	40 Ah
Nominal voltage	12 V
Dimension (P x L x T)	197mm x 165mm x 175mm
Life Cycle	500-800 cycles
Charging Voltage	14.4 V - 14.8 V
Operational Temperature	-20 °C - 50 °C

2.2 System Design

In the research conducted, a block diagram of the system to be created is necessary to facilitate understanding of the placement of the battery protection system. To understand the placement of the protection system on the battery in the Off-Grid solar power system, it can be seen in Fig. 1.

In Fig. 1, it can be seen that in the Off-Grid solar power system, there is a battery that needs to be protected from excessive power usage and battery DoD. There are two relays that function to cut off the electric flow to the battery, whether from the solar panel or towards the load. The protection system is implemented using the ATmega 328P microcontroller.

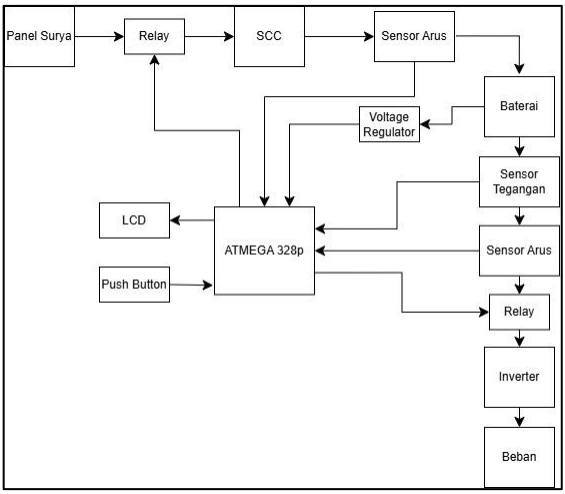


Fig. 1. Block Diagram of the Off-Grid Solar Power Battery Protection System

To facilitate understanding of the created protection system, a wiring diagram of the protection system or more precisely the module of the battery protection system is needed. To ease the understanding of the protection system module, please refer to Fig. 2 below.

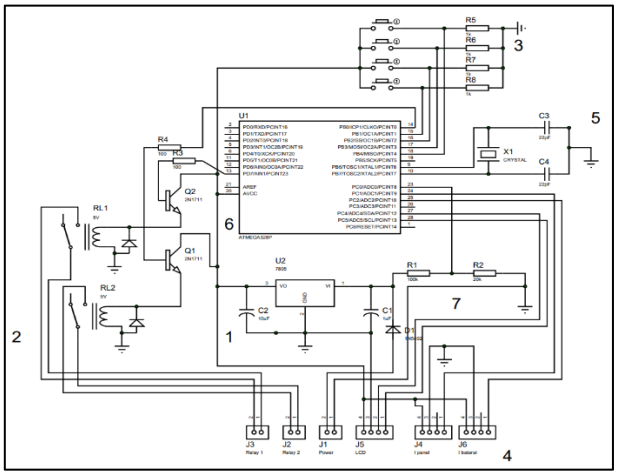


Fig. 2. Protection System Module

In the image above, the protection system module uses the ATmega 328P as its microcontroller. In section 1, the voltage regulator functions as the power supply for the system, using the LM7805 IC. In section 2, the relay control functions to disconnect the electrical flow to the battery as well as from the battery. Section 3 refers to the push button used for configuring the protection system, including setting the power and DoD

setpoints. Next, section 4 includes the connector terminals that facilitate the connection of the module to the solar power system. Lastly, section 5 consists of the supporting components for the ATmega 328P to operate.

2.3 Flowchart of the Device Operation

The operational system of the battery protection device in the Off-Grid solar power system can be seen in the flowchart below, which facilitates understanding of how the system works.

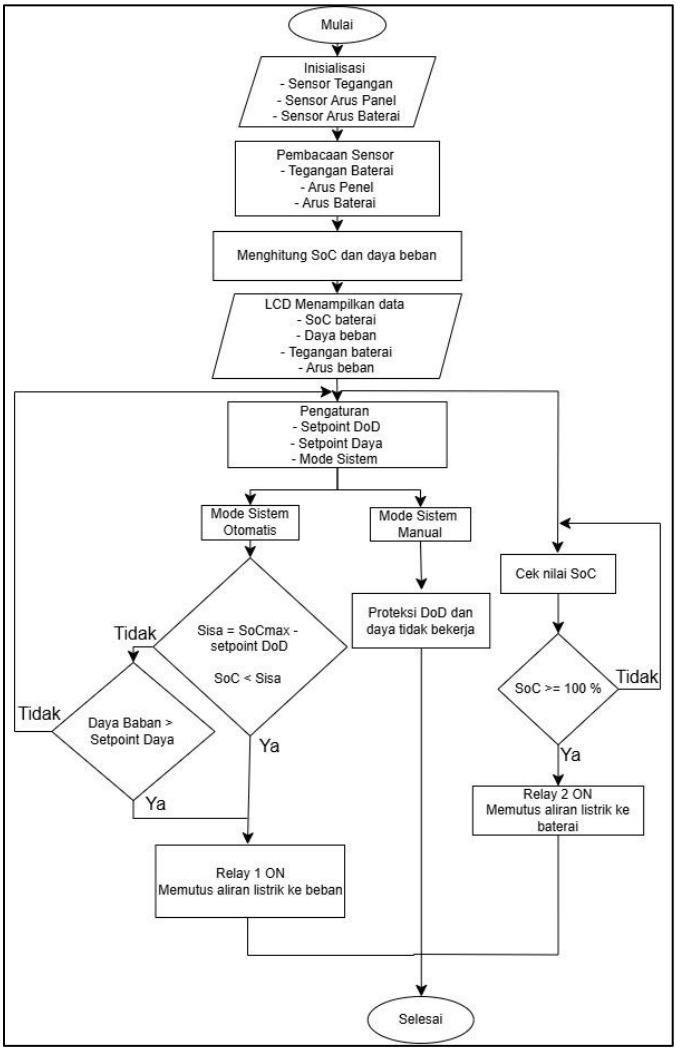


Fig. 3. Flowchart of the Protection System

In Fig. 3 above, the flowchart of the protection system shows that the system initially initializes the sensors used, namely the voltage and current sensors. Next, the sensor readings are processed, and the LCD displays the values of SoC, power, voltage, and current. From the flowchart above, it can be seen that there are two relays that will activate: relay 2 will activate if SoC >= 100%, and relay 1 will activate if the DoD or power exceeds the setpoint that has been set.

2.4 Research Method

In this research, the design of a battery protection system for the Off-Grid solar power system was conducted using a design method. The study involved analyzing the data obtained from testing the device using the power equation for DC electricity, as outlined in the following equation.

$$P = V \times I \tag{1}$$

where P is the power (watt), V is the voltage (Volt), and I is the Current (Ampere)

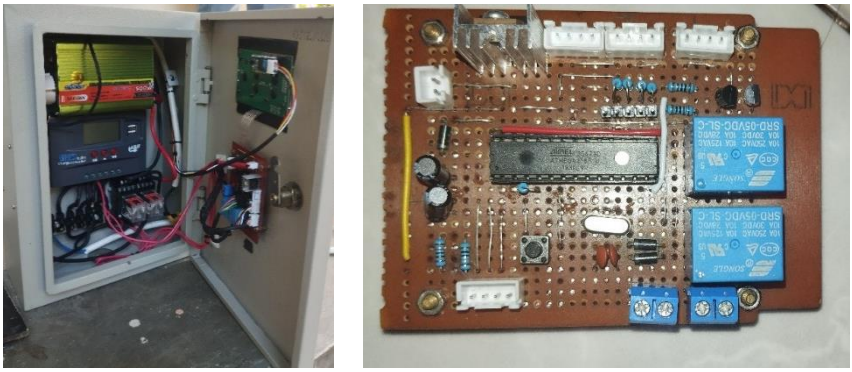
2.5 Research Location

The research was conducted at the Advanced Electrical Laboratory of Mulawarman University, Gunung Kelua, Samarinda, East Kalimantan.

3 Results

3.1 Device Photo

The results of the design and construction of the device can be seen in the image below.



(a) (b)

Fig. 4. (a) Overall system; (b) Protection system module

3.2 Test Results

This research was conducted by testing the protection system that has been created by connecting the battery protection module with the Off-Grid solar power system. The testing of the protection system was carried out during the day when the solar panels received sunlight. In the tests conducted, there were 5 trials, each lasting 20 minutes. The data collected during these trials can be seen in Table 5 below.

Table 5. Protection System Testing

No	Time (Minutes)	Voltage (V)	Current (A)	Power (watt)	Power SetPoint (watt)	DoD Setpoint (%)	SoC (%)	DoD (%)	Relay
1	20	12.80	1.69	21.70	50	50	95	5	Off
2	20	12.51	2.61	32.61	50	50	95	5	Off
3	20	12.43	3.44	42.72	50	50	95	5	Off
4	20	12.30	5.76	70.86	50	50	94	6	On
5	20	12.26	6.66	81.66	50	50	94	6	On

The power value is obtained from the multiplication of current and voltage, based on the readings from the current sensor outputting from the battery and the voltage reading of the battery. This gives the power consumption used from the battery.

The power value is calculated using the formula $P = V \times I$ and compared with the power values recorded in the table.

Given: Battery Voltage = 12.80 V
Battery Current = 1.69 A

Power consumed by the battery:
Power (P) = 12.80 × 1.69 = 21.63 W
Recorded power = 21.70 W
Difference: 21.70 W - 21.63 W = 0.07 W (this is very small, so the results are almost the same)

From the calculations above, we see that the power calculation using the equation $P = V \times I$ is very consistent with the power data recorded in the table. The difference is very small and can be disregarded.

4 Discussion

From the results of the system testing, it was found that the voltage decreased from 12.80 V to 12.26 V, which is quite unusual during the charging process. Typically, during charging, the voltage would increase or remain constant at a certain level. This decrease in voltage may indicate that the charging system is not optimal, or that the active load during charging is sufficiently high, causing the voltage to appear to drop.

Although the charging of the battery is supposed to supply power to the battery, the data indicates that the actual power used increased and exceeded the power setpoint (50 W) at several points. At the 60th and 80th minutes, the power used was 70.86 W and

81.66 W, respectively. This suggests that additional loads may be active during the charging process, so not only is power being supplied to the battery but also to the loads. In this condition, a larger current than desired is supplied to compensate for that power consumption.

Meanwhile, the relay remained "Off" until the power used exceeded the setpoint at the 60th minute, where the relay switched to "On" to protect the system from overload. This indicates that the relay functions to protect the system when the power consumption (both charging and load) exceeds the predetermined limit.

5 Conclusions

From the results of the system testing, it can be concluded that the protection system works well, as indicated by the relay functioning as expected: remaining 'Off' while the power used is below the setpoint (50 W) and switching to 'On' when the power exceeds 50 W. This demonstrates that the system protection effectively prevents overload or excessive power consumption that could jeopardize the battery. Furthermore, the DoD remains within safe limits (5% to 6%), which means that the battery charging does not excessively deplete the battery, and there is still a substantial capacity available. This indicates that even though the power occasionally exceeds the setpoint, the system does not experience significant depletion

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