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Power Performance Evaluation of Standalone Renewable Energy Source Energy Management Using Pass Filter

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***Abstract* – Hybrid energy storage systems have shown promise in enhancing solar panel systems reliability and efficiency. However, managing the power distribution balance with multiple energy storage units remains a challenge. This research addresses power distribution balancing during solar irradiation intermittency by employing a first-order filter with lowpass and highpass characteristics. The study aims to investigate energy and power management issues for off-grid electrical systems using this filter. Results from numerical simulations and experiments with a hybrid energy storage setup comprising a battery and supercapacitor show that the first-order filter effectively allocates the first-order signal to the main energy storage and subsequent orders to the supporting energy storage. During increased intermittency, the battery contributes 62 W and stores 387 W, while the supercapacitor contributes 167 W and stores 297 W. Conversely, during reduced intermittency, the battery stores 390 W and contributes 62 W, and the supercapacitor stores 295 W and contributes 164 W. The findings demonstrate the filter's efficacy in optimizing power distribution balance within hybrid energy storage systems. However, using the supercapacitor as the main energy storage does not result in higher power efficiency compared to the battery. In conclusion, the First Order Filter presents a viable solution for addressing power distribution challenges in hybrid energy storage systems, contributing to improved energy and power management for off-grid electrical systems. Further research on cost-effectiveness, maintenance, and environmental impact is warranted for practical implementation.**

***Keywords:* Battery, Efficiency, First-Order Filter, Photovoltaic, Supercapacitor**

I. INTRODUCTION

Renewable energy sources are widely installed to meet the increasing demand for electricity. However, addressing variability and intermittency remains a key concern for improving the reliability and efficiency of renewable energy systems. The current renewable energy management systems that rely on voltage similarity are being modified for this purpose [1]. Another main issue in renewable energy systems is the distribution of power among multiple energy storage systems [2]. Studies have shown the need to divide power distribution between primary and supporting energy storage systems in cases of solar irradiation intermittency [3]. Battery storage, with its high energy storage capacity, is suitable for longer-term use even when there is no power source. On the other hand, supercapacitors, with their high power absorption and release capacity, are suitable for intermittent use based on the characteristics of renewable energy input. A first-order filter, commonly used in telecommunications, can be an option to divide first-order and subsequent signals as power dividers [4] for primary and supporting energy storage [5]. This research aims to address the energy and power management challenges in off-grid electricity systems using lowpass and highpass first-order filters [6]. The research gap between recent research and this research is the usability of the first-order filter with the combination of battery and supercapacitor based on standalone photovoltaic.

The objective of this research is to design and evaluate an energy management system for power distribution equality among energy storage in off-grid solar panel systems using first-order filters, specifically focusing on the duty cycle in bidirectional converters for each energy storage and its modification with lowpass and highpass types. The aspects to be studied include power distribution as well as voltage and power stability in each energy storage [7].

II. BASIC OF THEORY

This chapter will discuss previous research studies and theoretical foundations related to photovoltaics, DC-DC converters, batteries, supercapacitors, and first-order filter control.

Standalone photovoltaic systems, also known as off-grid solar systems, have been extensively studied in the literature [8]. Previous research has focused on various aspects of standalone photovoltaic systems, including system design, component selection, energy management strategies, and performance optimization

[9]. Studies have explored different approaches for maximizing the energy production and utilization efficiency of standalone photovoltaic systems, such as MPPT (Maximum Power Point Tracking) algorithms, battery storage systems, and load management techniques [10]. Additionally, research has been conducted on the reliability, durability, and cost-effectiveness of standalone photovoltaic systems with the aim of improving their overall performance and sustainability [11]. These studies provide valuable insights and guidelines for the design, implementation, and operation of standalone photovoltaic systems in various applications, ranging from rural electrification in developing countries to remote area power supply and off-grid residential and commercial installations [12].

Battery storage systems play a critical role in standalone photovoltaic systems, enabling energy storage and utilization during periods of low solar irradiance or high demand [13]. Previous literature has extensively investigated various aspects of batteries for standalone photovoltaic systems, including battery types, sizing, charging and discharging strategies, state of charge (SOC) estimation, and battery management systems (BMS) [14]. Research has focused on optimizing battery performance, efficiency, and lifespan, as well as enhancing overall system reliability and stability. Studies have also explored the integration of different battery technologies, such as lead-acid, lithium-ion, and flow batteries, in standalone photovoltaic systems, considering factors such as cost, environmental impact, and safety. These studies provide valuable insights and guidelines for the design, operation, and maintenance of batteries in standalone photovoltaic systems, contributing to the advancement of sustainable and efficient off-grid solar energy solutions [15].

Supercapacitors, also known as ultracapacitors or electrochemical capacitors, have emerged as promising energy storage devices for standalone photovoltaic systems [16]. Previous literature has investigated the potential of supercapacitors to improve the performance of photovoltaic systems by addressing issues such as intermittent energy generation, high power demands, and short-term energy storage. Studies have focused on various aspects of supercapacitors for standalone photovoltaic systems, including their charge/discharge characteristics, energy storage capacity, power density, efficiency, and durability. Research has also explored the integration of supercapacitors with other energy storage technologies, such as batteries, to optimize system performance and reliability. These studies provide valuable insights into the potential of supercapacitors as a viable energy storage solution for standalone photovoltaic systems, offering potential benefits such as rapid charge and discharge rates, high power density, and long cycle life, and contributing to the development of efficient and sustainable off-grid solar energy systems.

First-order filters, a type of control mechanism, have been studied in the literature for their potential application in optimizing the efficiency of standalone photovoltaic systems [17]. These filters are used to divide the incoming power signal into first-order and subsequent-order signals, allowing for efficient management of power distribution among energy storage devices. Previous research has explored the use of different types of first-order filters, such as lowpass and highpass filters, to control the duty cycle in bidirectional converters for standalone photovoltaic systems. These studies have investigated the performance of first-order filters in terms of power distribution, voltage stability, and power stability in different energy storage scenarios. The findings from these studies provide valuable insights into the potential of first-order filters as a control mechanism to optimize power efficiency in standalone photovoltaic systems, contributing to the advancement of off-grid solar energy systems.

III. Method And Design

This chapter will explain the methods used in the research, including the literature review, system design, software design, block diagrams, flowcharts, and simulation design of the off-grid electrical system with first-order filter control to optimize power efficiency.

A. Energy Management System

Energy management systems for standalone photovoltaic systems have been widely studied in the literature [18]. These systems typically involve the integration of different energy storage devices, such as batteries or supercapacitors, with photovoltaic panels to optimize power generation, storage, and utilization [13]. Various control strategies, including first-order filters, have been proposed and evaluated for managing the energy flow in these systems to achieve high efficiency, stable voltage, and reliable power supply [19]. These studies provide insights into the design, simulation, and performance evaluation of energy management systems in standalone photovoltaic applications, contributing to the advancement of renewable energy technologies for off-grid electrification [20], [21].

In the literature, various methods have been proposed for utilizing first-order filters in energy management systems for standalone photovoltaic systems [22]. These methods typically involve the design and implementation of first-order filters, such as lowpass or highpass filters, to control the duty cycle of bidirectional converters, optimizing the power distribution among energy storage devices. Additionally, studies have focused on the simulation and evaluation of the performance of these systems, including the use of block diagrams, flowcharts, and software design [23]. These methods provide insights into the potential of first-order filters as an effective control strategy for managing energy in standalone photovoltaic systems, with the aim of improving power efficiency and stability. The findings from these studies contribute to the body of knowledge on energy management systems for off-grid solar energy applications and can be used as a basis for further research and development in this field [24].

B. Plant Simulation Testing

The methodology for photovoltaic simulation and plant testing typically involves several steps. First, a simulation model is developed using software tools, such as PVSyst, MATLAB/Simulink, or other specialized software, to simulate the behavior of photovoltaic panels under different environmental conditions, such as solar irradiance, temperature, and shading. The simulation model is then validated and calibrated using field data from actual photovoltaic installations. Once the simulation model is validated, plant testing can be conducted to evaluate the performance of the photovoltaic system under real-world conditions. This may involve installing monitoring equipment, collecting data on energy generation, and analyzing the performance of the photovoltaic system over an extended period of time.

The results from the simulation and plant testing provide valuable insights into the performance, reliability, and efficiency of the photovoltaic system and can be used to optimize the design and operation of standalone photovoltaic systems. The scenario of testing will be as shown in Figure 1.

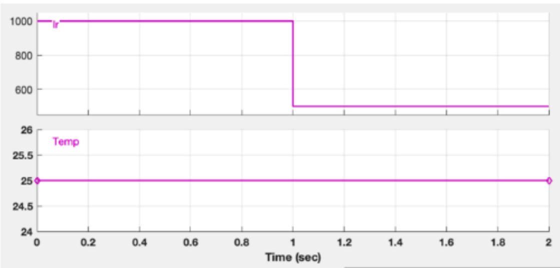

Figure 1. Irradiance and temperature setting for testing scenario

In this short circuit testing, as shown in Figure 2, there is a result that can determine if the simulation plant is working well or not. The result will be shown in Figure 3.

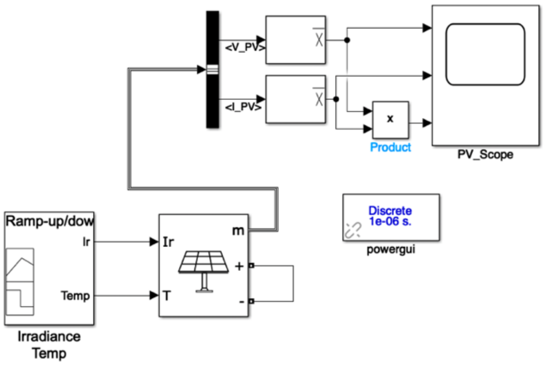

Figure 2. Plant testing short circuit using Simulink

The result is shown in the following figure 3. From the results, the voltage is indeed 0 V, but the current is at the peak of short circuit current from the datasheet.

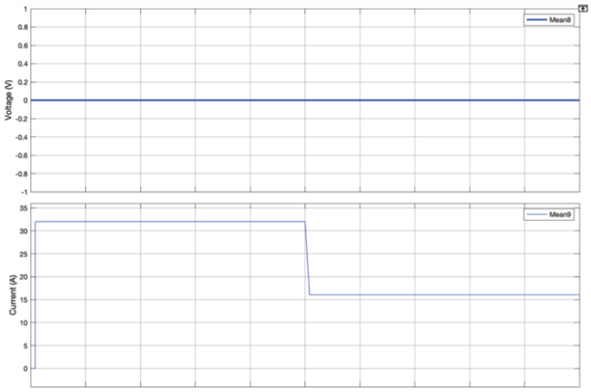

Figure 3. Plant testing short circuit result

Meanwhile, for the open circuit test, as shown in Figure 4, there is a result that can determine if the simulation plant is working well or not. The result will be shown in Figure 5.

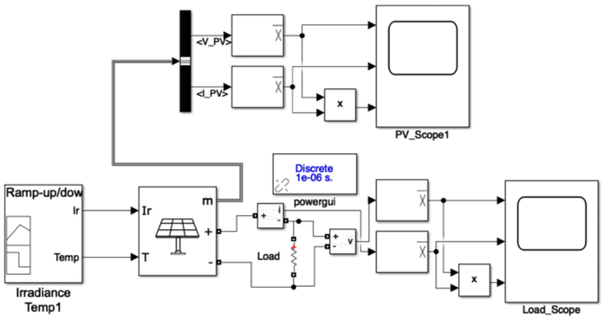

Figure 4. Plant testing short circuit using Simulink

The result is shown in the following figure 5. From the results, the current is indeed 0 A, but the voltage is at the peak of open circuit voltage from the datasheet.

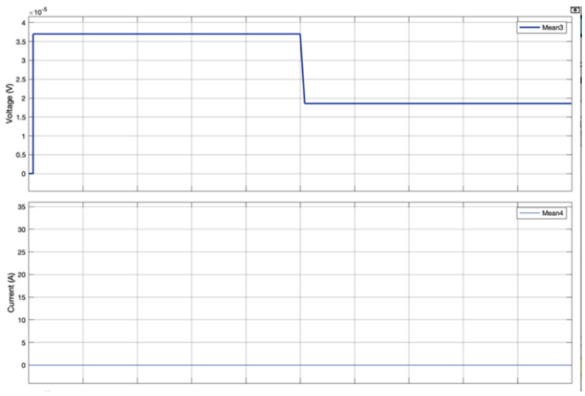

Figure 5. Plant testing short circuit result

From the results of the testing, it could be concluded that the photovoltaic system is doing well before the main simulation.

A. Filter Design / Scenario

The filter is modeled as below in figure 6. The smoothing is coming from the PI control, and the filter is at the junction for the determination of the battery or supercapacitor as the main storage. The reason why PI control is used as the component in the filter is because the responses need to be softened in terms of voltage reference, current reference, voltage response, and current response.

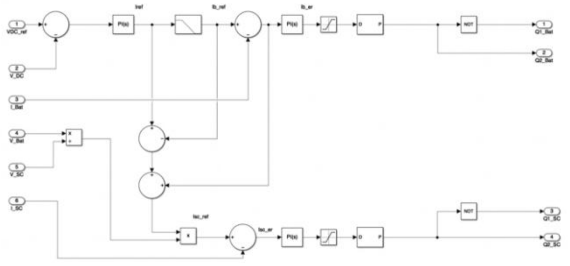

Figure 6. Plant testing short circuit result

The first-order power signal will go through the filter with a low-pass type, while the non-first-order signal will go through the filter with a high-pass type. The main power is in the first order, while the intermittency power is in the non-first order.

B. Simulation Procedure

The simulation procedure was set at a time step of 2 seconds to capture sudden changes in the first second (increase and decrease in irradiance) with both high-pass and low-pass filter conditions, resulting in four scenarios. A time step of 2 seconds was chosen to account for the simulation capacity of the laptop and discrete setting in PowerGUI to obtain accurate results. After the simulation, data points from the scope were extracted to analyze the outcomes for each parameter (voltage, current, power, and state of charge) and observe any overshoot or undershoot according to the relevant standards.

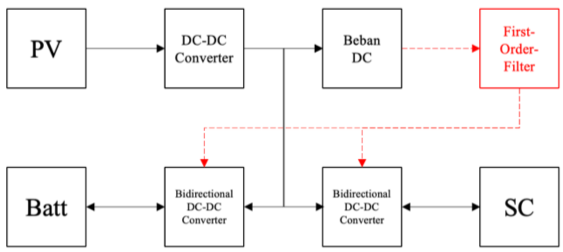

Figure 7. Schematic diagram

In the block diagram, it can be observed that initially the PV input goes through the DC-DC converter and then shares the same bus with the energy storage. The first-order filter obtains voltage and current data from the DC load, which is then used as input for regulating the duty cycle (energy management controller) of both the bidirectional converters for battery and supercapacitor storage. When there is surplus power, it goes to the main storage, but during changes, it goes to the auxiliary storage, which is controlled by the first-order filter..

IV. RESULTS AND DISCUSSION

This chapter will explain the performance results of low pass type and high pass type from the battery power and supercapacitor power.

A. Low Pass Filter Performance

From the figure 8 and 9, with the irradiance and temperature setting from figure 1, the photovoltaic power is going high and then low, but the load is demanded to be constant, the result of first order filter with low pass type is as follows.

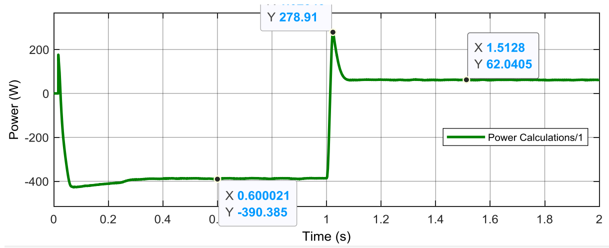

Figure 8. Battery power (main storage) scope result

The results show that the battery power was initially -390 W, then increased to 62 W during the change, with an overshoot of approximately 278 W.This is in line with the characteristics of the battery, where negative power (indicating charging) occurs when the load demand is less than the total power from the source, and positive power (indicating discharging) occurs when the load demand exceeds the total power from the source..

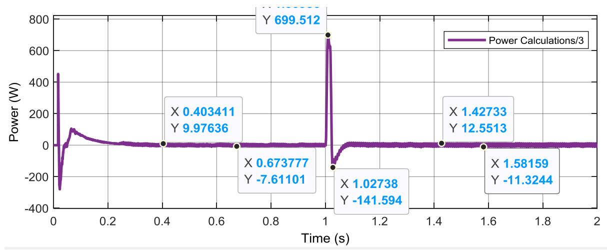

Figure 9. Supercapacitor power (supporting storage) scope result

It was found that the supercapacitor power during the initial condition was 0 W, and then increased to 1 W with ripple and overshoot reaching up to 699 W during irradiation.

B. High Pass Filter Type

From the figure 10 and 11, with the irradiance and temperature setting from figure 1, the photovoltaic power is going high and then low, but the load is demanded to be constant, the result of first order filter with high pass type is as follows.

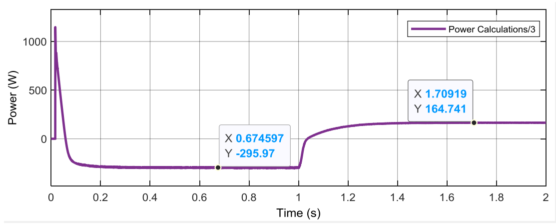

Figure 10. Supercapacitor power (main storage) scope result

The results showed that the power of the supercapacitor during the initial condition was -295 W and then increased to 164 W during irradiation. The results indicate that the supercapacitor is more effective as the main energy storage device due to its higher power absorption but less efficient during charging (-297 W) and discharging (167 W) due to its higher self-discharge characteristics compared to batteries when used as the main energy storage device.

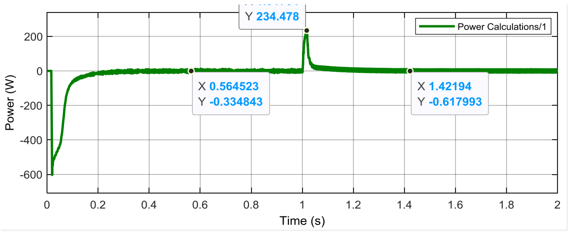

Figure 11. Battery power (supporting storage) scope result

The obtained results showed that the power of the battery during the initial condition was 0 W with ripple and then decreased to -1 W without ripple but with an undershoot of 234 W during irradiation. From the results, it can be concluded that the battery serves as an effective secondary energy storage, supporting the main energy storage during intermittency. From the previous research, it is not shown, but it can be compared by using the first-order filter with the system that does not use the first-order filter, improving the efficiency for the storage gain by 164 W (mainly additional power stored by the supercapacitor as the optimal storage).

V. CONCLUSION

From the research results, it was observed that during intermittent periods when the irradiance decreased, the battery, as the main energy storage, stored 390 W and contributed 62 W, while the supercapacitor contributed 295 W and stored 164 W. From the results, it can be seen that the supercapacitor as the main energy storage is not more efficient in terms of power efficiency but does well in terms of stability. First-order filters have also proven to be a decent energy management system method for standalone photovoltaic usage. Hopefully, this research could contribute more in the renewable energy area, specifically in power storage technology.

VI. ACKNOWLEDGMENTS

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