

Fuzzy Logic Controller-Based Energy Management System for Electric Vehicles

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ABSTRACT: Variable power generation is made possible by photovoltaic energy and is impacted by unpredictable variations brought on by weather changes (temperature and sun radiation). Therefore, in order to solve this significant problem, an energy storage system is necessary. It is not enough to employ a single energy storage component, such a battery. Super capacitors (SCs) can also be used as a power storage device for this purpose. A suitable energy management plan is necessary for the battery and SC combo to be a workable option. The designing and modeling are the main topics of the earlier research. This study used super capacitors and batteries to create a hybrid energy storage system (HESS) with a solar system.

Energy distribution between two distinct storage media, such as batteries and SCs, is necessary for the creation of an energy management plan. In order to manage the buck-boost converters connected to batteries and SCs and stabilize the direct current (DC) bus voltage, a new dimension for a PI controller design is thus presented. The DC bus voltage is stabilized at the reference value of 400 V by voltage management.

The reference current of batteries and SCs is determined using two additional PI controllers. A low pass filter is used in the energy distribution between batteries and SCs to remove the peak current on batteries and transfer it to SCs. The filter constant regulates how much energy batteries and SCs use. The results of the simulation demonstrate that the system model and suggested scaling design offer adequate DC bus voltage stability. Additionally, by lowering the battery's state-of-charge (SOC), the enhanced constant filter extends the batteries' overall lifespan.

Keywords: Supercapacitors, Hybrid energy storage system, Fuzzy logic controller

1. Introduction

Electricity protection is growing rapidly as it is strictly related to population growth and economic development. However, the expansion of industrial goods and the growing energy needs will increase pollution and CO₂ production. The use of clean energy in the transportation industry has attracted considerable attention over the past

20 years, with fuel prices and harmful gases being released by burning fossil fuels in traditional vehicles. Electric vehicles (EVs) do not use greenhouse gases and are therefore a potential alternative to combustion engine (ICE) vehicles. The energy management system aims to maximize solar energy use, reduce energy losses and improve the overall efficiency of the vehicle.

Renewable energy plays an important role in environmentally friendly energy generation to reduce waste produced from fossils and fissile materials. Electric vehicles (EVs) do not use greenhouse gases and are therefore a potential alternative to combustion engine (ICE) vehicles. The energy management system aims to maximize solar energy use, reduce energy losses and improve the overall efficiency of the vehicle. Renewable energy plays an important role in environmentally friendly energy generation to reduce waste produced from fossils and fissile materials.

Electric vehicles, which take over both batteries and supercapacitors, have attracted considerable attention for their unique skills in terms of energy in the research community. Considering the randomness and variation in load power required for electric vehicles HESS has been proposed by supercapacitors and battery. High-performance density supercapacitors have long cycle loads, lifespan and fast reaction speeds, but do not require frequent charging and unloading of high-energy density batteries. To protect the battery, improve lifespan and reduce fluctuations in battery charging and discharge flow, the supercapacitor provides high frequency components of load power fluctuations, while the battery provides low frequency components of load power fluctuations. The power supply is connected to the DC-DC power converter using a DC bus and further connected to the DC inverter. For the three energy sources mentioned above, various combinations of converters were presented along with their own working topology.

If the system is strong and nonlinear, a fuzzy logic controller (FLC) is used. The purpose of a fuzzy controller is to calculate the value of an action variable from observations of a process's state variable under the control of a process. A fuzzy control system is a control system based on fuzzy logic, a mathematical system that analyzes analogues in relation to logical variables, examining continuous values between 0 and 1.

[1] proposed an optimal energy management strategy based on the Pontryagin's minimum principle in this research, which instantaneously distributes the required propulsion power to the two ESSs during the vehicle's propulsion and also instantaneously allocates the regenerative braking energy to the two ESSs during the vehicle's braking. The objective of the proposed energy management strategy is to minimize the electricity usage of the EV and meanwhile to maximize the battery lifetime. The simulation results show that the proposed strategy saves electricity compared to the rule-based strategy and the single ESS case for the three typical driving cycles studied in this research. [3] proposed an analyzes the benefits of torque-vectoring in an autonomous electric vehicle, either by integrating the torque-vectoring system into the path tracking controller, or through its separate implementation alongside the steering controller for path tracking. A selection of path tracking controllers was compared in obstacle avoidance tests simulated with an experimentally validated vehicle dynamics model. A genetic optimization was used to select the controller parameters. Simulation results confirm that torquevectoring was beneficial to autonomous vehicle response. The integrated controllers achieve the best performance if they are tuned for the specific tire- road friction condition. However, they can also cause unstable behaviour when they operate under lower friction conditions without any re-tuning. On the other hand, separate torque-vectoring implementations provide a consistently stable cornering response for a wide range of friction conditions. [2] A Bi-level multi-objective design and control framework with the non-dominated sorting genetic algorithm-II and FLC is used to obtain an optimal sized hybrid energy storage system and the corresponding optimal real time power management system based on FLC simultaneously. A vectorized fuzzy inference system is presented which allows large-scale FLC to run in parallel and improves optimization efficiency. [4] A Intelligent Energy Management

Systems for Future Electric Vehicle Transportation Developing an intelligent system to manage EVs charging demands is one of the fundamental aspects of this technology to better adapt for all-purpose transportation utilization and ability to reduce vehicle emissions EVs energy Management challenges and solutions and present potential future research directions for EVs charging/discharging coordination applications. [5] The combination of battery and supercapacitor is used to power an electric scooter. Both of these power sources are adapted to attain maximum efficiency in transferring energy to the motors. To meet the objective, an FLC algorithm for energy management is presented to keep the battery and super capacitor at their optimal SOC to meet load demands during braking and counter-loading. [6] Electric vehicle charging stations and the employed energy management schemes increased adoption of the electric vehicle (EV) needs the proper charging infrastructure integrated with suitable energy management schemes. To mitigate this gap, this research survey is an effort to provide know-how about the important aspects of the overall EV charging setup with 239 relevant references. It reviews the achievements of energy management systems in terms of improving fuel consumption efficiency and reducing carbon dioxide emissions in EV charging systems.

In the rest of this paper, Section 2 explains the proposed controller in this paper. Simulation results are presented in section 3, followed by conclusions in section 4.

2. Proposed Methodology

Renewable energy sources mean somewhat sustainable energy that cannot be exposed. When you hear the term "alternative energy," you usually refer to renewable energy sources as well. It means the presence of several energy sources, such as solar power (PV), batteries, and supervisors, as alternatives to most frequently used sources such as coal. High energy density means longer drive cycles. "Auxiliary energy sources" are another type of factor that will satisfy load requirements during acceleration, and can be charged due to reversibility and high energy density using renewable brake energy.

2.1 Electric Circuitry of the System

The electrical circuits in the system consist of a solar PV connected to a boost converter, a battery, and a supercapacitor, which are connected to each of the boost converters and buck converters. The opposite DC bus is connected to a DC inverter used to activate the traction engine in the vehicle. Ideally, HESS requires high performance density, expansion work and relatively high efficiency. The HESS model proposed in Figure 1 meets all requirements.

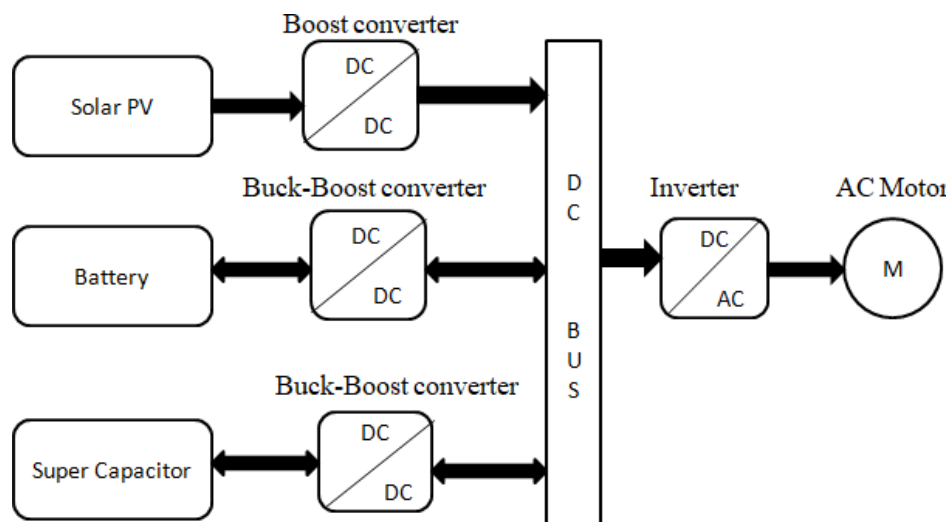


Figure 1: Structure of Proposed PV-SC-Battery Based EV

2.1.1 PV Array

Solar power is used using solar rock (PV) technology, which uses semiconductors to convert sunlight (solar radiation) into electricity. When the sun hits the semiconductor of a PV cell, the electrons are released, collecting electrons that run by the bus stop, leading to current. Connecting solar collectors calculated with solar exposure produces power and voltage in the form of direct current (DC), but in most countries of devices and equipment, alternative power (AC), all solar collectors and inverters must participate.

A detailed PV model is required to optimize the core design of a PV system, taking into account the effects of climate, radiation ratio, thermal derivatives of Solar array, and connections of parallel modules constructing the array. Figure 2 shows the solar cell circuit. The sections described with the dotted red lines represent the complete PV cell that acts as a DC voltage source. The standard method for PV cells is to mix the interfacial resistance and resistance values in series in parallel to mimic the actual behavior of the PV cells. Using a single diode model, the analog circuitry of the PV cell is shown in the figure 1.

A PV system consists of a large number of PV modules connected in series or in parallel to increase voltage and electricity. Due to the presence of bypass diodes, there are several peaks in the P-V characteristic curve of PSCS, also known as the local and global maximum points. Bypass diodes located in parallel with each PV module reduce the possibility of hotspots to the PSC if the shadow module acts as a demand rather than electricity.

The output in the form of current is given by Eq. (1)

$$I = I_{pv} - I_0(\exp(V + R_s I / V_t) - 1) - V + R_s I / R_s \quad (1)$$

When T is the temperature coefficient and G is the irradiation level, equations (3.2), (3.3), and (3.4)

are used to calculate the PV cell current, saturation current and thermal voltage.

$$I_{pv} = (I_{pv} + K_1(T - T_n))G/G_n \quad (2)$$

Saturation current is given as,

$$I_0 = (I_{SC} + K_1(T - T_n)) / \exp(V_{oc} + K_v(T - T_n) / V_t) - 1 \quad (3)$$

Thermal voltage is given as,

$$V_t = N_s K T / q \quad (4)$$

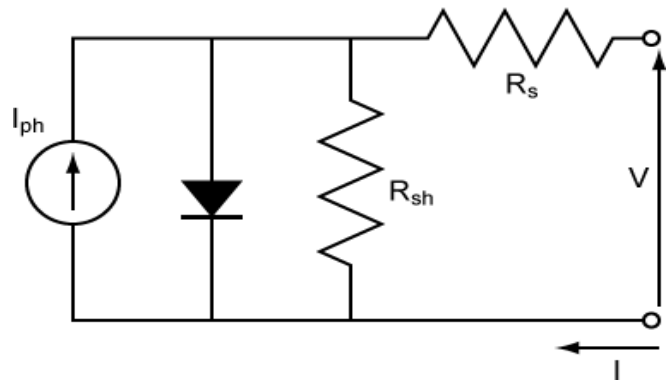


Figure 2: PV Cell Equivalent circuit single-diode model

PV systems are made up of a grid of PV cells. Current I is improved by the parallel cell combination while voltage V is added by the series cell arrangement.

The number of parallel cells is N_p , whereas the number of series cells is N_m . Eq. (1) is transformed into Eq. (5).

$$I = N_p I_{pv} - (\exp(V + R_{seq} I / N_m V_t) - 1) - V + R_{seq} I / R_{peq} \quad (5)$$

2.1.2 Battery

This is a frequently used energy storage device, whose electrical circuit consists of a power supply and a capacitor. Charging and replacing the battery depends on its load condition (SOC). This is a function of time and can be expressed as:

$$SOC_{bat} = SOC_{bini} - 1/C_{cap} \int I_{bat} dt \quad (6)$$

where, SOC_{bini} is the initial SoC of battery at $t = 0$ s and C_{cap} is the capacity of the capacitor. Battery is a rechargeable source and provides power depending upon the load requirement.

2.1.3 Supercapacitor

The working principle of supercapacitor (SC) is quite similar to the battery. The circuitry inside SC consists of a capacitor C and a series equivalent resistance R_s . The charging and discharging of the SC depends upon SoC which is a function of time and can be expressed as:

$$SOC_{sc} = SOC_{scini} - 1/C_{cap} \int I_{sc} dt \quad (7)$$

Where, SOC_{scini} is the initial SOC of the SC at $t = 0$ s and C_{cap} is the capacity of the capacitor.

2.2 Boost converter model for solar PV

The circuit consists of an IGBT having switch S_1 , which can have value 0 or 1 therefore, the converter operates in two modes depending upon position of switch S_1 . By applying KVL, following equations can be obtained:

$$d i_f c / d t = -R_1 / L_1 i_f c + 1 / L_1 v_f c - 1 - u_1 / L_1 v_{dc} \quad (8)$$

$$i_1 = (1 - u_1) \quad (9)$$

where, i_{pv} and v_{pv} are solar PV current and voltage respectively, u_1 denotes the duty cycle of switch S_1 ,

v_{dc} denotes the output voltage of DC bus and i_1 is the output current of boost converter.

2.2.1 Buck-boost converter model for battery

Working of battery can be divided into two modes; charging mode and discharging mode. A buck-boost converter having two switches S_3 and S_4 has been used. In discharging mode ($i_{batref} > 0$), S_3 is set to OFF and S_2 can take any position. Similarly, in charging mode ($i_{batref} < 0$), where i_{batref} is the desire reference value of battery current, S_2 is set to OFF and S_3 can take any position.

The model of the circuit during discharging mode is expressed as:

$$d i_{bat} / d t = -R_2 / L_2 i_{bat} + 1 / L_2 v_{bat} - 1 - u_2 / L_2 v_{bat} \quad (10)$$

Where, v_{bat} and i_{bat} denotes the battery voltage and battery current respectively and u_2 is the duty cycle of switch S_2 . The equations during charging mode can be obtained as:

$$d i_{bat} / d t = -R_2 / L_2 i_{bat} + 1 / L_2 v_{bat} - u_3 / L_2 v_{bat} \quad (11)$$

Where, u_3 is the duty cycle of switch S_3 . Combining the above equations, battery model takes the following form:

$$U_{23} = \{ 1 - u_2, i_{batref} > 0 \text{ (discharging mode)} \\ U_{3,ref} < 0 \text{ (charging mode)} \} \quad (12)$$

$$d i_{bat} / d t = -R_2 / L_2 i_{bat} + 1 / L_2 v_{bat} - u_{23} / L_2 v_{bat} \quad (13)$$

$$i_2 = u_{23} i_{bat} \quad (14)$$

Where, u_{23} and i_2 denote the average control input of the converter and output current of the converter respectively.

2.2.2 Buck-boost converter model for super capacitor

The charging and discharging of SC follows the same process as that of battery, therefore the equations of SC can be obtained in a similar manner as follows:

$$U_{45} = \{ 1 - u_4, i_{sc} > 0 \text{ (discharging mode)} \\ U_{5,cref} < 0 \text{ (charging mode)} \} \quad (15)$$

$$d i_{sc} / d t = -R_3 / L_3 i_{sc} + 1 / L_3 v_{sc} - u_{45} / L_3 v_{dc} \quad (16)$$

$$i_3 = u_{45} i_{sc} \quad (17)$$

Where, i_{sc} denotes the reference current of SC,

i_{sc} , v_{sc} , i_3 denote the SC current, SC voltage and output current of converter respectively whereas, u_{45} denotes the average control input of the converter.

2.3 Fuzzy Logic Control System

Fuzzy Logic Control (FLC) is the most active area of research in the use of fuzzy sets-theory, fuzzy arguments and fuzzy logic. The application of FLC ranges from industrial process control to

biomedical equipment and securities. Compared to traditional control techniques, FLC was most commonly used in complex, inadequate definition problems that could be controlled by efficient human operators without knowing the underlying dynamics.

If the system is strong and nonlinear, a fuzzy logic controller (FLC) is used. The purpose of a fuzzy

controller is to calculate the value of an action variable from observations of a process's state variable under the control of a process. A fuzzy control system is a control system based on fuzzy logic and is a mathematical system that analyzes analogues in relation to logical variables. This includes continuous values between 0 and 1.

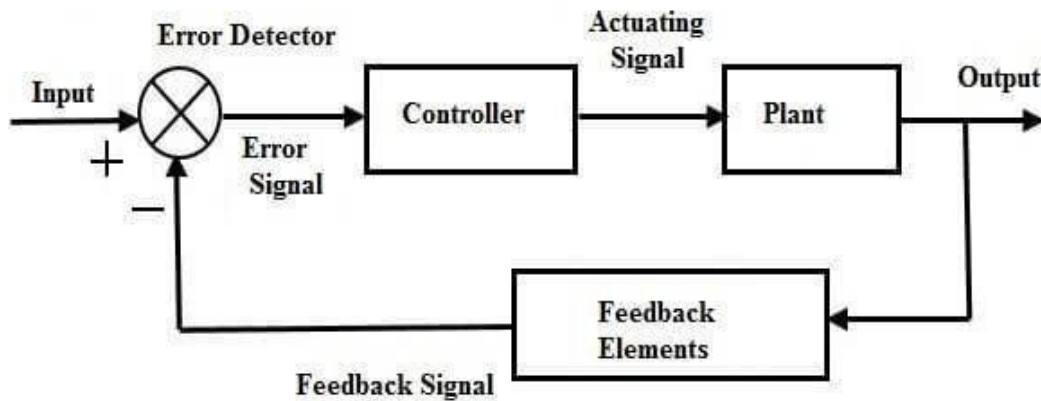


Figure 3: Closed Loop Control System

S. No	Parameter	Efficiency In Percentage
1	Battery	57
2	converter	58
3	Load	85
4	Power	90
5	Solar PV	76.6
6	Super Capacitor	79.8
7	Irradiance	57.60

Table 1: Output parameter and efficiency with percentage

3. Results and Discussion

In this section, we simulated and validated the proposed/designed controller under various load in this section, we simulated and validated the proposed/designed controller under various load conditions. The main objective of the proposed framework is to control DC bus voltage regulation and current flow by generating a reference current for the performance source. Power supply specifications are listed in the table, and the parameters of the DC- DC converter used in this study are shown in the table. These parameters were set to the desired reference according to load requirements and controller pursuit.

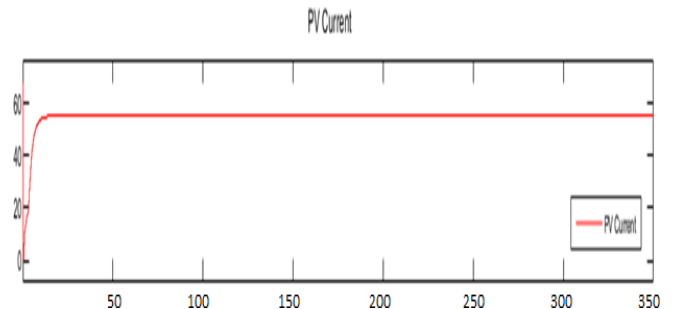


Figure 4: Output Current Waveform of Solar PV

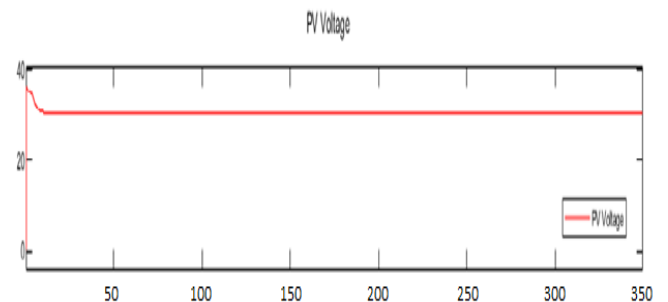


Figure 5: Output Voltage Waveform of Solar PV

Figure 4 and Figure 5 illustrates the experimental time current and voltage time response of PV. The Photovoltaic current in Figure 4 achieves the maximum value of 55 A at 20 s. The PV voltage Figure 5 varies according to the current imposed

on it. It is also clear that the PV has a slow behaviour compared to the SC.

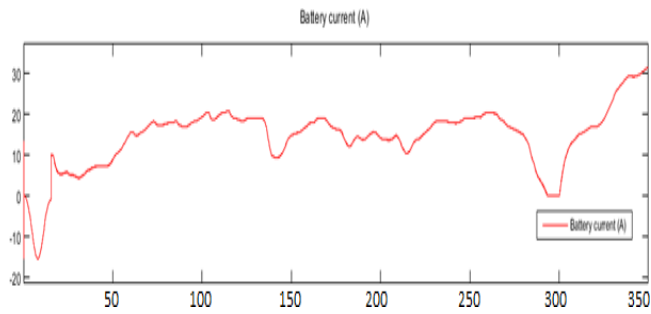


Figure 6: Output current waveform of battery

The curves in Figure 6 and figure 7 represent the battery current and voltage. From Figure 6 one can notice battery voltage will vary between 51V and 52A.

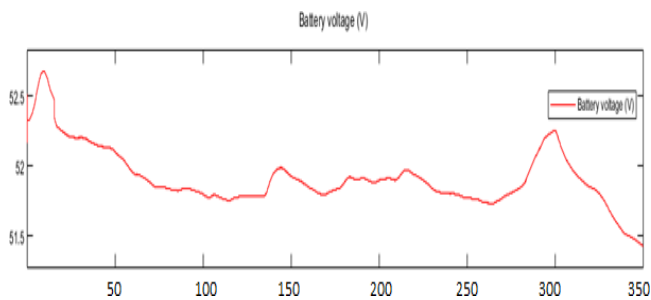


Figure 7: Output voltage waveform of battery

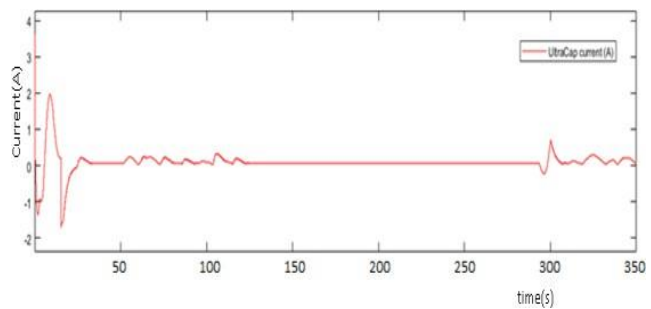


Figure 8: Output voltage waveform of super capacitor

Figure 8 and figure 9 depicts the dynamic response of the SC current and voltage and their references. Through Figure 8 the SC current tracks accurately its reference at all time. This is showing that the SC current is perfectly tracking its reference with almost zero error. Concerning the SC voltage in Figure 9, the desired SC voltage is of 270V and SC voltage returns to its initial value of 270V (mind that there is a zoom on this figure, consequently, the variation of the SC voltage is quite low).

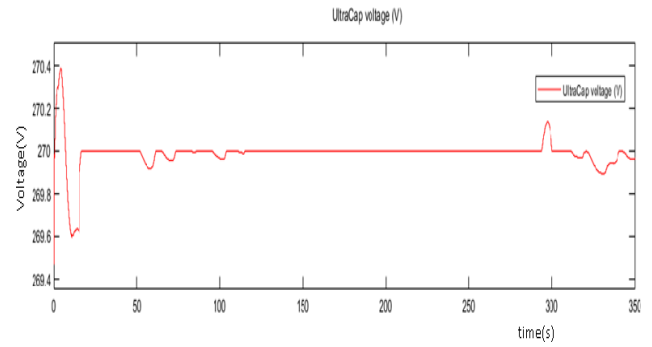


Figure 9: Output current waveform of super capacitor

4. Conclusion

In this research work, solar PVs were examined as the main source and hybrid energy storage system. It consists of a battery and a supercapacitor. Fuzzy logic-based energy management units with MBO were referenced for the energy storage units, depending on their respective charging status and load requirements. The fuzzy logic-based nonlinear controller was developed for the hybrid energy storage system of PV-HEVs. The proposed framework was simulated in a MATLAB/Simulink environment. A tax strategy using voltage commands has been introduced to stabilize the DC bus voltage. The control of the battery and converter connected to the SC is based on current control. The EMS design was proposed to include battery, SC, PV energy and loads. This EMS also provides reference power batteries and SC. Simulation tests were performed with various constants to demonstrate the effectiveness of the proposed control strategy. These simulation tests show that the proposed EMS can distribute energy between different devices. Furthermore, comparing SOC for batteries with different values of filter constants showed that SC integration reduces battery consumption and eliminates the top current. In fact, battery consumption is reduced by increasing the filter constant.

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