# Priority-Based Hierarchical Switching Charging-Discharging System For Continuous BESS Sustainability

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**Abstract:** Integration of solar photovoltaic system with energy storage system such as batteries is always seen as a better way to utilize the available output power from renewable energies. Considering continuous sustainability using batteries, charging – discharging the batteries to store the excessive output from solar photovoltaic panels is an important aspect to be considered. Therefore, this paper proposes hierarchical switching charging – discharging system for continuous sustainability integrated together with solar photovoltaic system. The hierarchical switching charging – discharging system comprises of the hardware and software development. The typical design of the hardware structure is setup to integrate the consumable renewable energy source to the battery energy storage system and the load. The hierarchical charging – discharging strategy which is the embedded software is proposed to allow the charging – discharging control and switching between the dual and more battery energy storages. The hardware research and development results shows that the proposed strategy have effectively justify the developed system's performances.

**Index Terms:** Battery Energy Storage System, Battery PV Plant, Battery Charging-Discharging, BESS Technology, BESS Management, Battery Charging-Discharging Control Scheme, Priority-based Switching System.

## 1 INTRODUCTION

Battery Energy Storage System (BESS) technologies has existed for a very long time, and the importance of BESS is significantly increasing due to the application of smart grid renewable energy systems [1]. As we know, the output power of solar photovoltaic (PV) system is not constant and its performance depends on the availability of solar irradiance and the PV panel temperature [2]. The output of a, solar (PV) system is low when the solar irradiance is low and when the temperature of the PV is high [3].Up to date, the conversion efficiency of a PV panel range from 10 – 25 % [4] which shows that the output power of a PV system is still low. Therefore, harvesting an optimum amount of electrical power is vital. BESS technology is one of the methods available to harvest the electrical charges from the PV system and can be utilized during low solar irradiance conditions. This technology acts as a storage system in which supply of electrical charges can be continued even when the PV system is not functioning. At presents, most researches on solar photovoltaic and hybrid storage system (HSS) are focused on the forecast or predictive technique. A controlling method for output power among the sub-modules in a system, and improving the voltage regulation is presented by [5][6][7]. A hierarchical control scheme presented by [2] for energy storage system. In the study, the control scheme is applied to centralize the energy storage system and the control scheme performed the desirable selection of energy storage system that fits to perform the processing task. Ming et al. (2014) applied two layer of hierarchical energy management method in which, a battery and a supercapacitor is used as hybrid energy storage system [8]. to determine the available current in the supercapacitor and split the power ratio between the battery and supercapacitor for charging and discharging purposes. The control scheme proposed by Tummuru, Mishra, and Srinivas (2015) uses the fast dc-link voltage-based management scheme to control the battery's current [9]. At the same time, the output power is balanced between the battery and supercapacitor. This control scheme also detected the equivalent changes between the battery and supercapacitor to perform the dedicated processing tasks. A proposed by [10], a new voltage control scheme successfully coordinated the power sharing between the battery and supercapacitor. This helped to maintain the constant DC voltage when the solar PV panel's output voltage changes. In [11], a hierarchical/droop control strategy based on the DC bus voltage is proposed. This technique detects the voltage variation to sense the power imbalance of DC microgrid system which is analyze under various conditions. To sense the power balance between the battery energy storage systems, this technique bidirectional-ly connected to the main DC microgrid system to charge and balance the overall system performances. Based on the conducted literature review study, different kind of control schemes have been employed to renewable energy systems to perform the output power management and store energy in the energy storage systems with different charging and discharging characteristics. All the proposed methods in the literature have focused on the charge distribution without considering the battery health issues such as sulphuric acid accumulation the battery terminals. This issue mainly occurs when a battery is over-charged. Hence, a control system that controls the charging and discharging of a BESS is important to avoid the battery's health to deteriorate. In this study, a design scheme of a two-battery hierarchical charging – discharging system is developed and investigated whereby, the system controls and selectively charges and discharges the batteries. The system determines the battery's' state and intelligently selects the charging and discharging process. The system is analyzed and validated through the hardware development.

## 2 HARDWARE AND SOFTWARE SYSTEM STRUCTURE

The proposed hierarchical charging – discharging system for continuous sustainability is divided into TWO (2) sections which are hardware and software development respectively. The hardware development section described in THREE (3) parts as follows:

i. Main Charging and Discharging Switching Circuit Design
ii. Sleep Mode Interrupt Circuit Design

iii. BESS Switching Circuit Design based on Hierarchical Charging – Discharging Strategy

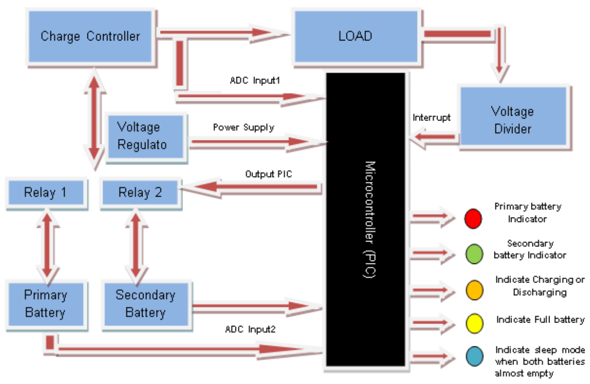



***Fig. 1.*** *Architecture of proposed hierarchical charging – discharging hardware system for continuous sustainability.*

The architecture of the proposed hierarchical charging – discharging hardware system is shown in Figure 1.

**2.1 Main Charging and Charging Switching Circuit Design**
The proposed main charging – discharging switching system design is shown in Figure 2. Two mechanical relays (Relay 1 and Relay 2) are used as control switches to switch ON or OFF the Primary and Secondary battery charging – discharging process. Peripheral Interface Controller (PIC) microcontroller is incorporated between the input and output peripherals as the system controller. The PIC microcontroller is powered using 5 Volt voltage and can only sense maximum 5 Volt voltage from all the connected input peripherals. Therefore, a 12 Volt to 5 Volt voltage sensing circuit is required. The voltage sensing circuit is connected at the output of Primary and Secondary batteries and the output voltages from the batteries is sent to the ADC2 and ADC3 inputs of the PIC microcontroller. The voltages measured at ADC2 and ADC3 are referred to the batteries State-of-Charge (SoC). The SoC data of each battery is important to send an output signal to the respective relay which acts as ON or OFF switch to perform the hierarchical charging – discharging strategy scheme.

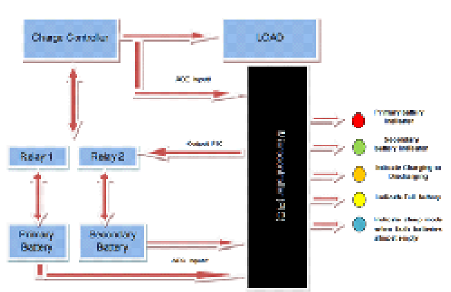



***Fig. 2****. Architecture of Main Charging and Discharging System Design.*

The ADC1 input is connected at the output port of the charge controller, which is connected directly to the load. The ADC1 is operates only when both batteries are disconnected from the charging – discharging control system. This condition only occurs when the stored energy in both batteries drops to the lowest safe level. Hence, the batteries are not allowed to be discharged anymore. Then, the PIC microcontroller will switch OFF both Relay 1 and Relay 2 to disconnect the batteries from overcharging condition. At this state, PIC microcontroller will go into sleep mode, at which it will continuously draw a minimum current from the primary battery until the solar PV system has sufficient output power to supply to the connected loads without the aid from the battery. At this stage, the solar PV system functions to run the loads and charge the batteries simultaneously. During this condition, the ADC1 will sense and measure any incoming input voltage from the charge controller's output and will interrupt the process to wake up the PIC microcontroller to start the overall system operation. The hierarchical charging – discharging switching system is integrated with FIVE (5) Light Emitting Diode (LED) as an indicator to display the system operations as shown in Figure 1. Table 1 shows the status colour of each LED at different system operations.

***TABLE 1***
*LED Indication for Hierarchical Charging – Discharging System*

| *LED* | *Indicator* |
|---|---|
| *Red* | *Connected to Primary Battery Bank* |
| *Green* | *Connected to Secondary Battery Bank* |
| *Orange* | *Connected to indicate Charging – Discharging* |
| *Yellow* | *Connected to indicate Fully Charged Battery Banks* |
| *Blue* | *Connected to indicate Hierarchical Charging – Discharging System is in Sleep Mode* |

**2.2 Software Operational of Main Hierarchical Switching Charging - Discharging**
The second section of this project is the embedded software system programming which is incorporated into the PIC microcontroller for overall system operations. According to Figure 3, the embedded software system programming is divided into TWO (2) parts as follows:

i. Charging
ii. Discharging

Firstly, the embedded software will initialize to check the batteries capacity. Based on the initialization result, the system will select to charge either the primary battery or the secondary battery. The charging process prioritizes primary battery charging followed by the secondary battery. The charging of Primary battery is automatically stopped when it surpasses the secondary battery by 20 %.

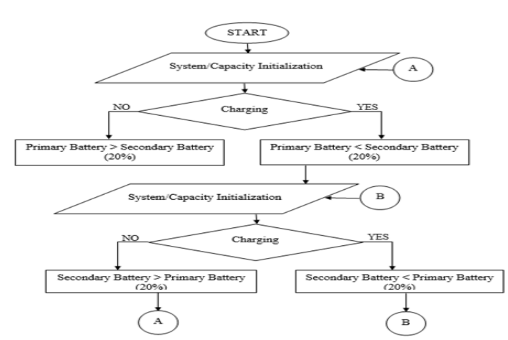



***Fig. 3****. Software Operational of Main Hierarchical Charging – Discharging Strategy Scheme Flowchart.*

Secondly, when the charging process is switched to secondary battery, the system will initialize again to check the batteries capacity and the initialization result will be redirected to charge the secondary battery.

### 2.3 Sleep Mode Interrupt Circuit Design

The sleep mode interrupt circuit design for the sleep mode feature is shown in Figure 4. This circuit operates when the voltage of the primary battery and the secondary battery decreases below the SoC threshold. At this stage, Relay 1 and Relay 2 are switched to Normally Open (NO) condition. Therefore, there will be no power flow to the batteries from the charge controller. When Relay 1 and Relay 2 are at NO conditions, the hierarchical charging – discharging switching system will go into sleep mode condition. The hierarchical charging – discharging switching system will be back to alive only when a certain amount of output power is measured at solar photovoltaic panels, and the output power is used as a threshold value to trigger the input port at the PIC microcontroller. Therefore, when the hierarchical charging – discharging switching system receives an interrupt signal, the system is activated and starts operating as normal again.

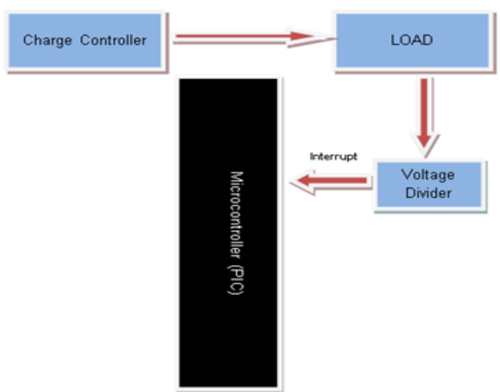



***Fig. 4.*** *Sleep Mode Interrupt Circuit Design Block Diagram.*

According to Figure 5, the system initialization checks the batteries capacity to deactivate the sleep mode condition of the charging – discharging switching system. The load triggering condition is the criteria to deactivate the sleep mode condition. This shows that the solar PV system is generating sufficient power to operate the loads and to charge the batteries simultaneously.

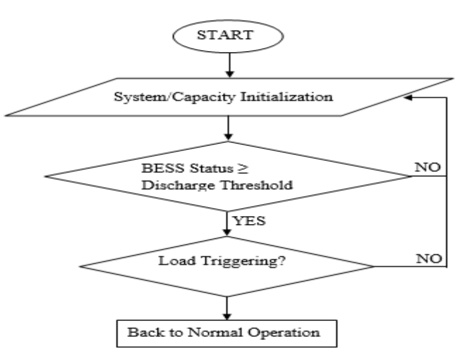



***Fig. 5****. Sleep Mode Interrupt Deactivating Process Flowchart.*

### 2.4 Battery Switching Circuit Design based on Hierarchical Charging-Discharging Strategy

Figure 6 shows the architecture of batteries switching circuit design based on hierarchical charging – discharging strategy scheme shown in Figure 7. The circuit is designed to control the charging – discharging switching between the primary battery and secondary battery. In designing this switching circuit, two additional relays are integrated together with the existing Relay 1 and Relay 2. These relays are powered by the output control signal which connect the primary and the secondary batteries. These relays also allow the charging – discharging switching between the primary and the secondary battery. When the primary battery is connected, the main charging – discharging hardware system is powered via the primary battery and on the other hand, the secondary battery powers the hardware systems when it is connected.

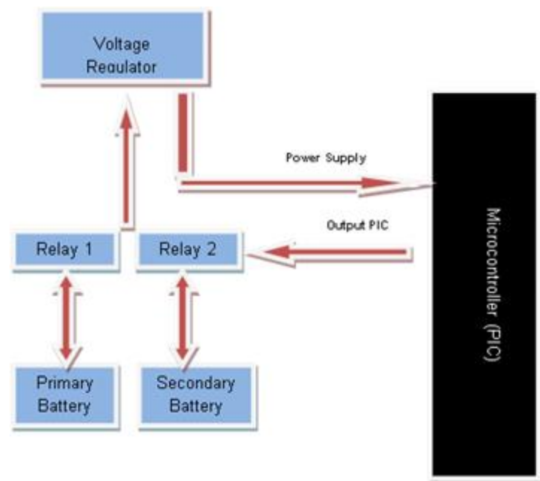



***Fig. 6****. Architecture of Batteries Switching Circuit Design Based on Hierarchical Charging – Discharging Strategy Scheme.*

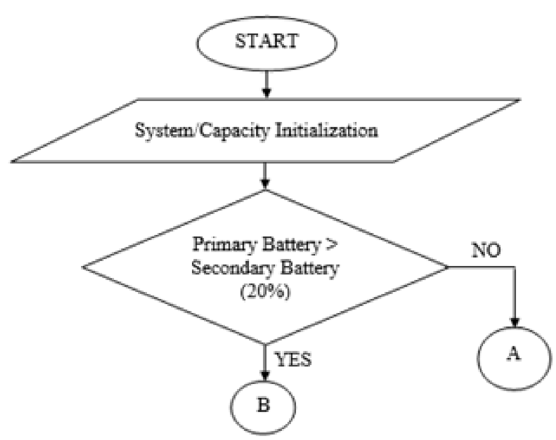



***Fig. 7****. Architecture of Batteries Switching Circuit Design Based on Hierarchical Charging – Discharging Strategy Scheme.*

### 2.5 Software Operational of Hierarchical Charging – Discharging Strategy Flowchart

As illustrated in Figure 7, the system initially checks the batteries status and triggers the respective relays to start the battery charging or discharging process.

## 3 DISCUSSIONS AND RESULTS

In this study, a priority-base hierarchical charging – discharging system is investigated. The system is able to control the charging and discharging of the BESS. The system is able to prevent the battery from being damaged by over/under charging conditions and preserve the battery lifetime. The software developed was implemented into the hardware design and the performance was compared and validated. Therefore, this section presents the preliminary research and development results and explained in accordance with the methodology conducted to develop the system.

### 3.1 Complete Circuit and Operation

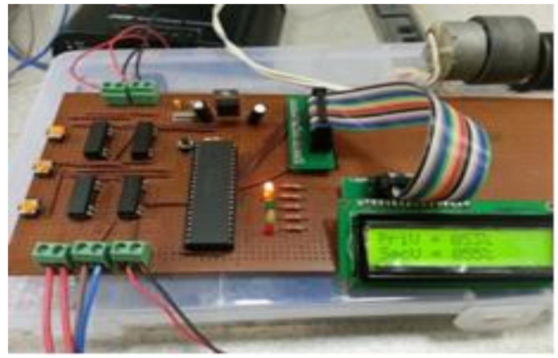
***Fig. 8.*** *Completed Hierarchical Charging – Discharging System Development.*

Figure 8 shows the complete hardware of the hierarchical charging – discharging system circuit. The system is developed on a donut board to test and validate the concept of the priority-base hierarchical charging – discharging strategy scheme described in section 2. There are also THREE (3) variable resistors in embedded on the circuit board shown in Figure 8. The functions of the variable resistors are as follows:

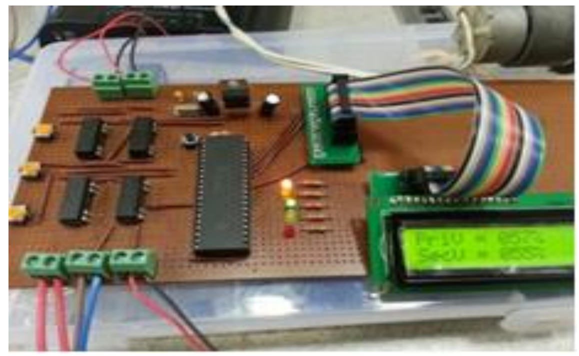
- To simulate Charging/Discharging on Primary battery
- To simulate Charging/Discharging on Secondary battery
- To change the sensitivity of the system towards the output of the system for interrupt during sleep mode

### 3.2 Circuit Operation

Figure 9(a) shows that the primary battery is connected to the solar photovoltaic system via the charge controller for charging or discharging process. At the initial stage, when the primary battery starts charging the third LED is switched OFF and as the system senses the primary battery capacity increases, the third LED is switched ON to indicate the charging process. The first and third LED in Figure 10(b) is switched ON to indicate that primary battery is connected to the system.



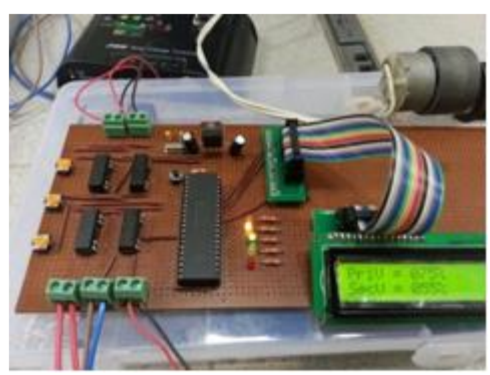
(a)



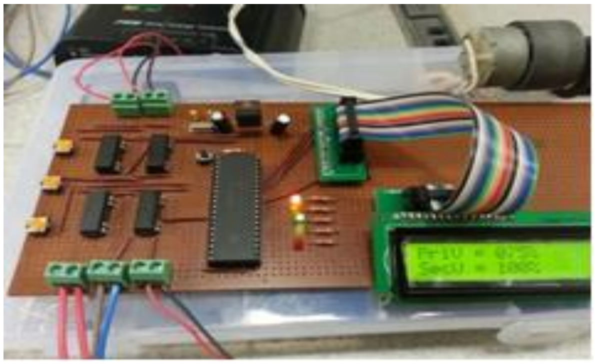
(b)

***Fig. 9****. Primary Battery Connected (LED1) & Charging (LED3).*

Figure 10 shows the charge on the primary battery surpasses the charge on the secondary battery by 20%. At this stage, the primary battery is disconnected from the system and at the same time, the secondary battery is connected to the charging – discharging system. The charging – discharging system switches the connection from primary battery to charge the secondary battery. The charging – discharging system's connection is switched back to the primary battery when secondary battery's capacity is 20% higher than primary battery or else when secondary battery is fully charged. Figure 11 shows that the fourth LED is switched on to indicate that the primary and the secondary batteries are fully charged. During this stage, the primary battery is prioritized and connected to the load system as described in the section 2 methodology. As an indicator, LED 1 is switched ON and LED 3 (Figure 12) is switched OFF to indicate that primary battery has start discharging.



(a)



(b)

***Fig. 10****. Switch to Secondary Battery Bank Charging (LED2) & Secondary Battery Bank Fully Charged (LED2 –OFF).*

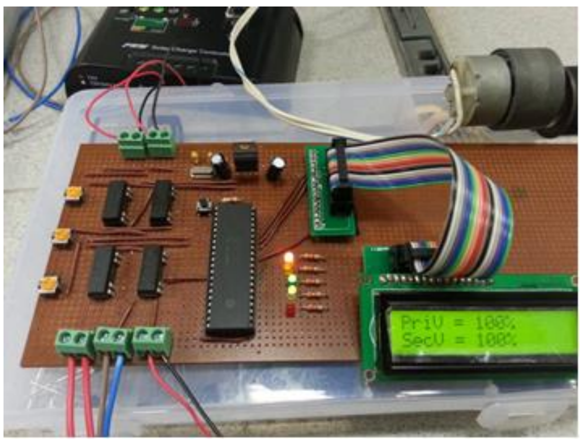
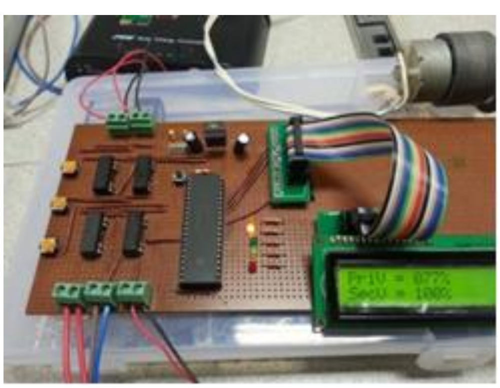
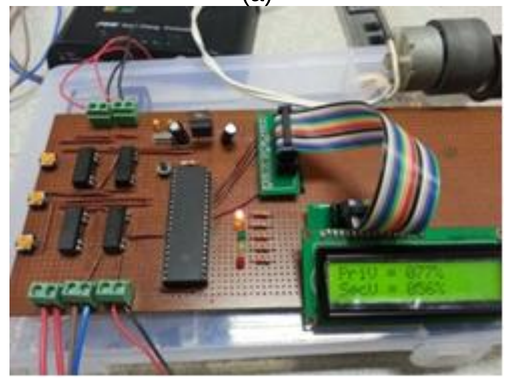



***Fig. 11****. Primary Battery and Secondary Battery Fully Charged.*

As it is shown in Figure 13(a) the primary battery capacity drops 20% below the secondary battery (which is in full-charge state), the discharging process is switched to the secondary battery and the LED 3 is switched OFF to indicate discharging process of the secondary battery. Like the charging process, the same process is repeated for discharging process. The system switches between the primary battery and the secondary battery when one battery capacity is 20% lower than the other battery as it is indicated in Figure 13(b). These switching between batteries is to divert the demand of the load to other batteries and let the exhausted battery to rest and recover itself quickly to increase the battery efficiency.



(a)



(b)

***Fig. 13.*** *Hierarchical Switching Discharging Between Primary Battery Bank and Secondary Battery Bank.*

Under discharging the batteries will damage the batteries and will cause the ability of the battery to store energy to deteriorate. With the hierarchical charging – discharging system developed, to the under discharging condition could be prevented by setting the threshold value of capacity level at limits of 50% of the ADC reading. As shown in Figure 14, when the primary battery and secondary battery capacity drops below 50%, the system will be disconnected from both batteries. At this state, LED 5 is switched ON to indicate that the system have is in sleep mode. The system will only wake up when there is enough output power from the solar PV system output power to energize the load, the system will receive an interrupt signal as load demand signal to itself wakes up and goes into normal operation again. When from the power generated from the solar PV system is adequate to power up the load, the charging process restarts simultaneously.

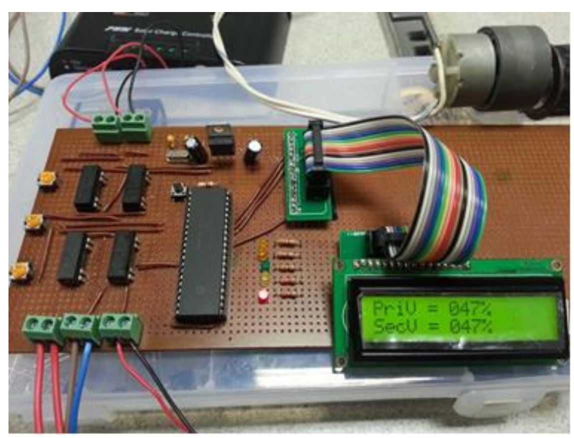



***Fig. 14.*** *Sleep Mode Condition.*

## 4 CONCLUSION

The development and validation of a priority-base hierarchical charging – discharging system for continuous sustainability have been conducted in this study. The software program and the hardware operation has been validated and the control scheme was found to be feasible.

## 5 ACKNOWLEDGMENT
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