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Research and Development of the Hierarchical Switching Charging Discharging System for Continuous Sustainability

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Abstract: Integration of photovoltaic system with battery energy storage system is always seen as a better way to utilize the available energy from renewable energies. Considering continuous sustainable battery charging discharging using the solar photovoltaic, this study proposes hierarchical switching charging discharging system for solar photovoltaic system application. This study will briefly describe the methodological design of the overall system which is proposed to control between the dual and more battery energy storages. The results of the developed hardware will validate the methodological design proposed earlier and the results also, effectively justify the developed system's performances.

Key words: BESS, continuous sustainable, hierarchical strategy, switching circuit, methodological design, performances

INTRODUCTION

Battery Energy Storage System (BESS) technologies existed for very long-time ego and its application have increased significantly in smart grid based systems (Natte *et al*., 2014). The BESS is integrated into the solar photovoltaic to avoid the inconsistency output power from solar photovoltaic system (Ye *et al*., 2016). Having said that if solar photovoltaic could/able to produce excessive output power, then, the excessive output power needs a storage system for emergency utilization.

This study will review some of the related research that presents the important of configuring the BESS. Solar photovoltaic with Hybrid Storage System (HSS) focused on the forecasting or predictive technique, controlling methods for the output modules and improving the voltage regulations (Reddy and Momoh, 2015; Lampropoulos *et al*., 2015; Sun *et al*., 2011). By Ye *et al*. (2016), hierarchical control scheme presented the centralization the energy storage system and performs desirable selection during the processing task. Two layer of hierarchical energy management control proposed by Ming *et al*. (2014) is used to hybrid the battery and supercapacitor. This proposed method splits the power ratio between the battery and supercapacitor for charging and discharging. By Tummuru *et al*. (2015), fast DC-link voltage based management scheme is proposed to control the current at the battery. At the same time, the output power is balanced between the battery and supercapacitor to perform the dedicated tasks. Summarizing the brief literature review, renewable energy systems employs different kind of control strategy for charging and discharging for BESS. However, utilization of bidirectional approach via. hierarchical charging discharging strategy for dedicated energy storage is required when energy forecasting is used in the renewable energy systems. To investigate the proposed hierarchical switching charging discharging strategy, hardware system is developed based on the proposed methodological.

MATERIALS AND METHODS

Methodological design of hardware and software: The methodological design of the hierarchical switching charging discharging system for continuous sustainability is divided into two parts. Each part will be described briefly.

The hierarchical switching charging discharging system for continuous sustainability methodology design is shown in Fig. 1. The hardware system is divided into 3 parts:

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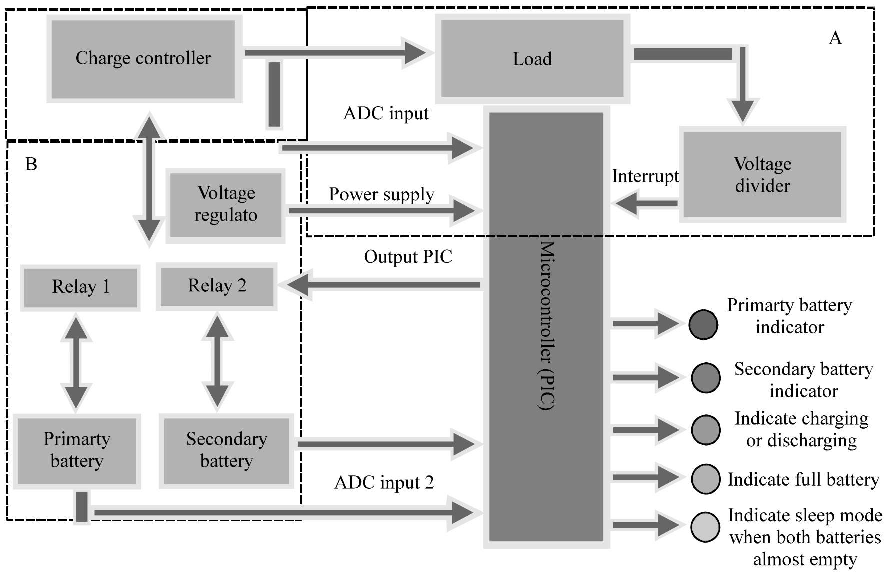


Fig. 1: Architecture of hierarchical switching charging discharging system for continuous sustainability

- Main charging and discharging switching circuit design
- Sleep mode interrupt circuit design
- BESS switching circuit design based on hierarchical charging discharging strategy

Two mechanical relays (Relay 1 and 2) are used as switches to switch on/off the primary and secondary battery energy storage during charging discharging process.

Operational of proposed main switching charging discharging system: PIC microcontroller is incorporated between the input and output peripherals to complete the design of hierarchical switching charging discharging system for continuous sustainability. This part of the circuit connects the primary and secondary battery energy storage to the ADC2 and ADC3 inputs to sense the batteries State-of-Charge (SoC). The SoC information are used to switch on/off the tasks proposed in the hierarchical switching charging discharging strategy.

Figure 1 shows the ADC1 input is connected at the output charge controller port and is used only when both battery energy storages are disconnected from the system. This condition only occurs when, the battery energy storages stored energy drops to the safest state of SoC. During this state, relay 1 and 2 are switched off and PIC microcontroller will go into sleep mode and will turn on back only when a sufficient amount of output power is available from solar photovoltaic panels. The said sufficient amount output power is meant to charge the battery energy storages and at the same time supply to the load.

The hierarchical switching charging discharging system is also integrated with 5 Light Emitting Diode (LED) as an indicator to the system operational.

Software operational of main hierarchical switching cahrging discharging: This study explains about the embedded software programming designed for the hierarchical switching charging discharging hardware system shown in Fig. 1. Figure 2 shows the flowchart of embedded software program designed using C language. Firstly, system initialization will check the battery energy storages capacity and base on the results, the system will be directed to charge either primary battery or secondary battery. When the primary battery is charged at additional 20% of secondary battery, the charging process will be halt and charging will be switched to secondary battery. When the secondary battery is charging, system initialization will check again the batteries capacity and the result will redirect to the respective battery energy storage for charging.

Sleep mode interrupt circuit design: The sleep mode interrupt circuit is labelled in yellow dotted lines in Fig. 1. The circuit will only operate when the voltage of primary battery bank and secondary battery bank decreases below the threshold SoC. The hierarchical switching charging discharging system automatically switched off. During this condition, no output power from solar photovoltaic

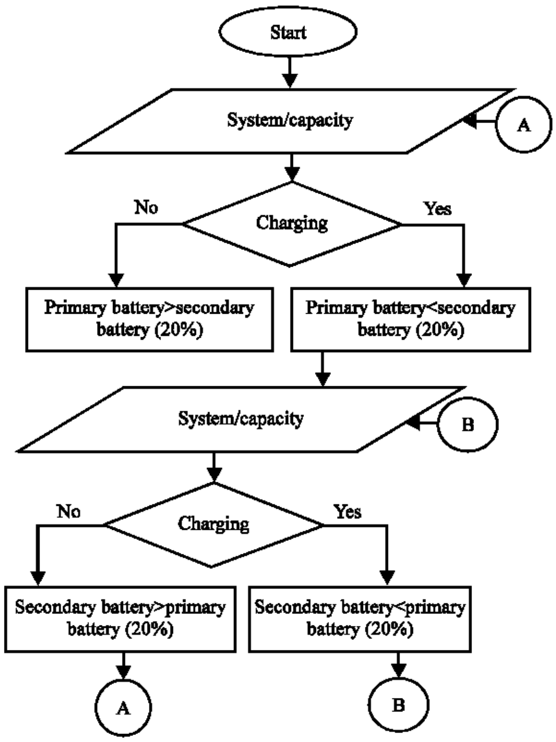


Fig. 2: Software operational of main hierarchical switching charging discharging flowchart

panels will flow to charge the battery energy storages. Therefore, hierarchical switching charging discharging system will goes into sleep mode condition. The system will come back alive only when the solar photovoltaic panels output power above the threshold voltage value. When the output power is sufficient, the hierarchical switching charging discharging system will receive an interrupt signal to start it operation.

According to Fig. 3, system initialization will check the BESS capacity to deactivate the sleep mode condition of hierarchical switching charging-discharging system. At the same time, load triggering is also considered as one of the criteria to deactivate the sleep mode condition because when solar photovoltaic panels produce sufficient output power to energize the load, it smartly shows the solar photovoltaic panels sufficiently able to produce output power to charge the BESS too.

Bess switching circuit design based on hierarchical charging discharging strategy: Figure 1 labelled the BESS switching circuit design in red dotted lines. The circuit is designed to control the switching charging discharging between the primary battery and secondary battery.

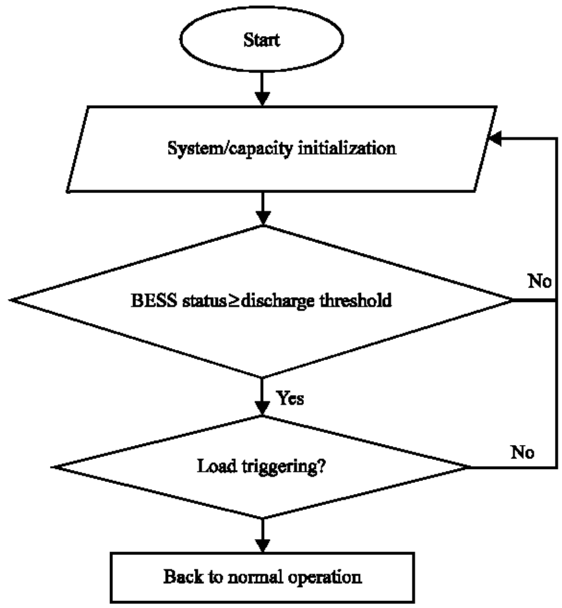


Fig. 3: Sleep mode interrupt deactivating process flowchart

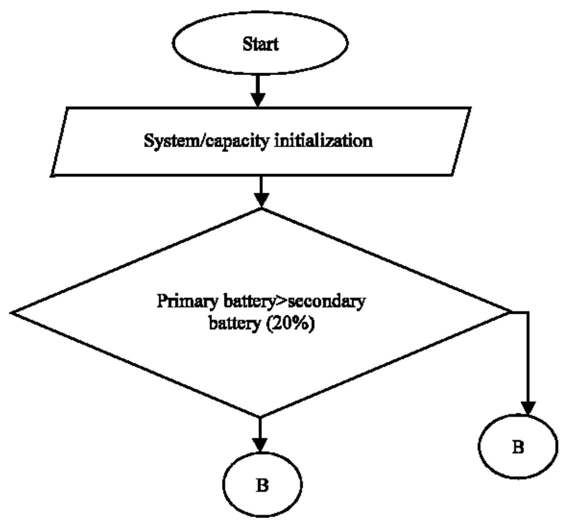


Fig. 4: Hierarchical charging discharging strategy flowchart

This circuit controls the relay 1 and 2. These relays are connected to the BESS which are controlled for charging discharging (Fig. 4).

Software operational of hierarchical charging discharging syrategy flowchart: After the system initialization process, the respective relay will be triggered to start the charging process of the respective battery energy storage as shown in Fig. 4. At the time charging, one of the battery energy storage is also discharged.

RESULTS AND DISCUSSION

The objective of this study is to research and develop the hierarchical switching charging discharging system for continuous sustainability and also to have a system which will be able to prevent the BESS from over discharging process. Therefore, in the following the research and development prototype results are presented and briefly explained.

Complete circuit and operation: The complete hierarchical switching charging discharging system circuit is shown in Fig. 5. The LED indications are used to present the developed circuit operation and functionality.

At the initial stage when the primary battery bank starts charging the third LED (Green) is switched off and as the capacity increases the LED (Green) switched on. The first LED (Orange) is switched on to indicate the primary battery bank is connected to the system.

Figure 6 shows primary battery bank is charged 20% more than secondary battery bank. Primary battery bank will be disconnected from the charging system and secondary battery bank is connected for charging. When the secondary battery bank charging, second LED (Yellow) is switched on. The charging connection will only switch back over only when secondary battery bank is 20% higher than primary battery bank or secondary battery bank is fully charged.

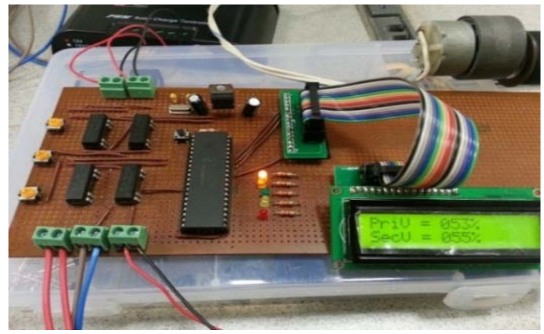
Figure 6 shows LCD display indicates the primary battery bank and secondary battery bank are fully charged at 100%. When both are fully charged, the LED4 (Yellow) is turned on. When both batteries are fully charged at 100%, then the primary battery bank is connected to the load.

To start discharging, LED1 (Orange) shown in Fig. 7 is switched on and LED3 (Green) is switched off to indicate primary battery bank is discharging. When the primary battery bank charges drop 20% compare to secondary battery bank, system will detect it as discharging and LED3 (Green) is switched off. Similarly, to charging process, discharging process will also be switched between both batteries. The switching among the batteries to help the exhausted battery to rest and allow some recovery time to increase the battery charging discharging efficiency.

In terms of discharging if the batteries are over charged it will damage the batteries. To avoid the damage, hierarchical switching charging discharging strategy is set to prevent the battery from damaging.

Figure 8 shows the primary battery bank and secondary battery bank capacity drops below 50%, the hierarchical switching charging discharging strategy will trigger to disconnect the BESS from the system. During this situation, the system goes into sleep mode condition, assuming solar photovoltaic panels is unable

(a)



(b)

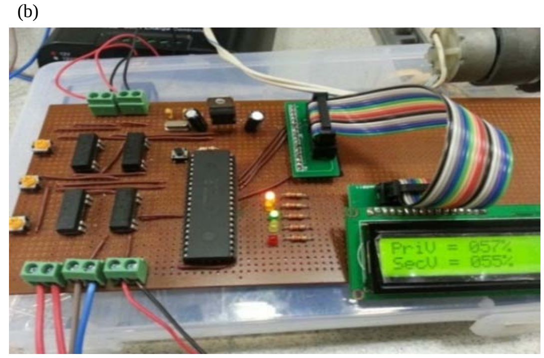
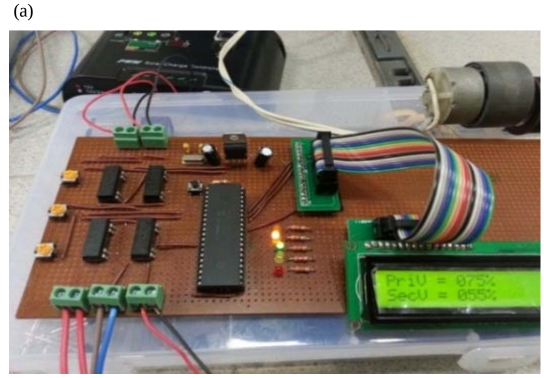


Fig. 5: a, b) Primary battery bank connected LED1 (Orange) and charging (Green)

(a)



(b)

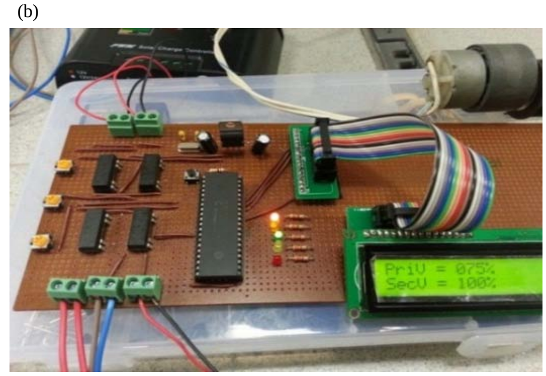


Fig. 6: a, b) Secondary battery bank connected LED2 (Orange) and charging (Green)

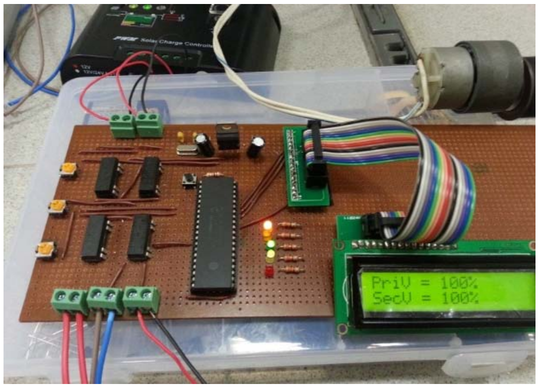


Fig. 7: Fully charged primary battery bank and secondary battery bank

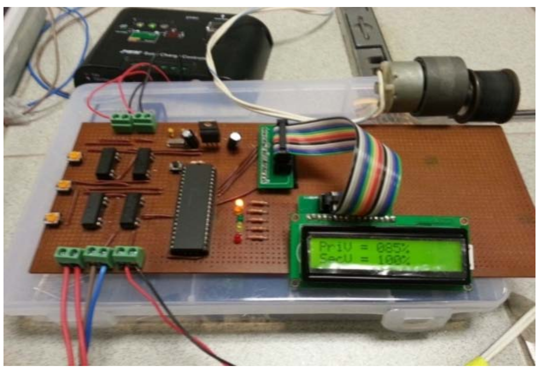


Fig. 8: Primary battery bank discharging

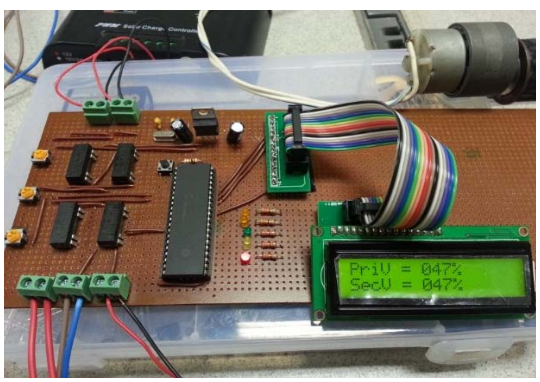


Fig. 9: Sleep mode condition

to sufficiently output power to operate the proposed system and at the same time LED5 (Red) is switched on as shown in Fig. 9.

CONCLUSION

The presented results for the proposed hierarchical switching charging discharging has validated the proposed methodology. The embedded software programming developed results also validate the researched and developed hardware prototype and it operation and functionality.

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