A Review of Battery Charging - Discharging Management Controller: A Proposed Conceptual Battery Storage Charging – Discharging Centralized Controller

Nur Ariana Zainurin
Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka (UTeM)
Melaka, Malaysia
m022020034@student.utem.edu.my

Siti Aisyah Binti Anas
Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka (UTeM)
Melaka, Malaysia
aisyah@utem.edu.my

Ranjit Singh Sarban Singh
Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka (UTeM)
Melaka, Malaysia
ranjit.singh@utem.edu.my

Abstract-This paper describes the development of a centralized controller to charge or discharge the battery storages that are connected to renewable energy sources. The centralized controller is able to assist, control, and manage the battery storage charging when excessive power is available from renewable energy sources. At the same time, the centralized controller also performs battery storage discharging when the connected load requires a power source, especially when the renewable energy sources are unavailable. Background studies regarding battery storage charging-discharging are presented in the introduction section. Also, generally developed charging-discharging methods or techniques were applied at the system level and not specifically to the battery storage system level. Due to the limited study on battery storage system charging-discharging, this paper reviews some of the similar studies in order to understand the battery storage charging–discharging characteristics as well as to propose a new conceptual methodology for the proposed centralized controller. The battery storage State-of-Charge (SoC) is used as the criterion to develop the conceptual centralized controller, which is also used as a switching characteristic between charging or discharging when only the battery energy storages are supplying the output power to the connected load. Therefore, this paper mainly focuses on the conceptual methodology as well as explaining the functionality and operationality of the proposed centralized controller. A summarized comparison based on the studied charging–discharging systems with the proposed centralized controller is presented to indicate the validity of the proposed centralized controller.

Keywords-management controller; centralized controller; battery charging/discharging; dynamic charging/discharging controller

I. INTRODUCTION

A battery is an energy storage device, which is considered not usable if it is unable to perform the energy storage functionality and to discharge the stored energy source. Batteries are used in electronic devices, electric cars, renewable energy systems, etc. As batteries are used into various applications, energy management when the battery is performing charging – discharging is gaining attention. Renewable energy systems are known as highly dependent systems to battery storages, which allows them to store the produced energy into the connected batteries [1-3] and optimize the battery charging-discharging operation [4, 5]. Looking at the gaining popularity of the renewable energy systems, especially the microgrid renewable energy systems, battery storage charging and discharging [1, 6-11] are equally crucial for the renewable energy system in both islanded and non-islanded modes. Both modes need to ensure the reliability of the output energy with little to no disruption to the connected load during the operation hours [12]. Furthermore, the modes also need to ensure the battery storages can perform better and improve the utilization of renewable energy systems [9, 13-15]. Looking at the importance of battery storage charging – discharging, methods or mechanisms such as the Adaptive Neuro-Fuzzy Inference System (ANFIS) [6, 16, 17], backtracking search algorithm [10, 18, 19], non-simultaneous charging and discharging [20], genetic algorithm [4, 21], particle swarm optimized fuzzy controller [22-27], model predictive control [28-32], dynamic optimal power flow [33-36], and grey model and genetic algorithms [37] are commonly used to perform the battery storage charging and discharging. The used methods or mechanisms also conduct system

Corresponding author: Ranjit Singh Sarban Singh

optimization to reduce the stress on the battery storages as well as protect the batteries from being damaged. Optimal scheduling was introduced in [38] to reduce the battery aging effects on batteries that are frequently charged. Similarly, authors in [39] proposed an optimization model for charging and discharging which again resulted in the improvement of the battery aging effects.

In [40-45], the Maximum Power Point Tracking (MPPT) method is applied with different schemes, based on the Perturb and Observe (P&O) algorithm [40, 41], Incremental Conductance (InC) algorithm [42, 43], Fractional Open Circuit Voltage (FOCV), or Fractional short Circuit Current algorithm (FCC) [44, 45]. All these schemes allow the MPPT method to maximize the harvesting process as well as analyze the behavior of the variantion during the harvesting which results to output power reduction. Indirectly, all these schemes are actually contributing to the battery charging process if the power system is connected to the battery storages. On the contrary, it is also important to have battery storage charging – discharging when these schemes are operating at the maximum capacity. Even though the mentioned algorithms, methods, or mechanisms perform the battery storage charging – discharging decisions such as to charge or to stop battery storages charging, a systematic or spontenously decision such as to assist, manage, or control the battery storages charging – discharging is not effectively implemented and also has the probability to damage the battery storages. In [46], a mathematical modelling to study the lithium-ion battery charging – discharging behavior is proposed. The developed mathematical model focuses on the lithium-ion battery charging – discharging voltage as well as on the temperature of the lithium-ion battery. This mathematical model can be used to conduct battery optimization process but yet unable to intelligently control or manage the charging – discharging process. Similar to the mathematical model, the Electrochemical Model (EM) [47] were proposed in [48] to study the lithium-ion battery State-of-Charge (SoC) estimation. The single particle model and Nernst equation were employed in this research and the charging – discharging of the battery were correctly measured to achieve an accurate SoC. The results of this study show that the EM for SoC estimation can be used to estimate the lithium-ion battery's SoC as well as its State of Health (SoH), but the EM method is not able to assist, manage, and control in terms of effective battery storage charging – discharging.

Various methods, meachnisms, or techniques have been used in renewable energy systems, but not specifically to assist, manage and control the battery storages charging – discharging. Mostly these methods, mechanisms, or techniques were applied to smooth the performance, especially in diversifying and stabilizing the overall system. Limited study also has been conducted to specifically study an apprioprite method, mechanism, or technique that can effectively assist, manage and control the battery storage charging – discharging. Also, looking into the critical situation, when one resource is not available, the decision making for the system to assist, manage, and control the battery storages in terms of charging – discharging has not specifically been implemented. Therefore, it is necessary to have a system that can assist, manage, and control the battery storage charging-discharging. Hence, selected papers such as [1, 6, 9] were extensively studied to understand the battery storage charging-discharging management systems. The studied papers were used to develop the conceptual methodology battery storage charging-discharging strategy proposed in this review paper. The main contributions of this paper are: (1) A study of the available battery storage charging-discharging controller management methodologies, (2) the summarization and proposal of a conceptual methodology for a centralized controller for battery storage charging - discharging that can be integrated into renewable energy systems while simultaneously assisting, managing, and controlling the effectiveness of battery storage charging – discharging based on battery SoC.

II. A STUDY OF SELECTED BATTERY CHARGING/DISCHARGING MANAGEMENT METHODOLOGIES

A microcontroller was used in [1] to control the hybrid energy system and the charge - discharge of the battery storages. Figure 1 shows the architecture of the developed system and explains the system operation. First, the system reads the V_{DC} and I_{DC} of the connected Direct Current (DC) sources. Then, if the DC sources are equal to or greater than 80% of the V_{DC}, I_{DC}, all the switches connecting to the connected LOAD are switched OFF. The DC sources are used to charge the battery storages if their capacity is less than 80%, otherwise, the battery storage will be connected to the LOAD for discharging. The system RETURNS to the start process and continuously checks on the available V_{DC}, I_{DC} from the DC sources.

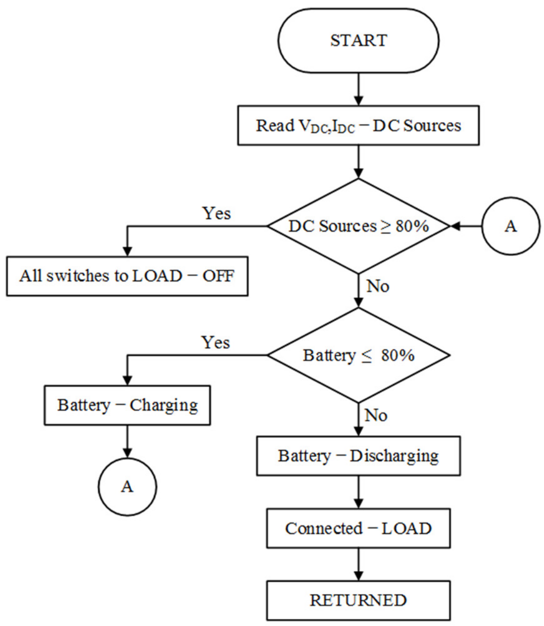

Fig. 1. Microcontroller embeded algorithm-battery charging-discharging.

In a similar research [6], an intelligent algorithm based on ANFIS was developed to simultaneously perform two different tasks: to protect the connected battery against overcharging and deep discharging. The ANFIS algorithm that has been developed in this research measures the V_{pv}, I_{pv}, SoC of the battery storage and Volt Direct Current (V_{dc}). This measurement is vital to find the Maximum Power Point (MPP) from the resources and control the battery storage charging - discharging. Figure 2 presents the algorithm process that controls the battery storage charging - discharging based on the power condition (P_c), battery SoC minimum (SoC_{min}) and battery SoC maximum (SoC_{max}). When the measured V_{pv} and I_{pv} input from the photovoltaic panel is equal to the maximum, the photovoltaic power is compared with the initial P_c before starting the charging process. Based on the calculation, when the photovoltaic panel power (P_{pv}) is equal to maximum photovoltaic power (P_{max}), then the P_{pv} is equal to P_c. Otherwise, the ANFIS algorithm keeps searching for P_{max}.

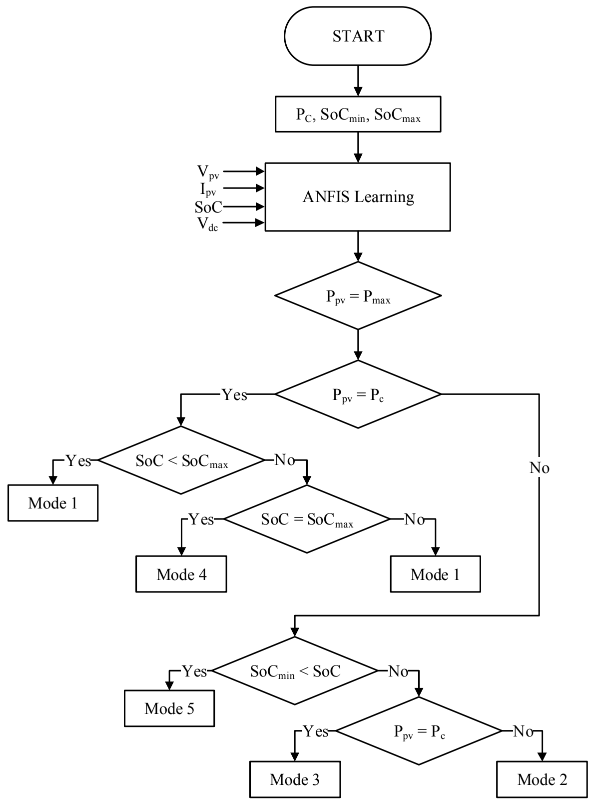

Fig. 2. ANFIS algorithm – battery charging-discharging based on SoC.

Figure 2 shows the battery storage charging - discharging process according to the battery SoC conditions. Based on the process, three different operation modes are controlled by three relays that act as switches, as presented in Table I. During Mode 1, the logic state for R_1 and R_2 relay switches equals to 1. The power generated from the photovoltaic generator (P_{pv}) is greater than zero, sufficient to source the connected load and batteries. During Mode 2, the logic state for R_2 and R_3 relay switches equals to 1. During this mode, the power generated by the photovoltaic generator is insufficient ($0 < P_{pv} < P_c$). In this case, the battery power is utilized to satisfy the additional required power demand, this mode is also known as battery compensation mode. During Mode 3, the logic state for the R_3 relay switch is equal to 1. The energy stored in the batteries is fed to the connected load. During this operation mode, the photovoltaic generator is unavailable to produce power, $P_{pv} <0$. During Mode 4, the logic state for the R_2 relay switch is equal to 1. The photovoltaic generator, $P_{pv} = P_c$ and the batteries are fully charged. Therefore, in this mode it is required to disconnect the batteries from being overcharged. During Mode 5, none of the relay switches is equal to 1. This condition shows that the photovoltaic generator P_{pv} is equal to zero, and the batteries' SoC is equal to SoC_{min}. Therefore, both the available recourses are disconnected from the connected load.

TABLE I. MODES OF OPERATION BASED ON RELAY LOGIC STATE

Relay switches	Operation				
	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5
R_1	1	0	0	0	0
R_2	1	1	0	1	0
R_3	0	1	1	0	0

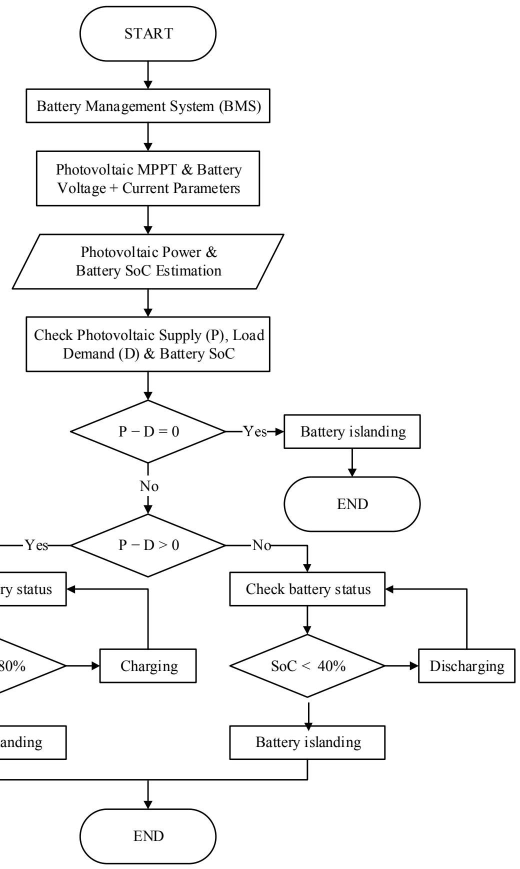

Fig. 3. Entire system and battery charging-discharging operation.

In another similar recent research [9], the intelligent power control shown in Figure 3 was developed to improve battery reliability and operational life. The power control operates in two control modes: 1) MPPT mode and 2) Battery Management System (BMS) mode. The SoC estimation technique incorporates the Back-Propagation Neural Network (BPNN) algorithm, which manages the battery's charging - discharging and islanding approaches, which helps prolong the battery's lifespan. The developed system is divided into stages of operation. Firstly, the available photovoltaic power, battery's voltage, and current information are collected. In the second stage, the photovoltaic power supply is compared with the load demand. If the photovoltaic power supply and load demand are zero, then the battery is connected to islanding mode. If the photovoltaic power supply is higher than the load demand, the battery SoC status is checked. If the battery SoC is more than 80%, then the battery is connected to the islanding mode. Otherwise, if the battery SoC is between 40% to 80%, then the battery is connected for charging. If the battery SoC is less than 40%, battery discharging is not allowed, and the battery is connected to islanding mode.

III. SUMMARY OF THE REVIEWED AND PROPOSED CHARGING/DISCHARGING MANAGEMENT CONTROLLERS

This section summarizes the most recent battery storage charging - discharging methods, mechanisms, or techniques. The battery storage charging - discharging process shown in Figure 1 starts to operate when the connected DC source is equal to or greater than 80% of the generated DC input. Otherwise, the proposed process is deactivated from all the connected loads. Therefore, if the DC is equal to or more than 80%, the proposed system checks on the battery SoC. If the battery SoC is above 80% and the DC source is equal to or more than 80%, only the battery source is connected to the discharging and connected load. Therefore, the developed system functionality is restricted and dependent on the DC source supply. If the battery source is sufficient, the system should be connected to the load. The battery storage charging - discharging shown in Figure 2 shows the overall proposed process simultaneously sensing and measuring the voltage, current, battery SoC, and direct current battery voltage. This information is used to calculate either the solar photovoltaic system power output or to analyze the total power condition. The proposed process operates fully only when the solar photovoltaic system power output is equal to the maximum power required and the power condition. The proposed system operates entirely when these conditions are satisfied. Otherwise, the system strictly follows the five mode conditions that have been explained in Section II. Furthermore, the proposed system can only operate unidirectionally, and the initial conditions need to be met for the battery energy storages to operate. The presented battery storage charging – discharging shown in Figure 3, operates when the photovoltaic power supply and load demand are equal to zero and the battery is connected into islanding condition. When the photovoltaic power supply is more than the load demand, only the battery status is checked for either charging - discharging or islanding. The proposed process shows that the battery can only operate when the battery's SoC is consistently above 80%, which also explains that the system needs to be installed at a location where solar irradiance is always available. The proposed system also shows that the functional period of the battery is only limited to 20%, which explains why the system needs to be installed at a location where continuous solar irradiance is available.

The study of three different processes of battery storage charging - discharging shows that each proposed process has its own methodology, operationality, and functionality.

In the following, a hierarchical SoC based battery storage charging - discharging system is proposed. The conceptual system fundamentally explains the methodology applied for battery storage charging - discharging and the proposed idea has the ability to extend the battery lifespan. Figures 4-6 show the conceptual hierarchical SoC battery storage charging - discharging methodology process that is divided into three parts as depicted in Table II.

TABLE II. BATTERY CHARGING-DISCHARGING CONDITIONS

Relay Switches	Operation
A	Batteries' SoC = 100%
B	Batteries' SoC = 60% to 80%
C	Batteries' SoC = 40%

Figure 4 (Part A) shows the hierarchical SoC battery storage charging - discharging when the proposed methodology measures the SoC of two batteries. If both batteries' SoC is equal to 100%, battery B will be connected for discharging and will be discharged at 20% of its SoC. When the SoC of battery A is more or equal to battery B, the discharging is switched to battery A. At the same time, battery B is connected for charging only if the charging source is available. If battery B is connected to the charging process, the battery B's SoC is measured and compared with battery A's SoC. If the SoC of charging battery B is more or equal than discharging battery A's SoC (20%), battery B is switched to the discharging process. The part A methodology process only happens when both batteries' SoC are between 80% to 100%.

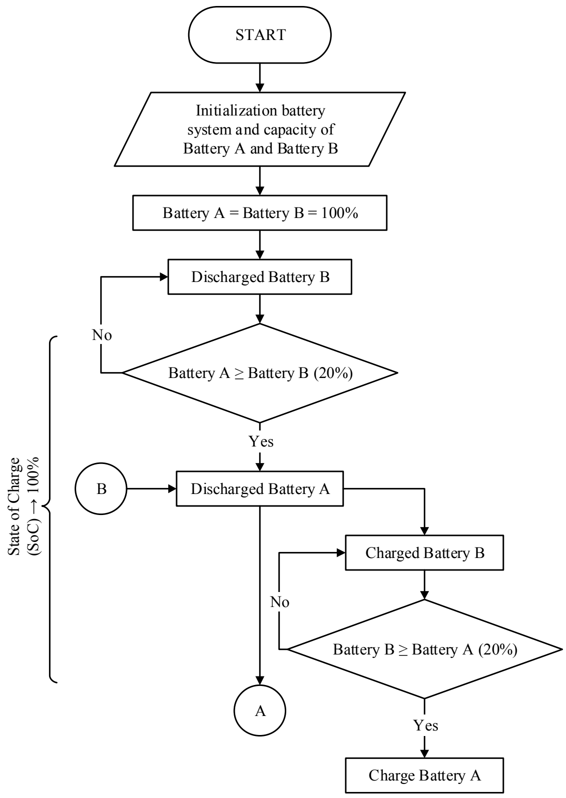

Fig. 4. Hierarchical SoC battery charging-discharging: Battery SoC = 100% (Part A).

Figure 5 (Part B) shows that the hierarchical SoC battery starts to charge/discharge when the battery' SoCs are between 60% and 80%. When battery A is being discharged, as shown in Figure 4, when the measured SoC is less or equal to battery B (20%), then discharging is switched to battery B, otherwise, it remains. Suppose the measured battery A SoC is less or equal to battery B (20%). In that case, battery B will be connected to the discharging process while battery A to the charging process, only if the charging source is available. The charging of battery A will continue until the battery A's SoC is more or equal than the 20% of discharging battery B's SoC. Additionally, if the measured battery A SoC is more than or equal to 20% of battery B at 60% SoC condition, the discharging of battery B will be switched to battery A. Battery B will be connected for the charging process when a charging source is available. During the battery B charging, the SoC of battery B will be continuously measured and compared with the SoC of battery A. If the SoC of battery B more or equal to the SoC of battery A (20%), discharging will be switched to battery B, otherwise, it remains. Figure 6 (Part C) occurs when both batteries' SoC is equal to 40%. The halt condition is required to prevent the battery from fully discharge, which will cause damage to the batteries. Therefore, the discharging process of the batteries is halted when both SoCs are equal to 40%. At the same time, battery A will also be connected to any available charging source to start charging until the SoC of both batteries is at least 60%. When both batteries' SoC is at 60%, then the hierarchical SoC battery charging/discharging methodology process is activated.

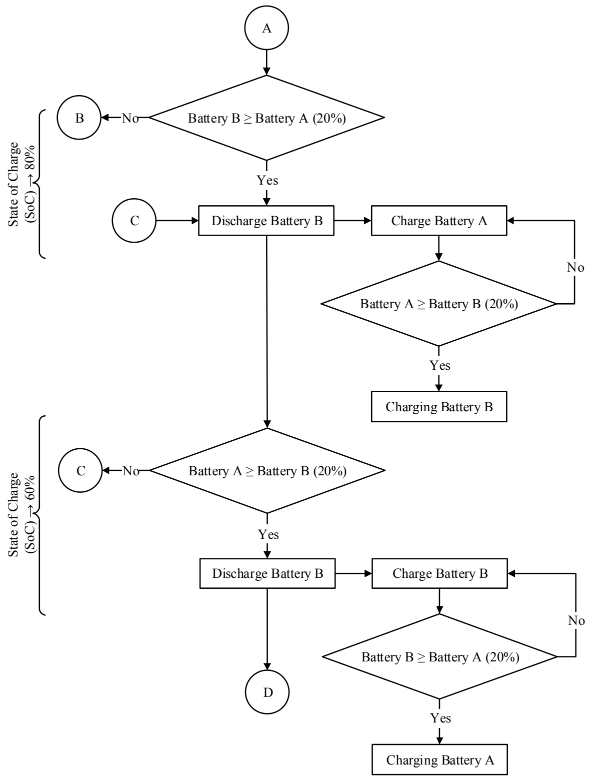

Fig. 5. Hierarchical SoC battery charging-discharging: SoC battery equal to 60% or 80% (Part B).

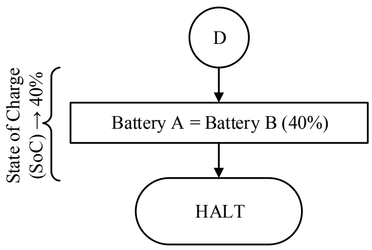

Fig. 6. Hierarchical SoC battery charging-discharging: SoC battery equal to 40% (Part C).

IV. CONCLUSION

The reviewed and presented battery storage charging - discharging methodology processes have limitations in continuous provision of power source supply to the connected load when the battery capacity is at SoC equal to 80%. Hence, the proposed hierarchical SoC battery storage charging - discharging presents the ability of the batteries to perform continuous power source supply to the connected load until their remaining SoC is equal to 40%. Also, the hierarchical SoC battery storage charging - discharging shows its ability to perform continuous battery charging when the source is available. With this ability, the hierarchical SoC battery storage charging - discharging functionality to supply power to the connected load continuously can be extended as well as maintained longer.

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