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Design and Simulation of a Hybrid Battery Charging System

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Abstract
The main purpose of this paper is to design a hybrid battery charging system. The simulation is performed in Proteus 7. The whole system is designed for charging two or more 12V lead-acid batteries at a time. For this hybrid system, the energy sources are PV array and supply from the Utility grid. The charging and discharging of batteries have been controlled by the control logic of charge controller. The controller switches between the sources and ensure the charging and discharging pattern of the batteries. This system is capable to charge a multiple number of batteries at a time by stetting the priority on the state of charge the battery. This system offers a stable energy storage operation for PV based battery sources.

Keywords: Charge Controller, Control Power Switch, Battery Charging System, Photovoltaic Panel, and State of Charge (SOC).

I. Introduction

The production and transportation of energy is playing a very important role in the technological development of a society. As the energy demands are increasing with the progress of technology, conventional energy sources are not adequate to accomplish the needs. Now it is the prime time to harvest energy from the alternative sources i.e., renewable energy sources. Renewable energy sources can be a cost effective solution for the remote areas where the access to the utility grid is difficult. But with the renewable energy sources two major area of concern are the power quality and reliability as mentioned in (A. K. Rohita *et al.*, 2017). However, a renewable energy sources with the battery storage can improve the situation. The innovation of electric vehicle with battery storage has made a huge revolution in the transportation sector. This type of system provides support in the reduction of Carbone emission on the environment, which is one of the key factors and requirements of modern technology (P. W. Parfomak., 2012). Because CO_2 emission from fossil fuels has negative impact on the environment for example the influence on global warming (G. Coppez *et al.*, 2010). The development of hybrid battery storage technique will make the utility more compact and reliable for conventional energy sources integrated with renewable energy sources. These improvements will probably decrease greenhouse effect, mitigate the power demand and cut down electricity bills.

While developing a charging system for energy storage purpose, the charging and discharging time are very crucial. According to (N. Amin *et al.*, 2017) overcharging and discharging can reduce the lifetime of a battery. Besides that, the unstable operation of the main source can damage the load. Moreover, the lifetime of a battery will be less without the charge controller.

According to (H. S. Maraud *et al.*, 2016, K. Sayed *et al.*, 2016) the battery charging system can be classified as :

- Utility Grid Based System.
- AC Generator Based System.
- DC Generator Based Charging System for fast charging (K. Sayed *et al.*, 2016).

Grid Based Battery System is most popular. However, its productivity is less because it requires huge amount of electricity and it can

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charge few batteries at a time. AC Generator Based System is feasible for remote location and for fast charging purpose. The application area of DC Generator Based System is revealed in the journal (K. Sayed *et al.,* 2016).

This paper has focused on the design and simulation of a Hybrid Battery Charging System. The objective of this design is to extend the lifetime of battery and stabilize the voltage extracted from the PV panel.

II. Battery Charging System

A. Conventional Charging System

According to (Charging Lead Acid battery, 2018), a conventional PV based battery charging system is shown in Fig. 1, where PV sources are connected in parallel. However, the major limitations are:

- Over charge flow.
- High discharge rate.
- Short lifetime.
- Long charging time.
- Possibility of explosion.

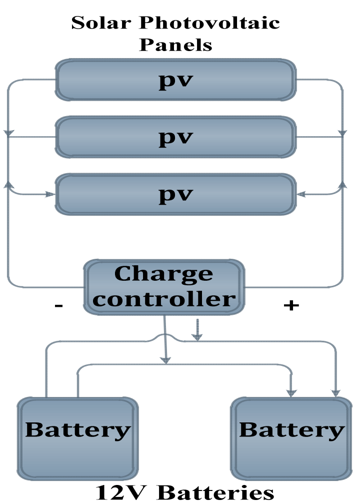

Figure 1: Conventional Charging System

B. H ybrid Charge Controller

The designed charge controller can overcome the charging and discharging problems associated with the conventional storage system. As mentioned in the article (Parallel Charging Using Multiple Controllers with Separate PV Arrays, 2018), this battery charging system will reduce the charging and discharging time and draw the desired current from the PV's. This system is modeled considering a 12V battery as the charging unit. The basic functionality of the charge controller is:

- To sustain highest possible SOC.
- To protect the battery from overcharging.
- To disconnect the battery to protect from deep discharging.
- To control the state of charge of the battery in the ideal case. This will prevent from continuous rate of change flow if the battery is over charged.

This system will address the problems as mention in (C. Simpson *et al.*, 2018).

III. Simulation Model of the System

The complete block diagram of the proposed system is shown in Fig. 2.

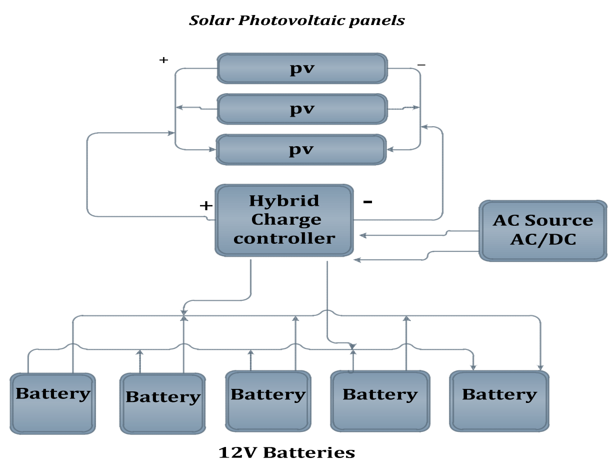

Figure 2: Block representation of Proposed Hybrid Charging System

The charge controller can select any of the two inputs (PV system or AC source) to charge a particular battery. In this design, PV system has been considered as the primary source and AC source as the backup source. According to (J. Yan, 2017), the PVs can be arranged in series parallel manner, to get the desire voltage and current levels.

A simulation model is developed in Proteus 7, which is shown in Fig. 3. Two 12V batteries have been considered with load-connected operation.

The charge controller will cut down the load when the battery voltage goes down below 11.5V. It is possible to charge the battery as long as the voltage level is in between bellow 12.5V to 12.55V. For simulation, lead-acid battery has been considered which should not discharge below 80% when load is off (D. Pavlov *et al.*, 2011, High-Side Current-Sense Measurement: Circuits and Principles, 2018).

The SOC rate of the batteries used in this model is given in Table 1. In the journal (D. Pavlov *et al.*, 2011) the charge controller has indicated the fully charged state when the battery voltage is at 14.1V. But in our proposed charge controller the fully charge state is indicated at 12.55V. It is the actual full charge ratio of our system. Similarly, to prevent from very low discharge usually the level should be at 11.5V, but in this case, it has been indicated at 11.45V. At this voltage, the battery will automatically start to charge from the controller. Thus, the charging time will be decreased and the battery performance will be increased. This system will provide uninterrupted power supply to the load with the proper utilization of PV source.

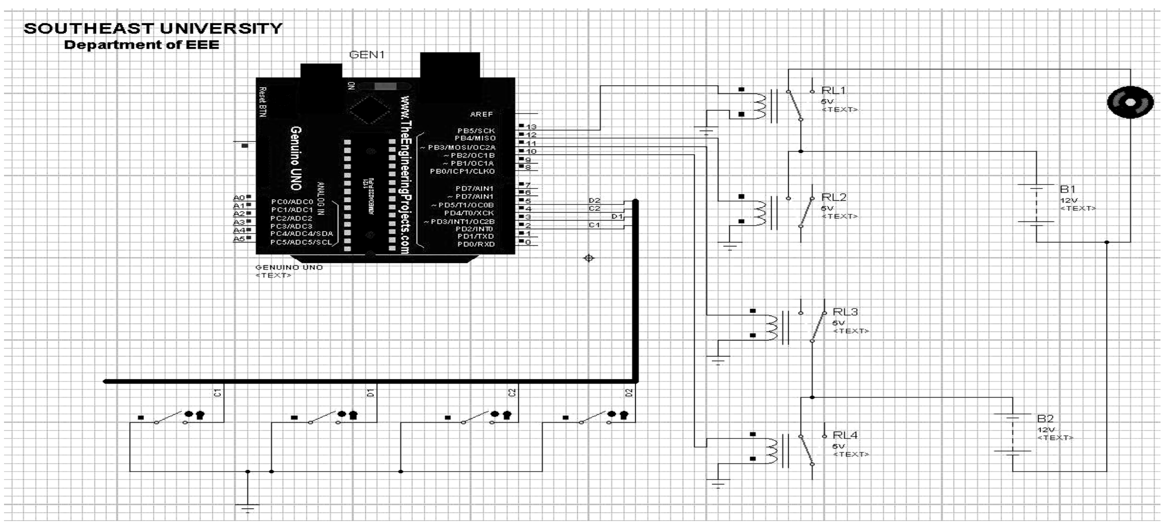

Figure 3: Simulation Model

Table 1: State of Charge Rete

Percentage of Charge	Voltage Rating
20%	11.45-50
40%	11.55
50%	11.65
55%	11.75
60%	11.95
70%	12.1
75%	12.2
80%	12.25
85%	12.3
90%	12.35
95%	12.40
100%	12.5-12.55

The standard features are overcharge protection, low voltage disconnection, low load disconnection, high voltage disconnection. The functionality of the proposed system is chosen according to features highlighted in the article (Charging Lead Acid battery, 2018).

- The batteries can be connected to the high current terminal and withstand at least 20A at 20V (C. L. Liu *et al.*, 2013).
- To analyze the power flow from the input to the output side of the system provision is there to measure voltage, current and power.
- Over current and short circuit current monitoring mechanism in there in this system.

Condition monitoring and estimation of the remaining charge storage is available in the system.

IV. Operating Method of the System

The charging process of a battery is performed in three stages (Charging Lead Acid battery, 2018):

- Constant-Current Charging.
- Topping Charging.
- Float Charging.

The battery can get substantial amount of charge in Constant Current Charging State. It can be overcharged to some extent but the current starts to decline in Topping Charging Stage. This is important for recharging the battery to its actual capacity of 100%. Self-discharge is compensated during the last stage (C. Simpson *et al.*, 2018). The simulation model runs with the help of certain algorithms.

A. Algorithm for Charging State Detection

The charging state algorithm is given in Fig. 4, which represents the voltage level and current level of individual cell with the help of corresponding generated PWM signals. At the beginning when the batteries are started to charge, the controller examines the SOC of the batteries i.e. whether a particular battery is at high, medium, low, or very low SOC. Then it selects the battery to charge. Different PWM signals will be generated for different SOCs of the battery. If any of the battery is damaged, the controller will provide signal to replace the battery. It will also analyze connection of the batteries whether a particular battery is properly connected or empty. The charge controller can be planned in several stages.

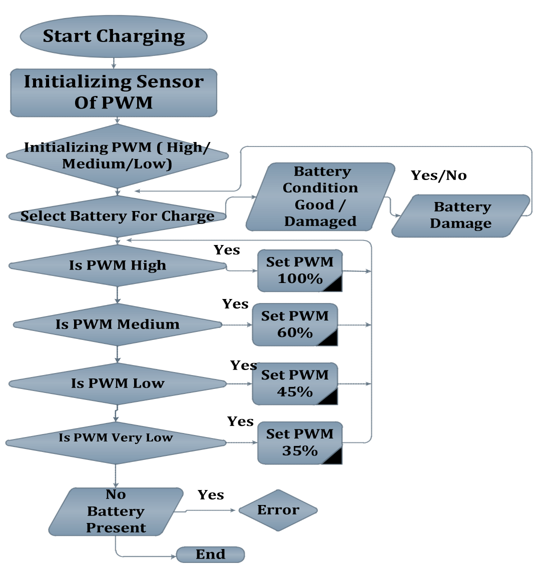

Figure 4: Algorithm for Charging State

When a single battery is loaded and voltage goes down below 11.45 V, the controller sends the signal to disconnect the load from the battery. It is possible to charge that battery continuously until the voltage is above 12.55V. The controller indicates the battery voltage HIGH when, the battery termination voltage is about 12.5V to 12.55V. A 12V Lead-acid battery should not be charged more than 12.55V for a longer period of time and also maintain the temperature level which can be found from the temperature data sheet of the battery (Design Guide for 12V Systems – Dual Batteries, Solar Panels and Inverters, 2018).

B. *Charging and Discharging Algorithm*

The charging and discharging algorithm of the control logic unit is shown in Fig. 6. The algorithm is developed based on the charging and discharging procedures of the batteries as shown in Fig. 5. After having fully charged, the battery No-2 will wait for the discharging signal from the controller. Then the battery No-3 will start to charge and continue to charge the incoming batteries. For discharging operation, the controller will select the battery with highest amount of charge that is battery No-1 in this case. Then it will discharge battery No-2 and continue to discharge the incoming batteries.

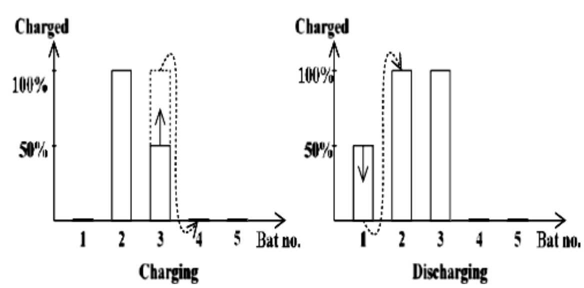

Figure 5: Charging and Discharging Procedures of the Batteries

As shown in Fig. 6 initially, the control logic unit senses the amount of charge from the incoming battery. Based on that information, the charge control and load distribution panel make the final decision of charging or discharging of the battery. The control power switch is ON for the incoming charging battery. The measuring unit will ensure the proper SOC for each charging battery. When the battery is fully charged, it will go to the return stage. When the control power switch is ON for the discharging battery, the load is connected with the battery and discharges it. The SOC should not be less than 40% else, the battery will be disconnected from the load and it will need to go through the charging steps again. When the battery is fully charged, it will go to the return stage and wait for the discharging process again.

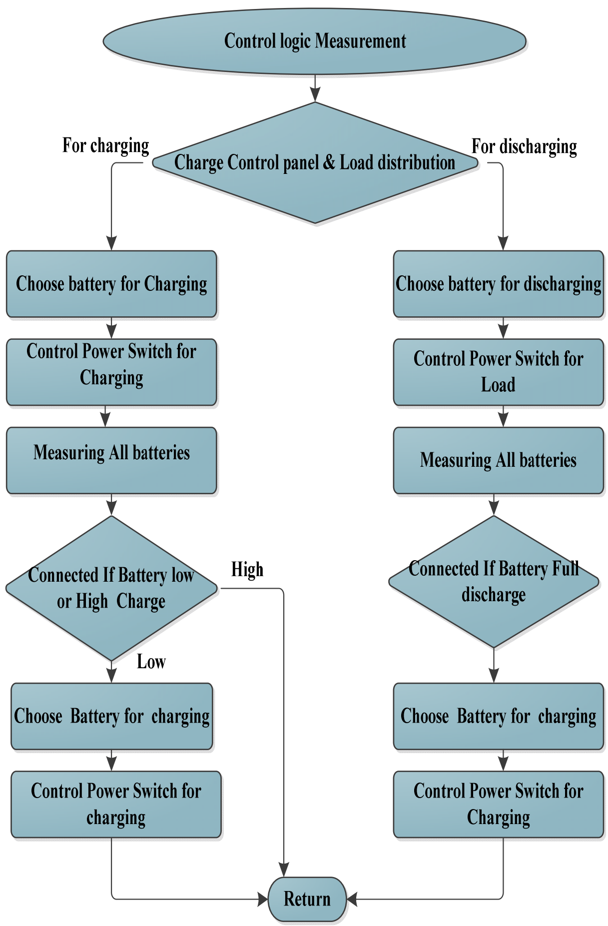

Figure 6: Charging and Discharging Algorithm

V. Result Analysis

The charging response of the simulation model is shown in Fig.7. The PV system only operates during 0 to 41minutes. After 5 minutes, the charge controller connects the battery No-1 to charge as it is the only empty batter of that point of time.

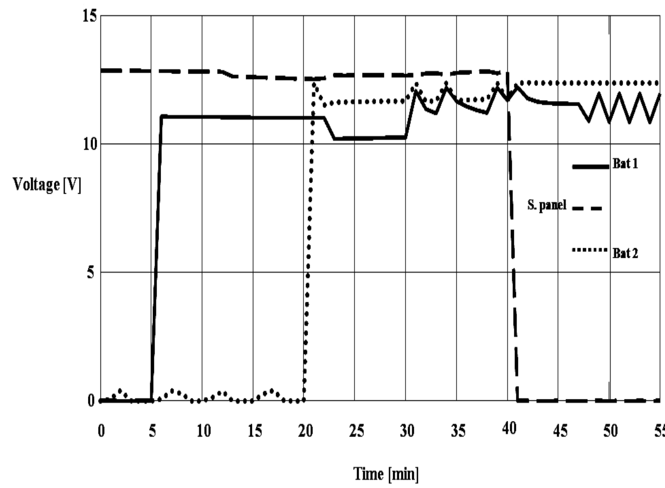

Figure 7: Analysis of Charging Operation of Batteries

Voltage across its terminal is constant during 5–12 minutes. At 12 minute, the load is connected across its terminal and a significant amount of discharge is noted at 23 minute. It has been observed that at 20 minute, the controller selects battery No-2 to deliver energy to the load. During the period of 20–30 minutes, the charge controller choses battery No-1 to charge again as its voltage is going down. During the period of 30–40 minutes, the battery No-1 is chosen over battery No-2 because of its high amount of charge by the controller and fall down below the threshold for fully charged battery frequently. During 40–47 minutes as battery No-2 is the only left, it is connected and started to charging. There is fluctuation of voltage levels of battery No-1 between 48 to 55 minutes because the battery continued to rise above and fall below the threshold for fully charged battery.

Following observation can be made from the simulation:

- It has the capabilities to connect and disconnect the batteries properly.
- The controller can generate disconnection signal for the PV system when it is connected with the load.
- It is found that, there is proportional relation between measured current and load power, which is expected.

Table 2: State of Discharge Rete and Voltage regulation

Time [min]	On Load V1	Off Load V2	Regulations
5	12.55	12.55	0
7	12.19	12.55	2.95%
10	12.17	12.48	2.55%
15	12.16	12.46	2.47%
18	12.14	12.44	2.47%
22	12.11	12.41	2.48%
25	12.09	12.39	2.48%
27	12.06	12.38	2.65%
31	12.03	12.35	2.66%
33	12.02	12.28	2.16%
35	12.01	12.29	2.33%
38	11.96	12.28	2.68%
41	11.93	12.25	2.68%
44	11.9	12.22	2.69%
45	11.87	12.17	2.53%
49	11.84	12.18	2.87%
50	11.79	12.12	2.80%
53	11.76	12.11	2.98%
55	11.74	12.07	2.81%
58	11.7	12.04	2.91%
60	11.68	12.02	2.91%

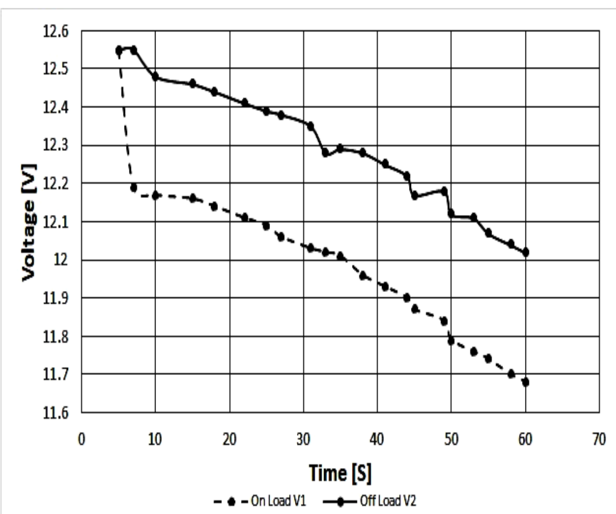

Figure 8: State of Battery Discharge Operation

The state of battery discharging operation simulation is done in "Chroma Soft". The data of the simulation is shown in Table 2. A graph of state of discharging is shown in Fig. 8. The system performed as it is expected. The voltage regulation varies between 0 to 2.95%.

VI. Conclusion

The design mechanism used in this paper can be used to charge a multiple numbers of batteries. From the simulation result, it has been observed that the batteries are charging effectively. The controller can detect the connectivity of the battery automatically and send a signal accordingly. Through this system, it will be possible to use older batteries together. In that case, there will be no need to change new batteries by replacing the old batteries as their capabilities fall below desired level. A prototype can be modeled based on this simulation. In that case, a protection system will be considered to protect the hardware from short-circuit and overheating of the battery. A protection against transient over voltage and reversal of batter will be introduced in future for the prototype design. This type of system can be implemented for the electric vehicle charging station and telecommunication based equipment charging system.

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