Implementation of Battery Management System with State-of-Charge estimation (SOC) and equalization based on Modified DC/DC converter Topology

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Abstract- **In this Paper, to maintain the reliability of the Battery, state monitoring and evaluated by a sensing device that have implemented in this proposed technique. For equalization purpose Bi-directional DC/DC converter is used while the switching losses is reduced and boosts the performance during equalization period. The paper includes the development of the power electronic switching devices and State-of-Charge algorithm for improving battery charging/discharging performance and efficient utilization. To design the simulation modelling of a Battery pack with a charge module and expectation outcome for the charge equalization topology using MATLAB/ Simulink software to demonstrate the capability, voltage and current stability of the Battery stack.**

Keywords- **Battery Management System (BMS), Lead-Acid batteries, DC/DC converter, Charge equalization system, State-of-Charge (SOC) Estimation.**

I. INTRODUCTION

An electric battery is a device consisting of one or more group of electrochemical cells that converts store chemical into electrical energy is known as a Battery. Every portable electrical/ electronic device uses a secondary Battery to meet up its energy needs. For example, batteries are used in Personal Computers, laptops, emergency lights, electric vehicles, power industries etc. Accessibility of energy storage units are alkaline batteries, zinc-carbon batteries, Lead-Acid, mercury batteries, lithium batteries etc. Each batteries have a different capacity depends on industrialized tolerances, aging and environmental surroundings. In series connected Batteries after several charging and discharging the battery cells tends to out of the balance in form of uneven voltage and current parameters. A BMS may monitor the state of the Battery as represent the State-of-Charge (SOC) and Depth of Discharge (DOD) to indicate the charge level of the Battery. State of Health is indicating the determination of overall condition of the Battery. Fig. 1 shows the charging characteristics of a Battery. For charging the Lead-Acid Battery has different operating modes and the curve is denoting the regulated voltage and current respectively. For Battery charging one of the schemes is used it depends upon the application and features of a Battery, commercially the Open Circuit Voltage (OCV) is used for charging the Lead-Acid Battery. There are different topologies for Battery management fall in three categories. A single controller is connected to the Battery cells in a centralized stage. In a distributed stage a particular communication cable between the Battery and a controller. In a modular topology a few controllers each are handling a certain quantity of cells, communication between the controllers.

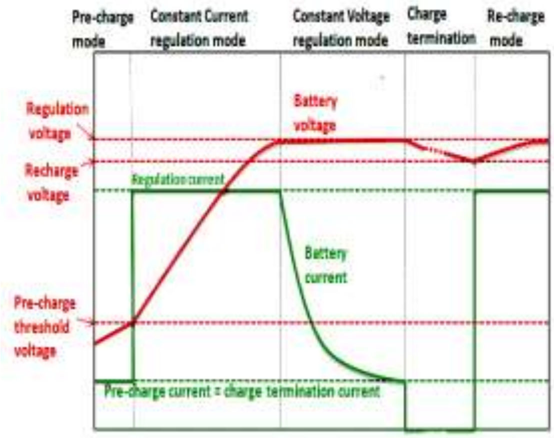


Fig. 1 Charging Characteristics of a Battery

The main objectives of the Battery stack with management system are:

- Protect the Battery beside any fault condition;
- Prolong the Battery;
- Sustain the Battery in a state in which it can fulfil the functional requirements of the application specified.

In this paper, a Battery having lower State-of-Charge is consider as a weak state, and another Battery having higher State-of-Charge is considered as a strong state. A master controller sense by using sensors which the Battery have lower SOC and it transmit the corresponding signal to the control circuit and it transfer the power to weak module collected from storage element.

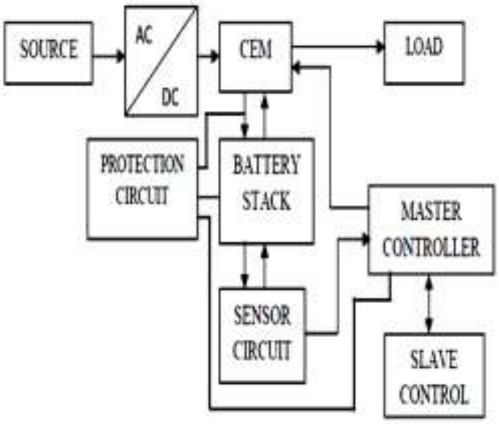


Fig. 2 Block Representation of BMS

Fig. 2 illustrates the block representation of a proposed scheme. The control circuits having a Bidirectional DC/DC Converter for smooth energy transfer and the external signal from keyboard is used for switching the equalization process.

The contexts of this paper are organized as follows: The conventional proposed Schemes are described in section II. Design and implementation of a proposed scheme is described in section III. Modelling of Battery pack with individual equalization module and obtained results includes the balanced state of individual Batteries in terms of State-of-Charge (%) are described in section IV, and followed by conclusion in section V.

II. CONVENTIONAL PROPOSED SCHEMES

A Battery Management System uses charge equalization for balancing stack of Battery and estimate the State-of-Charge (SOC). They are numerous conventional methods for equalization. Basically the two methods are:

- Active charge equalization and
- Passive charge equalization

Passive charge equalization contain a dissipative element (resistors, transistors etc) is connected as a shunt with Battery for drain the extra energy in the cell. This type of equalization is also known as dissipative charge equalization method. Active charge equalization contains a non-dissipative element (capacitor, reactor etc) is used to transfer the energy from one cell to another. Hence it is also known as non-dissipative charge equalization. In resistive shunt equalization the shunt resistor should bypass the charging current the main drawback of this method the extra power is dissipate in resistive element so the dissipative loss effect the charging characteristics of a battery. In analog shunt the transistor connected with the individual battery arrangement the resistor plays a major role for bypass the circuit to ON the comparator the zener diode will stabilise the comparator voltage thelimitation of the system is the resistor plays a critical state.

The Active Equalization having different topologies such as switched capacitor, multi winding, bi-directional DC/DC converter, resonant equalization, switched reactor etc., The limitation of switched capacitor topology is does not consider the reference voltage as long as equalization period. The individual cell equalizer is connected individually in batteries for smooth transfer and this scheme will reduce the current ripple.

In this paper proposed that Bi-directional DC/DC converter is a charge equalization module used for energy transfer from storage element to a weak module. The sensing devices examine the voltage and current in a Battery stack as shown in Fig. 2. The protection device for each individual Battery manages against over voltage/under voltage. The architecture arrangement of proposed Battery Management System using Modified Bi-directional DC/DC converter Topology is described in [12]. Many different schemes for equalization are shown as: In a resonant equalization the composed components of inductor and capacitor is shown in Fig. 3. It takes place in parallel for transferring the energy [2], [9]. The determination of SOC is decided by fuzzy logic control is recommended that speed of equalization and performance is too low for practically.

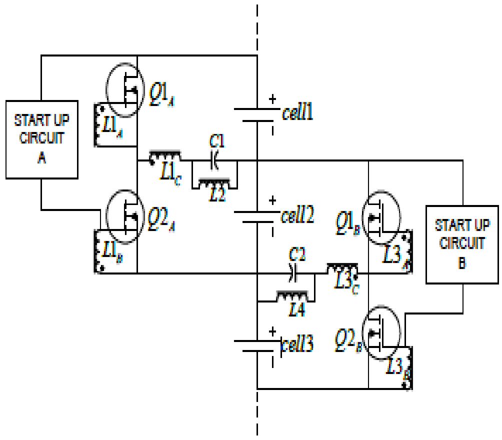


Fig. 3 Resonant Equalization

By using super capacitor and during discharging the power transfer from strong to weak module by using bi-directional DC/DC converter for zero current switching in the capacitor module the controller sends the pulse if any unbalance occur to the switching device. This scheme is implemented in resonant system in Fig. 3. The amplitude of the current in the inductor L1 can be expressed in (1).

$$I_{m1} = \frac{V_{C11} - V_{B2}}{\omega L_1} = (V_{C11} - V_{B2})\sqrt{\frac{C_1}{L_1}} \tag{1}$$

$$V_c = V_{c1min} \leq V_{B2} \tag{2}$$

$$V_{c1} = V_{c1max} \geq V_{B1} \tag{3}$$

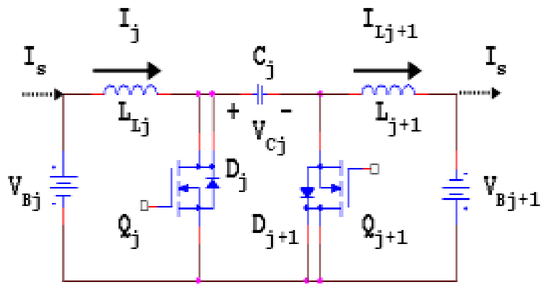
The inequality conditions of a battery expression is been explained in (2) and (3) is described in [11] and controlling the State-of-Charge of a Battery the time taken for equalization is long and while large stack it tends to imbalance. Another approach for equalization by using hybrid energy storage element the connection of capacitor is different in each topology is described in [4].However due to the complicated of the electrochemical description the optimal charging control is difficult to obtain [10]. The cost function decided the charging and capacity of a Battery expression of normalized cost function is shown in (2).

$$\text{Normalization}_i = \alpha \times \left(\frac{C_{i\_step}}{C_{i\_CC/CV}}\right) + \beta \times \left(\min\_C + \left(\frac{\max\_T - T_i}{\max\_T - \min\_T}\right) \times (\max\_C - \min\_C)\right). \quad (2)$$

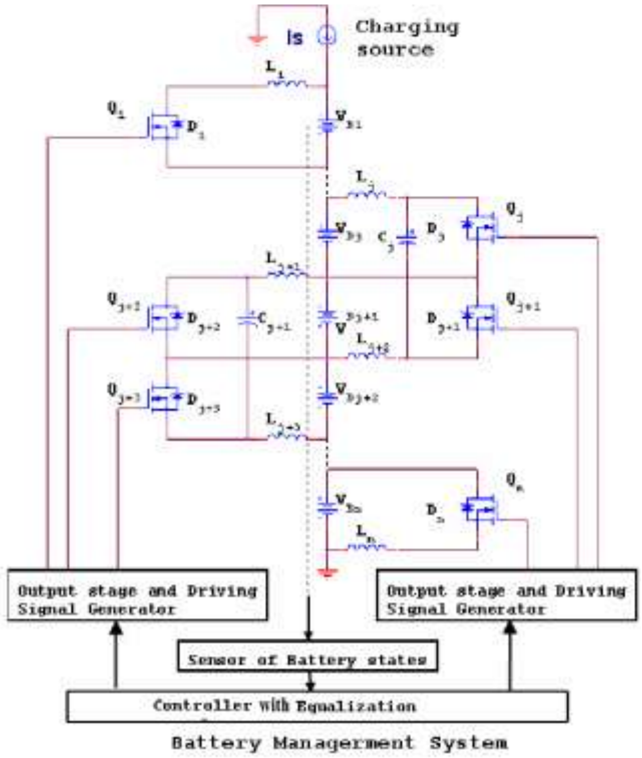
Due to different ampere hour rating of stack is difficult for monitoring of the SOC of a Battery [1]. For linear programming it limits the direct power consumption to a determined system level have low timing criticality [5]. Diagnosis of estimation algorithm measurement data is corrupted by noises. Results the soc determined upon the derivative basis [13]. Another approach by Kalman filter to minimize the square error using mathematical model but this model is complex [6]. In [3] the charge equalization having a multi winding transformer topology with filter having multiple number of core winding is reducing the forward converter topology. The main drawback of this scheme the transformer has leakage inductance while conversion to reduce the real power. The estimation of SOC via ac impedance method means the ac signal is injected throughout a generator the duty cycle of the power converter is used for synchronization. This system is a Deriving method and it takes a lengthy duration for determine the quantization error and the Battery impedance [8]. The paper proposed that the determination of SOC of a Battery using sensing devices it monitor the voltage and current individually, the sensing signals given to the controller via sensor cables.

III. OPERATING PRINCIPLE

As aforementioned, in Battery powered device a DC/DC power converter is usually used to interface the Battery and the load in the order for regulated voltage and current. The bi-directional DC/DC converter operates as a boost converter during charging/ discharging condition. In many applications DC/DC converter in command to allow for simultaneously charge and discharge operation of the Battery system. The architectural arrangement of proposed Battery Management System is described in [12]. Thus the Bi-directional converter topology the equalization control is to speed up the equalization process for a Battery Management System.



(a)



(b)

Fig. 3 Battery Management System: (a) Proposed ICE DC/DC converter, (b) Architecture of BMS with Individual Cell Equalizer

The PWM signals correspond to the respective cell voltage through the ARM processor based BMS is shown in Fig. 3(a), which controls the switches Q_j and $Q_{j+1.}$ The initial capacitor voltage equals the two adjoining batteries. For example Q_{j+1} get the signal from the controller the stronger Battery voltage is given to the weak Battery module. The equalization development will be continuous until the voltages in the remaining batteries are all steady to the same end-of-charge level. The system is mainly designed for operating both continuous and discontinuous mode. The single stage of the proposed modified CUK DC/DC converter having two inductors L1 and L2, and an energy transfer component capacitor shown in Fig. 3. This technique is guided by ARM processor based BMS. The expression of time average of voltage is denoted as V_{cj} and V_{dj+1} is in (3) and (4).

$$Vcj = \frac{T_s}{2C_j} I_j(1-D)\,(1-D+D_1) \qquad (3)$$

$$V_{Dj+1} = -\frac{T_s}{2C_j} I_j(1-D)\,D_1 \qquad (4)$$

Where T_s denotes the switching period of the converter and the duty cycle of the generated pulses is denoted as D. The notations are all indicate in the converter model and this system is briefly explained in [12]. The energy transferring takes place between two adjoining cells by capacitor. By switching the MOSFETs on/off the voltage of adjoining Battery voltage are balanced considerably. The PWM generator generates the switching pulses and the controller decides which chare module is required the pulse for switching the MOSFET.

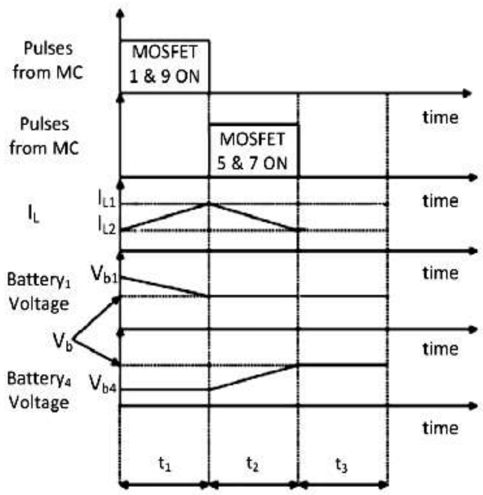


Fig. 4 Timing Diagram amid Two Batteries

The Timing Diagram represents the energy transfer from one Battery to another Battery controlled by master controller. Simply that the charge equalization is decided by the size of an inductor. Because the energy is collected from inductor and the stored energy is transferred to the Battery is explained in [2].

The expression of Battery nominal voltage is:

V=2*L*Ieq*f (5)

This topology is working underneath the voltage sense of balance control algorithm. The control sequence of the charging and discharging of the proposed scheme is understood by flow chart in Fig. 11.

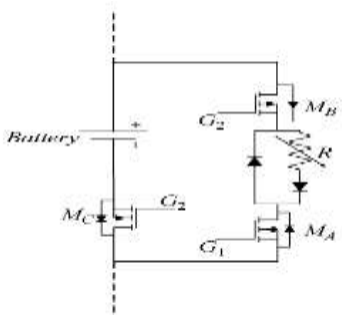


Fig. 5 Protection circuit against over voltage and under voltage

The major concern for reliability for a system requires the voltage across a Battery is always operate within a safe operating area (SOA) using protection circuit is shown in below Fig. 5. The Resistor R plays a major role for bypass the excess current; the selection of R is essential because in excess voltage occurs the heat will develop in the shunt resistor it effects the characteristics of a battery. The threshold voltage is takes as a reference voltage in controller. It monitors the Battery voltage it exceeds the error signal should switch the MOSFETs. The value of Resistor is determined to bypass the whole charging current is explained in [7].

IV. SIMULATION AND RESULTS

In order to validate the performance of proposed DC/DC converter demonstrates were carried out two Lead-Acid batteries with two equalizer modules are shown in Fig. 5. The experimental results described the Battery at balanced condition. While charging/discharging condition the Battery nominal voltage is an equal. For the simulation purpose the Lead-Acid Battery is been configured the discharging characteristics of a 6Volt and 12Volt Battery is shown in the Fig. 7. The switching sequence of the MOSFETs is decided by a control signal from the processor. In modelling the pulse generator is developed by delay timers. The configuration of delay timers is depends the duty cycle and their expectation of output obtained. Lead Acid batteries are serving as the energy storage unit, power generating unit and charge unit by the converter. Fig. 12 shows the simulation results of voltage and current waveforms. Run the configuration model at time is considered at one second (T=1SEC). While charging condition the amplitude across the capacitor and voltage across inductor V_l=25.78v experimentally.

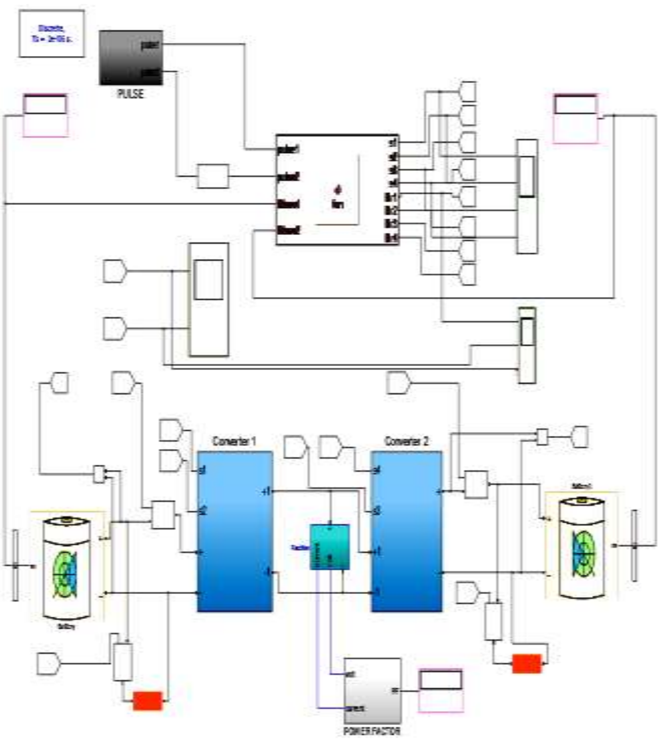


Fig. 6 Configuration of Proposed Scheme

Design the parameters based on Battery type and nominal values parameter to edit the discharge characteristics is shown in Fig. 8. We absorbed that the discharge characteristics of a Lead-Acid battery is shown in Fig. 8.

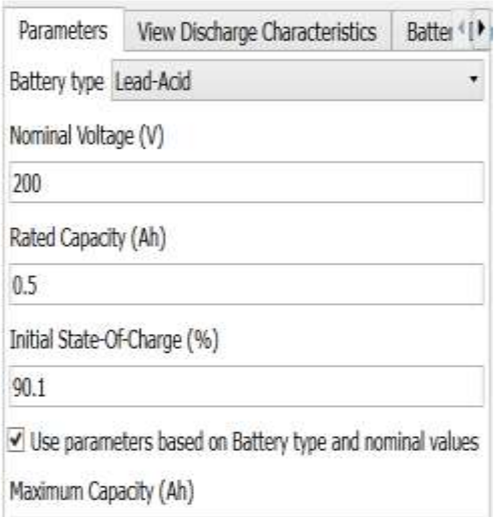


Fig. 7 Parameter Modelling of a Battery

The charge equalization is decided by switching pulses given to the switching circuitry. The parameter while design the pulses consider which type of delay is suitable. The modelling of modified cuk DC/DC converter is shown in Fig 9.

The proposed charge equalization topology is designed using MATLAB/Simulink and the results are been Figured. In this converter the port numbers 1 and 2 is a Battery terminal voltage and 3 and 4 denotes the input source of the system and the corresponding switching pulses are shown in Fig 9.

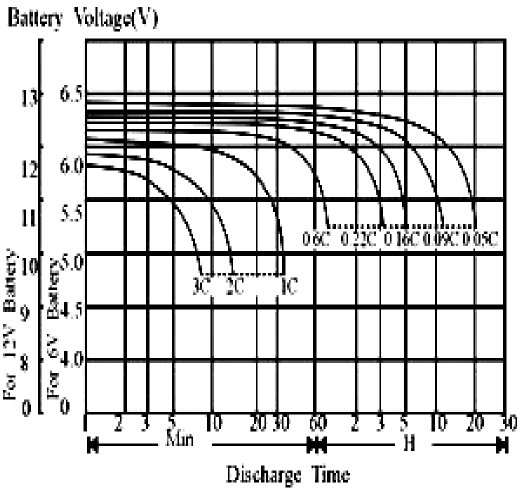


Fig. 8 Discharging characteristics of a 6Volt & 12Volt Battery

In advanced monitoring the operation of the stack of Battery is known as Data Acquisition control using Battery Management Software installed in Personal Computer.

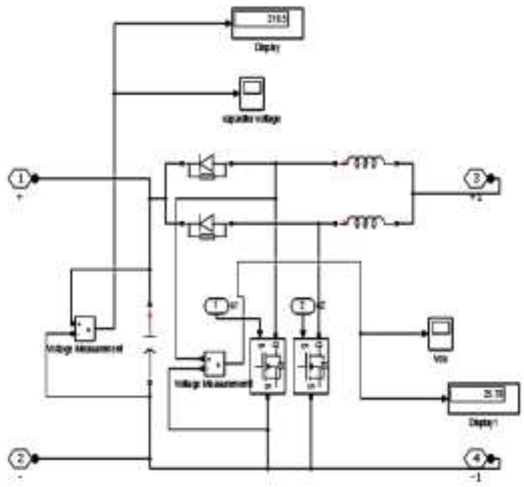


Fig. 9 Modelling of Converter Topology

The corresponding capacitor voltage waveform is denoted as Fig. 12a. The cell balancing is achieved at V_c=216.5v. The balanced condition is stopped when the voltage across the Battery is equalized to the same end-of-charge state. The terminal voltage of the Battery pack is depends upon the duty cycle of the control signal for switching the MOSFETs in a Bi-directional DC/DC converter. The control strategy of the switching sequence of the converter can be examined by the control logic flow chart is shown in below Fig. 11.

If the State-of-Charge of the Battery1 is smaller than reference voltage 90v, the pulses p1 and p2 should trigger the s1 and s2 of MOSFET switches. Similarly the SOC of the Battery2 as BtSOC2<=90 the controller sends the pulses to trigger the MOSFET switches s3 and s4. While using circuit breaker the value of Br3 and Br4 is assumed as zero.

Table 10. Parameter modelling of pulse generator

Amplitude	1
Period (secs)	1/1e3
Pulse width	50
Phase delay	0

The switching pulses are generated by pulse generator; the parameter model is shown in Table 10. The output of the generator is a control signal for trigger the MOSFETs switches controlled by a master controller. Depends upon the present state of condition the controller sends the control signals to the equalization module the sensing device is always monitor the condition of the Battery interface with processor.

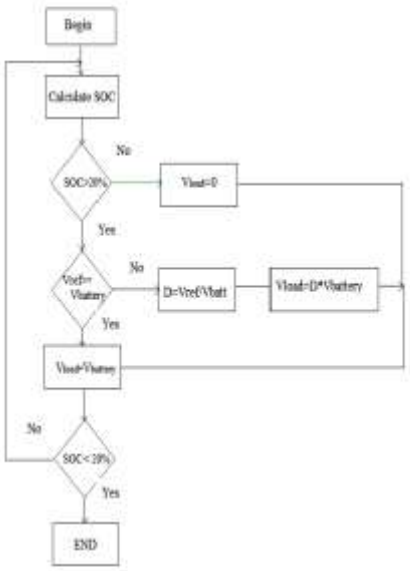
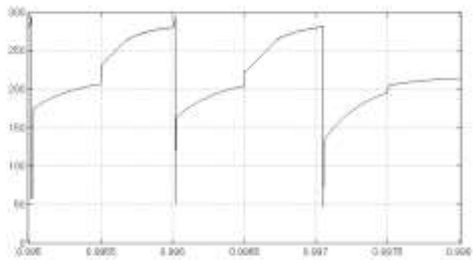


Fig. 11 Flow chart of control logic

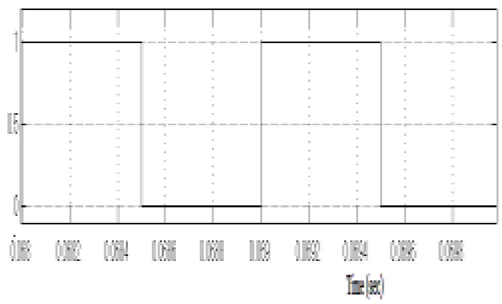
In Fig. 12a, denotes the capacitor voltage while Battery is at charging condition it explains that the capacitor voltage is zero (V_c=0) previously charged voltage is applied to weak Battery module for balance condition and once again the capacitor starts charging. The control logic diagram is explained that the SOC of a Battery is beyond the limit as 20% of the Battery capacity the equalization module starts the equalization process until the Battery stack tends to balanced. Once the equalization process is ON it operates until the Battery gets balanced. The Battery response time is set to 1e-6. The current State-of-Charge (SOC) of a Battery can be calculated from the data acquirement is simulated shown in Table 13.

The initial state of the Battery is calculated by using below SOC Equation in (6).

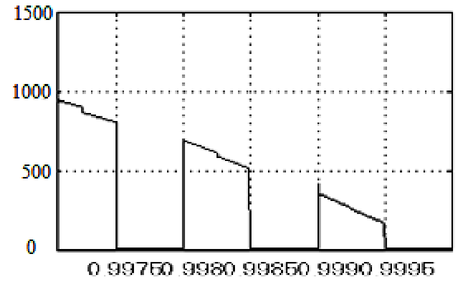
$$SOC(\%) = \frac{AHcapacity \times \frac{Initial\ SOC(\%)}{100} - \int_{t_0}^{t} \frac{I\,dt}{3600}}{AHcapacity} \times 100 \quad (4.1) \qquad (6)$$



(a)



(b)



(c)

Fig. 12 Simulation output waveforms: (a) capacitor voltage while Battery is charging. (b) Voltage across between gate-source of MOSFETs. (c) Inductor current while charging condition.

Table 13. SOC (%) Vs Open Circuit Voltage for a 6 Volt Battery

SOC (%)	Open Circuit Voltage (volts)	
	Cell Voltage	6 V Battery
100	2.12	6.37
90	2.10	6.31
80	2.08	6.25
70	2.06	6.19
60	2.04	6.12
50	2.01	6.0

Finally, simulate the configuration model of a proposed scheme the two Lead-Acid batteries are balanced at the State-of-Charge is 90% at the unity power factor is shown in Fig. 14.

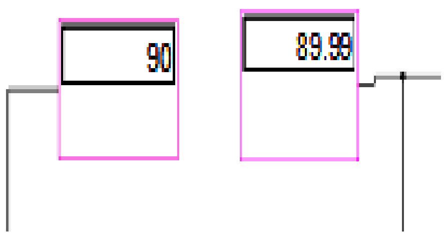


Fig. 14 Balanced SOC (%) stage of a Battery

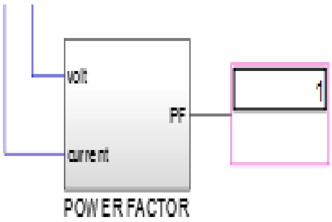


Fig. 15 Power Factor monitor model

Similarly the different values of State-of-Charge SOC (%) and the corresponding cell voltage for 6Volt Lead-Acid Battery is shown in Table 12. By the simulation approach the system operates at unity power factor but in practical the power factor is always a phase angle difference between voltage and current the display of power factor by the way of simulation is shown in below Fig. 15.

V. CONCLUSION

In this paper, the proposed Battery Management System has been developed using adjoining Lead-Acid Batteries, which can perform the charge equalization and by theoretical explanation for protecting energy storage device against over voltage and under voltage. The feature of the proposed scheme the life of the Battery and reliability is also improved and it operates within the Safe Operating Area (SOA) to prevent the sulfation effect. Moreover the description of convectional schemes and attempt to conquer the drawbacks by using developed Battery Management System the proposed scheme should serving a Bi-directional DC/DC Converter as a charge equalization for energy transfer from strong Battery module to weak module. The State-of-Charge (SOC) estimation to monitor the voltage and current in an individual Battery using a sensing device and the master controller monitor the State-of-Charge of a Battery and generate the corresponding pulses for switching the MOSFETs. Simulation process is done by using adjoined Lead-Acid Batteries and the various output waveforms while charging and discharging state of Modified Bi-directional DC/DC converter.

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