Simulation of Battery Management System for Protection in Electric Vehicle Against the Battery Failures

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Abstract The developed industries are heading toward the success path, where every industry researches and develops new gadgets to make day-to-day life more reliable and accessible. It can also be said that changes and developments in life bring positive merits with some negative merits too. Similarly, observing the automotive industry, it can be easily noticed how hard these industries have worked for a long time. Bringing the internal combustion engine to market and efficiently using available fuel was a good achievement. However, due to the increase in air and noise pollution rate from internal combustion engine vehicles, hybrid electric vehicles were developed by using both conventional fuel and electricity, which has drastically decreased air and noise pollution but could not reduce it to zero. So, after hybrid electric vehicles, electric vehicles are developed which are working on batteries. The main merits points of electric vehicles are that it doesn't cause any harm to the environment, have less maintenance cost, and have high reliability. The de-merits are chances of battery failure or cells used, which leads to fire hazards. As it's not easy to handle batteries if it fails, and the results can be dangerous. This paper will define the basic idea of what a battery is, the types of batteries, how batteries fail, the consequences of the battery failure, and the battery management system and thermal protection method. The battery management system is simulated in MATLAB to take care of the battery for complete protection as it will protect the battery from overvoltage, undervoltage, and temperature rise.

Keywords Battery management system · Battery · Battery failure · Battery protection

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S. K. Goyal et al. (eds.), *Flexible Electronics for Electric Vehicles*, Lecture Notes in Electrical Engineering 1065, https://doi.org/10.1007/978-981-99-4795-9_52

1 Introduction

Energy generation was generally dependent on fossil fuels and various renewable energy sources. The energy demand is increasing daily due to population and industrial development, and providing energy instantly and efficiently after the generation from grids was difficult [1]. Many problems and challenges have arisen for the operators in the smart grids, such as the increase in the frequency variation, reduction in the transient voltage, reliability, and decrease in power quality due to the high penetration of unreliable and unbalanced Renewable Energy sources [2]. These issues were a significant concern, and the solution was to separate energy generation from energy demand. This was possible when the Energy Storage System (ESS) approach was adopted with auxiliary facilities. In ESS, the vital role was played by the battery energy storage system. The invention of the battery was in 1859 by Gaston Planté of France [3]. The battery was the device that had several advantages, which are as follows:

- Long-life cycle.
- High abilities to charge and discharge rates.
- Storage size.
- Rate of discharging.
- A small amount of conditions maintenance.
- Quick response.

Due to these advantages, the need for a battery is increasing, which adds one more merit point to it, i.e., the cost of batteries is cheaper [4].

Like the energy generating industry, the automotive industry is now using batteries. Earlier, the batteries used in the vehicle were to provide energy to the small component installed in the vehicle, for example, the lights, media player, etc. With such good reliability, it has been used in electric vehicles as a good source [5]. Installing the batteries in a vehicle reduces air and noise pollution increases the vehicle's efficiency with techniques like regenerative braking, and reduces the dependency on non-renewable fuels like petrol, diesel, and CNG [6]. Such a development has made a significant impact on industries. Then there are still some loopholes where batteries are lagging, have issues to resolve, and need to focus on development. This paper explains the battery, type of batteries, battery and cell failure reasons, and consequences of a battery failure. To all these concerns, the solution is provided by proposing two different types of BMS methods for the battery's protection. BMS is simulated in MATLAB to take care of the battery for complete protection as it will protect it from overvoltage, Undervoltage, and temperature rise.

2 Battery

Cells are the smallest electrochemical unit and deliver a voltage that depends on cell chemistry. There are two types of cells: primary (single use) and secondary (rechargeable). Batteries and battery packs are made up of a group of cells. When cells are wired either in series or in parallel or both forms a battery pack. For example, automotive 12 V lead-acid batteries comprise six 2 V cells in series. Sometimes connections can be externals as per need. There are types of batteries according to efficiency, life cycle, voltage, charging, and discharging. The different battery types are differentiated. Still, the research is going on batteries for three more reliability, but these are types of batteries listed below, which are commonly used in an electric vehicle for energy purposes. Some examples are Lead-acid batteries, Lithium polymer, Lithium Phosphate, and Nickel Metal Hydride (NiMH) [7].

3 Reasons for Batteries Fail

There are several reasons listed below for which failure of batteries can be seen.

3.1 Cell Fault

When various cells are connected to form a battery package, and during that time, if a connection is not made correctly, then the chance of a short circuit getting maximum further explosion can happen. This generally happens during the installation process in vehicles.

3.2 Manufacturing Processes Out of Control

Suppose manufacturing companies do not follow the standard process and resulting in the making of cheaper quality of the battery. For example, the separator which is installed in between the electrodes works to isolate the positive and negative electrodes to avoid short circuits and self-discharge. So, during the making, if the used separator has defaulted, this could lead to battery failure.

3.3 Aging

During manufacturing, age limits are already defined. When a battery is regularly used, an electrode is due to continuous charging and discharging the reaction, so negative and positive electrodes get neutralized, and further, no reaction can occur. This generally occurs in public transport vehicles where vehicles continuously get charged and discharged with overworking.

3.4 Uncontrolled Operating Conditions

This includes overcharging and undercharging conditions. The operators already publish voltage limits on the battery. The damage from overcharging and undercharging can lead to a re or explosion. Example: if a PbA battery is not maintained at a high state of charge, lead sulfate deposits on both electrodes will begin to form hard crystals, which cannot be reconverted by a standard fixed voltage (13.6 V) battery charger [8].

3.5 Abuse

This includes battery handling. For example, if a battery while transport is not properly handled or stored, it is misplaced similarly to other components like overweighting and temperature, leading to overheating of battery cells and decreasing the battery's efficiency.

3.6 External Factors

This includes external source disturbances and load disturbances. If the battery is continuously having a disturbance in the discharging and charging process, that could affect electrode plates and lead to a breakdown of plates, and no other chemical reaction could take place and, as a result, battery failure.

3.7 Thermal Management

A battery always needs a specific temperature to be stored. For example, if a battery is used at high-temperature conditions, then the battery temperature cooling system should be used immediately. That system is known as a battery management system

(BMS), as every rated battery temperature rating may differ, and if it is not maintained correctly, the battery fails [9].

4 Reasons for Cell Failure

The reasons for cell failure are listed below.

4.1 Active Chemicals Exhausted

In a cell, chemical energy is converted into electrical energy. So, if an active chemical gets exhausted, it leads to cell failure.

4.2 Change in the Physical Structure of the Electrodes

When proper venting of cells is not done, it causes gassing (gas formation due to chemical reaction) in the cells and causes a reduction in capacity, leading to cell failure.

4.3 Breakdown of the Electrolyte

With normal chemical reactions, the electrolyte gets weaker, and no further reaction can occur, leading to cell failure.

4.4 Electrode Plating

In a lead-acid battery, the chance of electrode plates having corrosion is high, so if electrode plating is not done, no further reaction could occur, leading to cell failure.

4.5 Reduced Capacity

As already said, active chemicals get exhausted, and at one time, the capacity of cells also becomes reduced up to zero.

4.6 Increased Self-Discharge

After the decrease in capacity and increase in internal impedance, the cell starts losing its properties. Due to overcharging, one cell stops getting charged, and if it got charged, then gets discharged by itself.

4.7 Pressure Build-Up

Due to aging effects, the chemicals will exhaust, and pressure is created by the chemicals, i.e., excitation of an electron in the cell, and because of this, the cell will fail [10].

4.8 Overheating

While extended charging of battery the temperature rise is avoided, then that rise will affect the life of cell as well as plates of cell and will result in cell failure.

4.9 Undervoltages

When the batteries are not charged for a long time, the cell's voltage gets affected and will not give the proper, efficient voltage resulting in battery failure.

4.10 Overvoltage

When overvoltage is provided to cells, it affects their life cycle, and due to this, overheating issues can also occur, leading to cell failure [11].

5 Consequences of Cell Failure

If the battery and cells are a failure, then further various consequences can happen, and are listed below.

5.1 Open Circuit

In open-circuit conditions, the voltage expected to get can never be obtained.

5.2 Short Circuit

During connection, wires should be appropriately and tightly wired. If not, then the chance of a short circuit occurring are high.

5.3 Hard Short

Due to the electrode's corrosion, a permanent connection will exist.

5.4 Soft Short or Micro Short

Instead of a permanent connection, many small particles will form and get connected when in charging conditions.

5.5 Explosion or Fire

Storage thermal issues include a temperature rise, the chemical particle getting excited, and because of the explosion of the excited particle or re could happen [12].

6 Results

When considering battery protection, a device should consider the various protection features of the battery, which are as follows:

- Excessive current during charging or discharging.
- High ambient temperature
- Overvoltage—overcharging
- Abuse
- Undervoltage—exceeding preset depth of discharge (DOD) limits
- High ambient temperature

- Overheating—exceeding the cell temperature limit
- Pressure build-up inside the cell
- Polarity
- Short circuit
- System isolation in case of an accident

So, for the protection of the battery, the methods are.

6.1 Thermal Protection

When the battery is installed, it is impossible to sense the change in temperature or any damage because of temperature in cells without sensors, so for battery protection, different senores are used, which are listed below.

Thermal Fuse

It is a physical material in the battery; whenever the temperature rises, the thermal fuse will break down so that no other process can occur.

Thermistor Fuse or Resettable Fuse

Working of both the component is the same, which is to detect the change in temperature in battery and breakdown, but the difference in both components is that in the thermal fuse while temperature changes it will get break down and will have to be replaced by a new whereas resettable fuse will get automatically recover once the normal temperature has occurred.

Temperature Sensor

When batteries are charged without checking voltage, and the battery is getting charged from overvoltage or undervoltage, the battery can get heated up, so to check that rise and protect the battery from rising temperature, a temperature sensor is used to protect it.

6.2 Simulation of Electronic Protection (Battery Management System)

This includes the protection of the battery through power electronic controllers, which is part of the Battery Management System. So, let's see how battery management protects charging and discharging. The below charging and discharging model is simulated using MATLAB Simulink. This model will help the user charge the battery automatically and also help know when the battery is low. The steps followed for the simulation of the BMS system are as follows:

NAME	VALUE		
Modeling option	Uninstrumented | No thermal port		
▾ Main			
▾ Nominal voltage, Vnom	24	V	
Configurability	Compile-time		
Current directionality	Disabled		
▾ Internal resistance	2	Ohm	
Configurability	Compile-time		
Battery charge capacity	Infinite		

Fig. 1 Battery parameter

- In this model, a battery is taken whose nominal voltage is 24 V, internal resistance 2 Ω. Then taking the resistor as a load and parameter resistance value is 24/2 Ω, as shown in Fig. 1.
- Now the circuit is enabled, then take the MOSFET; there are two types of MOSFET. One is N-channel MOSFET, and the other is P-channel MOSFET. In the model, P-channel MOSFET is used for proper output.
- When connections are made, MOSFET will act as a relay and load and add resistor at the minimum value, i.e., resistance is 0.5 Ω. This connection is made because the circuit should be protected when reversed battery terminals.
- To check wheatear the connection is proper or not, add a voltage sensor at both at source and load.
- Similarly, for MOSFET polarity check voltage sensor is added to measure the voltage across the device.
- Now add the current sensor in between the load and source.
- Take PS-Simulink converter to connect the scope to voltage and the current sensor for the output graph.
- Before running the model, add the solver configuration because it's a simscape block model and the electrical reference ground to the model, as shown in Fig. 2.
- wo scopes are added; one will give the source voltage and MOSFET voltage graph, whereas the other Scope will provide the load voltage and load current with the Source voltage graph. So these two graphs are for comparison.

Case I When Battery is Connected with the Proper Terminals of a Battery

When the source (battery) positive is added and connected to the drain, then the current flow in a positive direction; this is due to P-channel MOSFET, and the drain will connect to the source(S) of MOSFET, and the circuit will act as a closed circuit by which load will receive the current.

When the model is run in MATLAB, there is two Scope connected to get the output graph where Scope 1 shows the Source voltage and MOSFET voltages graph, and Scope 2 shows the load current, load voltage, and source voltage. Figure 3 shows the Scope 1 output.

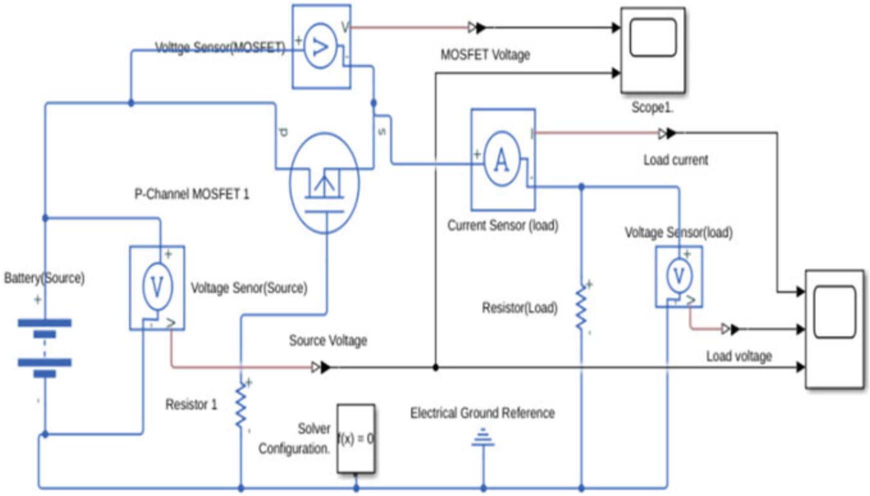

Fig. 2 Simulink model of battery management system

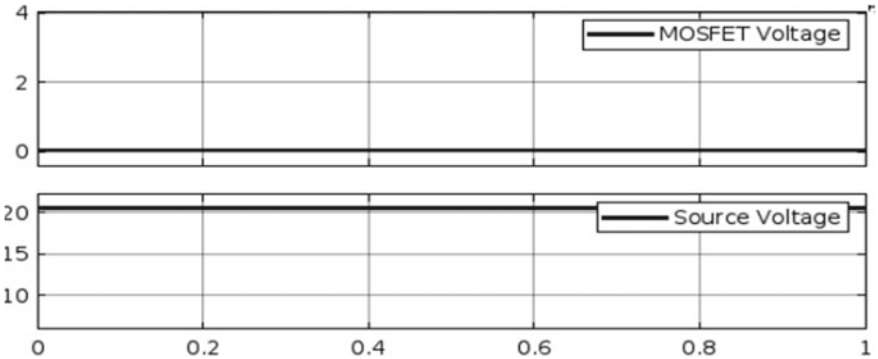

Fig. 3 Scope 1 output graph

In Fig. 4, Scope 2, it can be seen that the load receives the current where input voltage and output voltage both have the same value, which means the model is working and connected with proper terminals.

Case II When the Battery is Connected with Reverse Terminals of a Battery

When battery connections are reversed, as shown in Fig. 5, then the direction of flow of current will be in a reverse direction, and that current will ow from resistor 1 to the gate terminal of MOSFET, then drain (d terminal) will act as an open switch due to negative polarity the circuit will be open-circuit, and that leads to no flow of current to load.

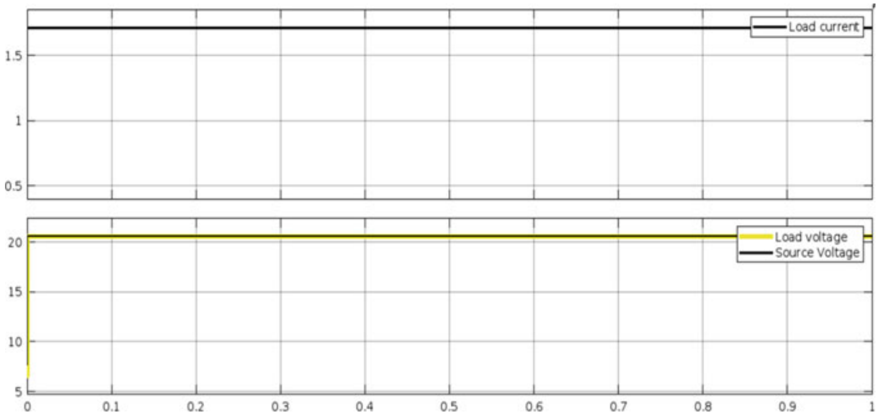

Fig. 4 Scope 2 output graph

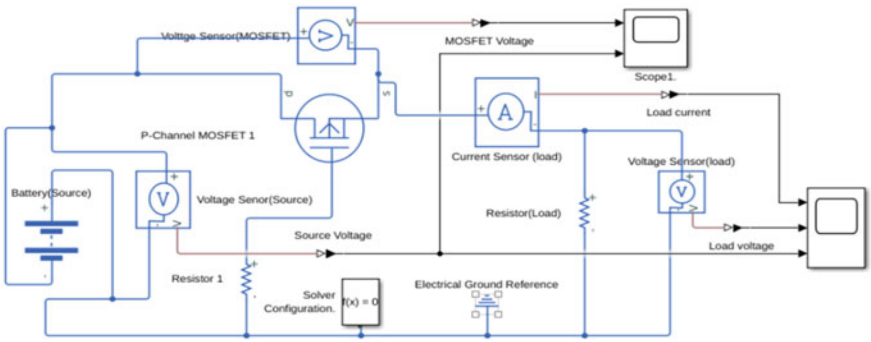

Fig. 5 Simulink model of battery management system with reverse connection

In this condition, the input voltage output has a value, whereas potential voltage across MOSFET can be seen in Fig. 6.

In Fig. 7, it is seen that the Source voltage and MOSFET voltage have a value negative which represents the reverse battery connection, whereas when Fig. 7 is seen then, it could be concluded that the circuit is an open-circuit as input voltage as the value where the output voltage is zero and also load does not receive current.

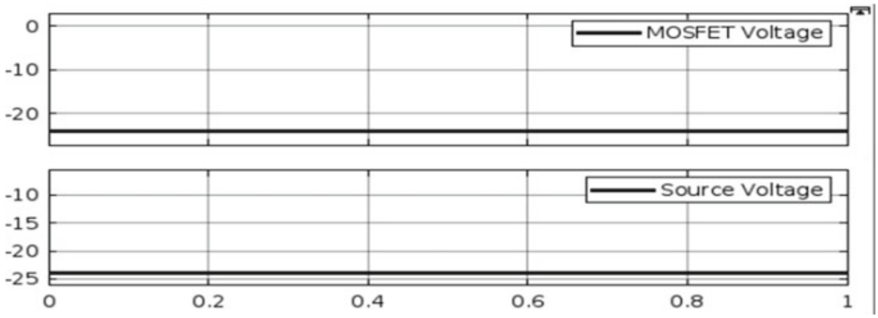

Fig. 6 Scope 1 output graph in case II

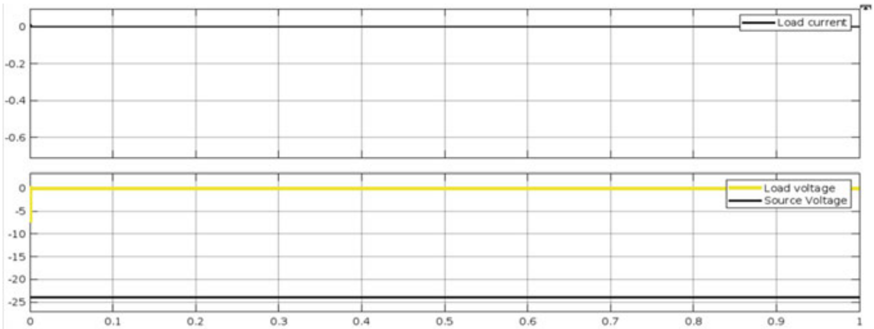

Fig. 7 Scope 2 output graph in case II

7 Conclusion

If the battery is handled with all the manual guidance, then the chance of the battery getting damaged becomes less. By following the rules in the manual, the battery life cycle and healthy backup of the battery are always longer. The proposed battery management system should be more so that it could take care of the battery with complete protection as it protects the battery from overvoltage to undervoltage, and by the rise in temperature also maintains the temperature of the battery between 25 and 27°.

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