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Simulation Circuit for Constant Current Test for Battery of Electrical Vehicle

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Abstract : The paper focuses on the testing of the battery of an electrical vehicle in a very simple and effective manner. The paper focuses on constant current test. The procedure to test the battery includes the simulation of the constant current test and its hardware implementation using power electronic switches. The charging and discharging of the battery is controlled using these switches. Simulation provides the software idea of the specific test. The test concludes with the LCD display showing the condition of the battery whether it is good or bad. Basic simulation results has been included in the paper. In simulation point of view, the graph showing the voltage and state of charge of the battery with time along the x axis is shown. Since in simulation the battery employed is an ideal case, the state of charge of the battery after each discharge is same and thus the battery is determined to be good. The paper finds itself a huge place in the futuristic automobile service stations where it is required to test the battery of electrical vehicles. The method is simple and reliable and hence can be globalized.

Keywords: Electrical vehicle, Battery, Power electronic devices, constant current test, state of charge.

1. INTRODUCTION

The most powerful way of achieving a clean and effective transportation which is important for the enhanced development of the world is electrification. The major categories of electrical vehicles include hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and pure battery electric vehicles (BEVs).In future they are going to hold their own significance in ruling the transportation sector. The major factor to this revolutionary change is the battery. Hence the study of the batteries employed in an electrical vehicle is highly relevant and thus the testing of such a battery has got its own importance. The first EV was developed in 1800s with rechargeable lead acid batteries and motors as its core components. Years of 1900s were the golden period of electric vehicles. During that period, the electrical vehicles were double in numbers compared to that of gasoline power vehicles. However, EVs were completely doomed after the discovery of internal combustion engine(ICE) cars in the 1920.The main reason for this drastic failure of EVs were heavy weight, poor durability, long charging time and short trip range of the batteries. Batteries employed in EVs differ from those batteries employed in other electronic devices such as mobile phones, laptops, calculators etc in terms of its power rating, stability and efficiency. Electrical vehicle's battery is certainly meant to handle high power (in kW) and also high energy capacity (in kWh) and also desired to be compact and cheap. Lot of researches are being done for getting better battery technologies that are suitable for the EVs across the globe. The modelling of Electrical vehicle batteries is to be done which enhances the power engineers to incorporate such a design to the power electronic interfacing converter design, system level studies and battery management. The major challenge faced while modelling these batteries are its instability to the change in charging or discharging current, temperature, state of charge (SOC) etc.

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Minimal research is available on battery testing as cited in[1] and [2].[1] and [2] summarizes the constant current test procedure. In [5] the modelling and testing of low speed electric vehicle is done. [6] provides an idea regarding the hybrid vehicle technology developed. In [7], methods which are employed in calculating the state of charge of the battery is discussed. Coulomb's counting method is discussed in detail. An idea providing how constant current can be obtained is discussed in [8]. But it can't be directly applied to the constant current test since the current ratings of the electronic devices discussed in [8] doesn't satisfy the current in constant current test of the battery. [9] discusses how the state of charge of the electrical vehicle's battery is estimated using various driving cycles.

2. LITERATURE REVIEW

Different types of batteries employed in the automobile industry for serving the purpose of movement of electric vehicles are Lithium ion battery, Lead acid battery, Nickel Cadmium battery, Lithium ion polymer battery, Nickel metal hydride battery worldwide. The commonly used batteries worldwide include Lithium ion, Nickel Cadmium and Lead acid batteries. The major characteristics of these batteries are discussed in the ensuing sections. The criteria for battery selection is also explained.

2.1. Lead acid battery

Lead acid ($PbSO_4$) batteries are those batteries employed in the automobile industries due to its increased life span of around 20 years[1]. They can be operated for longer time periods without any failures. The chemical composition of the battery consists of some negative plates made of Lead placed in between the positive plates also made of Lead added with some Calcium or Antimony (Additive).The micro porous material acting as an insulator prevents the electrode from shorting and thus provides an insulation from each other. Both anodes and cathodes are coated with lead oxide (PbO_2) which is an active material and lead sulphate ($PbSO_4$) is some other cases. The purpose of this active material is to provide a huge surface area for the storage of electrochemical energy. The main features of a Lead acid battery includes minimum energy dissipation, very low energy to weight ratio, capacity to deliver high currents at a very low cost.

Appendices

Table 1
Nominal battery parameters for lead acid batteries

Specific Energy	*20-35 Wh kg^{-1} depending on usage*
Energy density	54-95Wh L^{-1}
Specific power	~250W kg^{-1} before efficiency falls very greatly
Nominal cell voltage	2V
Amp hour efficiency	~0%, varies with rate of discharge and temperature
Internal resistance	Extremely low, ~0.022Ω/cell for 1 Amp hour cell
Commercially available	Readily available from several manufacturers
Operating temperature	Ambient, poor performance in extreme cold
Self-discharge	~2% per day
Number of life cycles	Up to 800 to 80% capacity
Recharge time	8h(but 90% recharge in 1 hour possible)

Table 1 indicates some of the major characteristics of the lead acid battery[1]. It provides an idea regarding how the battery is going to perform in the automobile industry, its performance, efficiency and complexity while conducting the constant current test.

2.2. Lithium ion battery

Lithium ion batteries are employed worldwide due to its main advantages over other batteries. They possess higher chemical stability in the presence of an electrolyte[1]. The density in terms of power of a Lithium ion battery is twice that of the standardized Nickel-cadmium battery. There is provision for higher densities of energy also which enhances the options of getting greater power from the same battery specifications. The characteristics particularly in the load side of a Lithium ion battery are reasonably good they behaves similar to nickel-cadmium battery considering the discharge. Also they are low maintenance batteries. Taking the comparison of Lithium ion and Nickel cadmium battery in terms of its self-discharge, Nickel cadmium battery is almost twice to that of Lithium ion battery which makes it most suitable modern automobile applications. While disposing, Lithium ion cells can cause very less harm.

They are fragile and they always require a protection circuit to safeguard the whole battery operation. They are built and confined to separate packs, and the peak voltage of each cell during charge are limited by the protection circuit and secondarily, cell voltage from dropping too low to discharge is prevented. Temperature extremes are avoided by monitoring the cell temperature frequently.

2.3. Nickel Cadmium battery

Nickel-cadmium batteries are those batteries which offers good performance and cycle life and at low temperatures with a good capacity[1]. It has got the ability to deliver practically its full rated capacity at higher discharge rates. The major disadvantage of these batteries are the cost of the material employed in the composition of the battery and is higher compared to lead acid battery. These cells have got higher self-discharge rates.

2.4. Battery selection

The battery which is to be employed in the electrical vehicle is decided based on the following criteria's[1]. First and important factor is the source side voltage and battery discharge requirements. Batteries may be connected in parallel to provide the battery capacity to yield the required run time and in series to achieve the required input voltages. It's important to understand and study the behavior of the battery, its behavior in various environmental conditions etc. The chemical stability of the battery is another area of concern which determines the stability of the battery in different conditions like temperature variation, explosive environment etc. It's also important to begin with the necessities to ensure that the battery design falls within the limits of the automobile technology. Battery's maximum discharge rate is another factor determining the type of battery to be used in addition to the storage and operating temperature ranges. Cost affordable by the consumer is also an area of concern which may reflect in the initial cost of the vehicle to be owned by him.

3. PROPOSED WORK

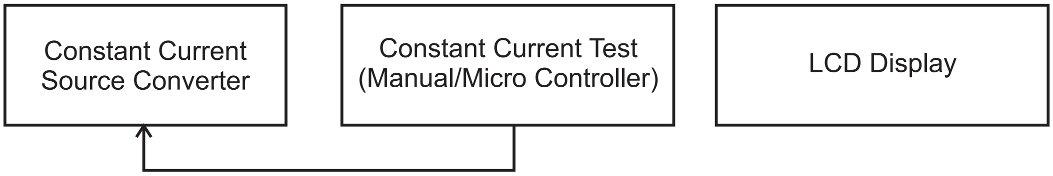

Figure 1: System overview of the constant current model

Fig 1 illustrates the overall concept of the constant current test.

Though various tests like constant current, peak power, constant power, variable power and hill climb tests for battery exist, development of test bed for current test is the focus of this paper[2]. The constant current testing is to be done by charging and discharging the battery continuously over three to four cycles. The variation in the state of charge of the battery after these cycles if is within the allowed range, the battery is said to be in a good condition. The software employed to test the battery (constant current testing) is MATLAB. The test procedure employed in MATLAB to get the specified result is as follows:

Simulink model is opted for doing the test procedure in the MATLAB software. The battery chosen from the simpowersystems block is Lithium-ion battery having 12V, 7A-hr capacity. The battery state of charge is initially kept as 0 in the battery block parameters. The nominal voltage of the battery is taken to be 12V and the Ampere-hour rating of the battery is kept as 7A-hr. The charging circuit for charging the battery is developed using a bridge rectifier and a dc-dc buck converter. The output of the converter acts as the charging source of the battery. Battery is charged in its optimum way. That is by providing the charging current of the battery to be 1/10th of the Ampere-hr. rating and it is 0.7A.After the charging the battery is made to discharge by placing specific resistors acting as the load. Battery is made to discharge to 20% SOC (state of charge) or 80% DOD (depth of discharge) and this completes one complete charge discharge cycle. The experiment is repeated for different discharge currents and the SOC of the battery is noted at the end of each discharge. If the SOC variation of the battery at the end of the discharge is within a 2% limit, then the battery can be said to be in good condition and can be used further for the automobile purposes.

MATLAB simulation and results

The MATLAB simulation model for obtaining the dc supply needed for charging the battery is described below:

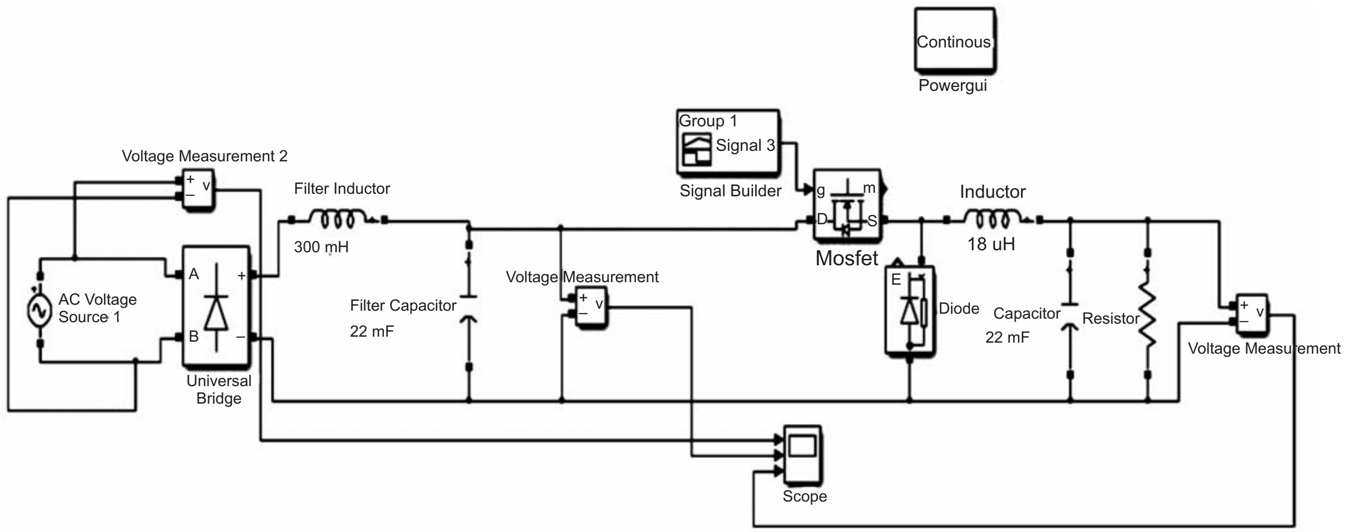

Figure 2: Developed Simulink model for obtaining the DC voltage source

Fig 2 indicates the MATLAB Simulink model of the dc supply source to charge the battery. The components employed in obtaining the dc voltage of desired voltage level are bridge rectifier, inductor, capacitor, MOSFETs, diodes resistors driver circuits for the MOSFET switching device and some measurement devices.230V, 50Hz supply is step down to 50V, 50Hz ac supply using an autotransformer and the latter is then rectified to a DC voltage with ripple using a bridge rectifier. The ripple content of the output voltage is reduced by employing a LC filter. The output of the bridge rectifier is then provided as the input to the dc-dc buck converter which step downs the dc voltage to the required dc voltage level which henceforth acts as the supply source for the battery. The output voltage of the buck converter acts as the supply for the battery and it is taken as 15V.

The MATLAB model for the constant current testing is as follows:

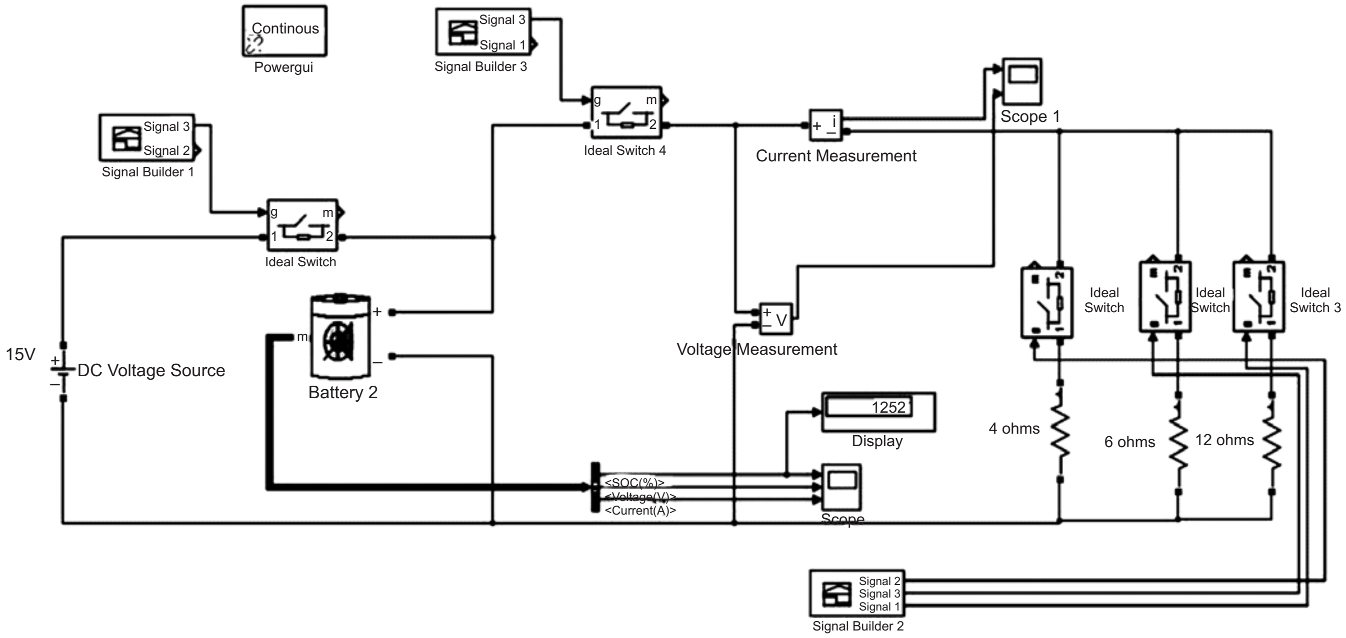

Figure 3: MATLAB Simulink model displaying the constant current testing of the battery

Fig 3 shows the MATLAB Simulink model of the constant current test enhancing the charge discharge setup of the battery. The battery is initially kept at 0% SOC. The battery is allowed to charge at C/10 A. The battery is kept for charging for ample amount of time and after getting fully charged, the MOSFET connecting supply and the battery is turned off. Likewise MOSFET connecting the battery and the load circuit consisting of resistors are turned on. The triggering of the MOSFETs in MATLAB Simulink is done by employing the signal builder where the respective turn on and turn off of the MOSFETs can be controlled. Load circuit diagram is as follows. Three resistors are connected in parallel. The resistance value of each resistor is 12Ω, 6Ω and 4Ω respectively. The discharge timings are distributed according to the current drawn by the load. If it is 12Ω resistor connected, the load current will be 1A.Then a 7Ahr battery will take 7 hours to discharge completely. Hence the MOSFET switch connected to the 12Ω resistor will be triggered for 7 hours. After the discharge process, the SOC of the battery is noted. Again the same charge discharge process is repeated and the SOC at the end of each discharge cycle is noted. A comparison between the SOC of the battery at the end of each discharge process is done and if the SOC variation stays within a limit, then the battery is said to be in good condition.

The triggering signals for the MOSFET switches connected in series with each load are as follows:

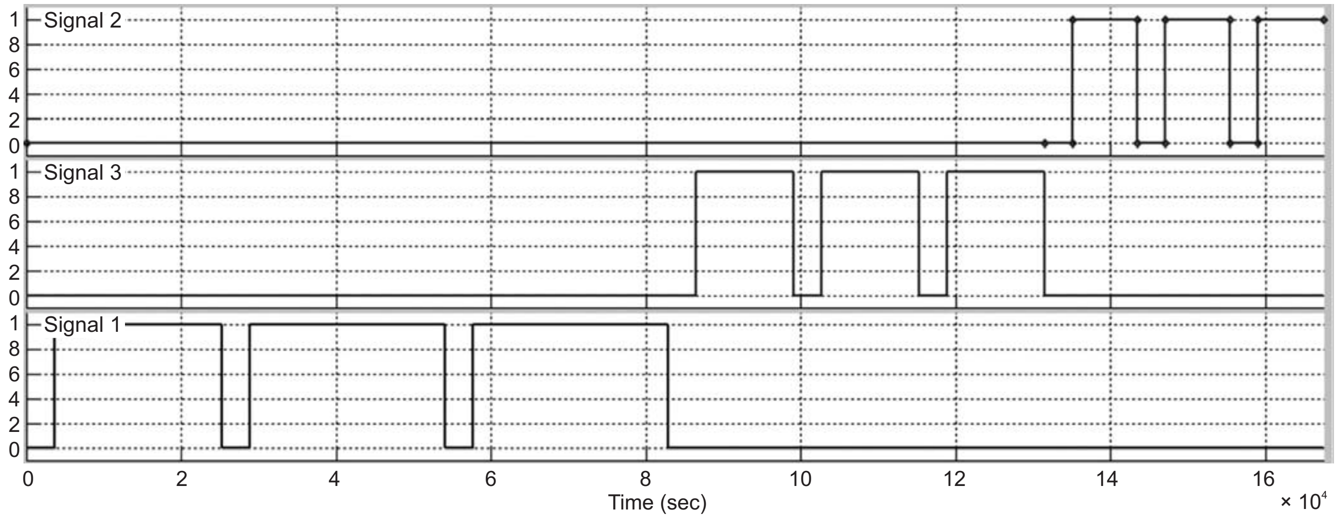

Figure 4: Signals generated in the signal builder for controlling the switching of the loads

Fig 4 illustrates the switching pulses given to the load switches. The discharging of the battery is based on these switching pulses. Signal 1, 2 and 3 are the switching pulses given to the MOSFET switches of the 12Ω, 6Ω and 4Ω load resistors respectively. The switching of these MOSFETs are to be done in hours and hence their switching are controlled using dsPIC30f4011 controller.

The MATLAB Simulink model for the faulty battery is illustrated as follows:

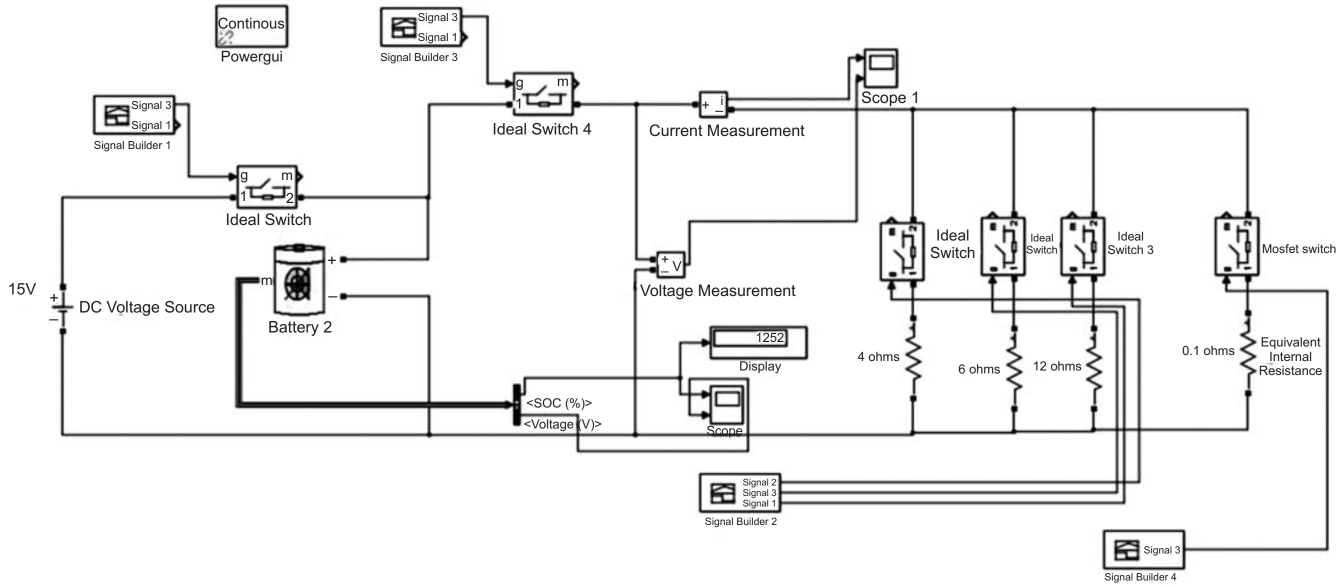

Figure 5: MATLAB Simulink model of the constant current testing of faulty battery

Fig 5 indicates the constant current test of a battery in bad condition. Practically, the chemical composition of the faulty battery will be different compared to the ideal condition battery, and as a result of that the charging discharging current and time varies for such batteries. Considering this point into account, an equivalent resistance indicating this chemical disturbance of the battery is placed in parallel with the load such that virtually it increases the current through the load and the battery drains out much faster. Here, an additional resistance indicating the equivalent internal faulty resistance of the battery is switched at a particular time of discharge of the battery. The switching of the faulty resistance is controlled by the triggering pulse of the MOSFET connected in series with the resistor and the signal in signal builder is as follows:

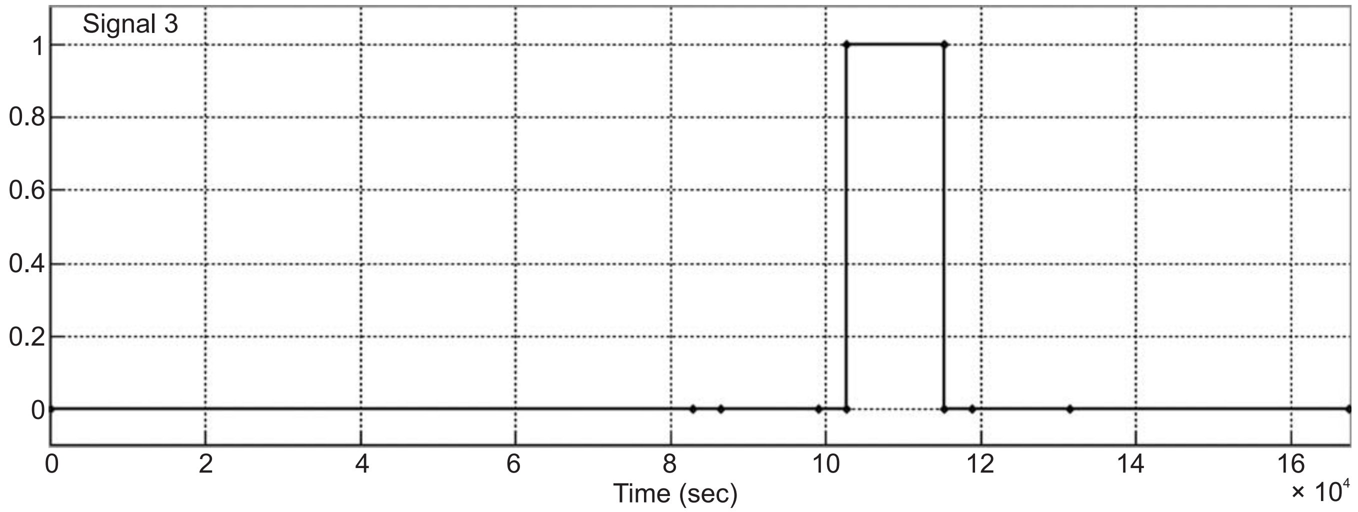

Figure 6: Signal provided in the signal builder for triggering the MOSFET switch connected to faulty resistance

Fig 6 indicates the triggering pulse provided to the MOSFET switch connected in series with the faulty resistor. The fault is provided during the discharge at 2A discharge current.

Simulation Results

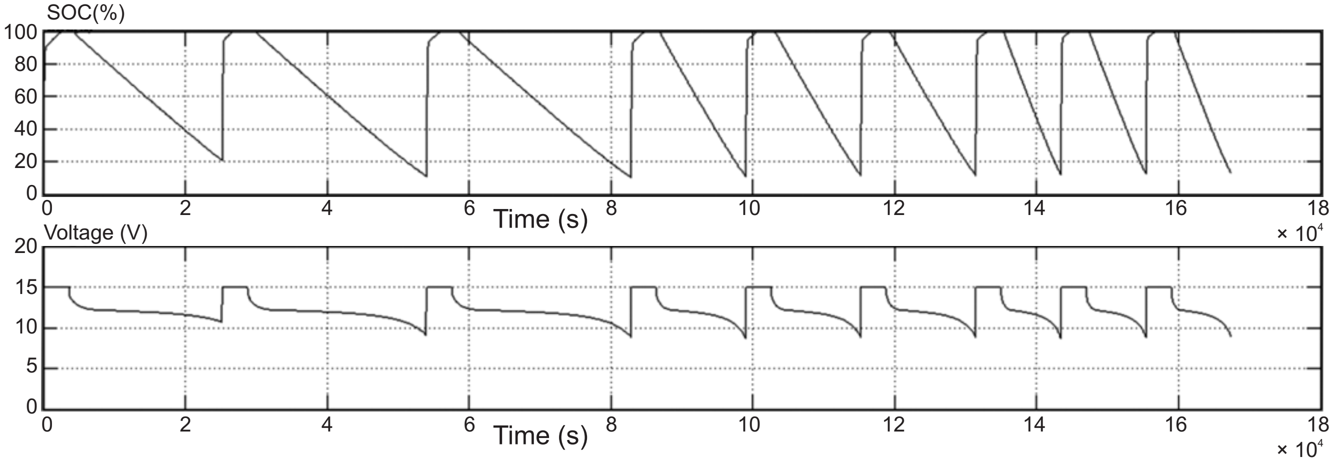

Figure 7: SOC and voltage waveforms of the battery while charging of battery in ideal conditions

Fig 7 illustrates the SOC and voltage waveforms during charging and discharging of a battery in good condition. As it is shown the state of charge of the battery at different currents at the end of each discharge is same and is within the tolerance band limit.

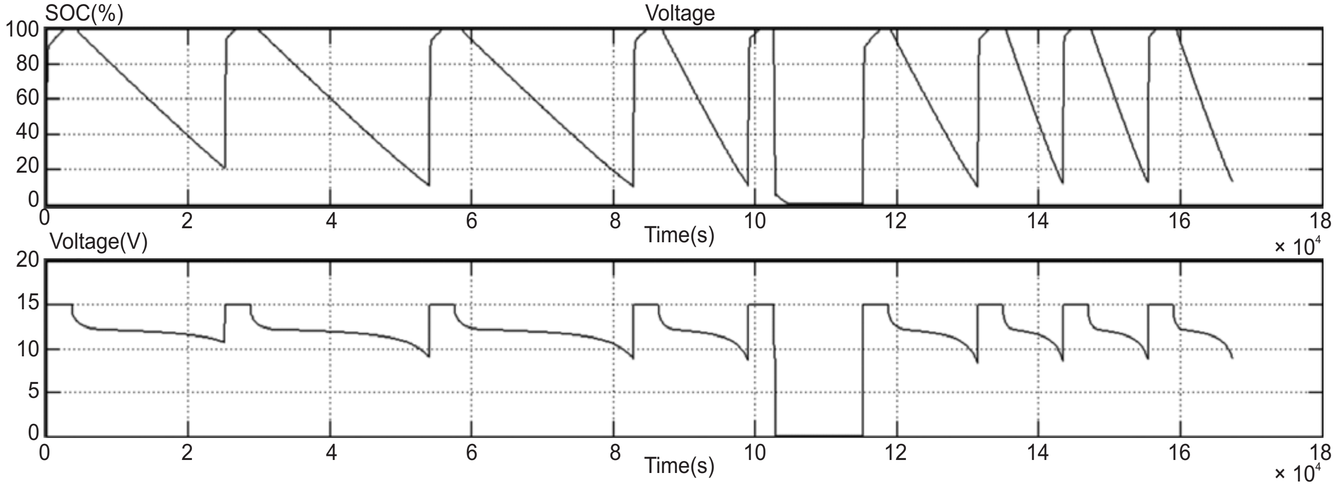

Figure 8: SOC and voltage waveforms of the faulty battery while charging and discharging

Fig 8 shows the SOC and voltage waveforms of a faulty battery during charging and discharging. The state of charge of the battery at a particular current is varying vigorously and this indicates the bad condition of the battery. Hence constant current testing can be used to test the state of health of the battery at different conditions

4. CONCLUSIONS

A test bed for constant current test employing power electronic components is developed. It is proposed to develop the circuitry in hardware. This will serve as a reference circuitry for electric vehicle entrepreneurs who wish to establish electrical vehicle test facility. With the test bed setup discussed in this paper, any type of electrical vehicle's battery can be tested and the state of health of the battery can be determined in a more effective manner.

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