STUDY OF LEAD ACID CHARGING & DISCHARGING CHARACTERISTICS

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ABSTRACT:-The lead-acid batteries provide the best value for power and energy per kilowatt-hour; have the longest life cycle and a large environmental advantage in that they are recycled at an extraordinarily high rate. No other chemistry can touch the infrastructure that exists for collecting, transporting and recycling lead-acid batteries.The rechargeable and secondary batteries category includes lead acid batteries. Despite the battery's low energy-to-volume and energy-to-weight ratios, it can deliver higher surge currents. This refers to the fact that lead acid cells have a high power-to-weight ratio. These are the batteries that transform chemical energy into electrical energy by using lead peroxide and sponge lead. Because of the elevated cell voltage levels and low cost, these are commonly used in substations and power systems. Lead Acid batteries are widely used in automobiles, inverters, backup power systems etc. Unlike tubular and maintenance free batteries, Lead Acid batteries require proper care and maintenance to prolong its life. The Lead Acid battery consists of a series of plates kept immersed in sulphuric acid solution. The plates have grids on which the active material is attached. The plates are divided into positive and negative plates. The positive plates hold pure lead as the active material while lead oxide is attached on the negative plates.

A completely charged battery can discharge its current when connected to a load. During the process of discharge, the sulphuric acid combines with the active materials on the positive and negative plates resulting in the formation of Lead sulphate. Water is the single most important step in maintaining a Lead Acid battery. The frequency of water depends on usage, charge method and operating temperature. During process, the hydrogen atoms from the sulphuric acid react with oxygen to form water.This results in the release of electrons from the positive plates which will be accepted by the negative plates. This leads to the formation of an electric potential across the battery. The electrolyte in the Lead Acid battery is a mixture of Sulphuric acid and water which has a specific gravity. Specific gravity is the weight of the acid-water mixture compared to equal volume of water. The specific gravity of pure ions free water is 1.

1. INTRODUCTION:- DETAILS OF LEAD ACID BATTERY:- The lead-acid batteries provide the best value for power and energy per kilowatt-hour; have the longest life cycle and a large environmental advantage in that they are recycled at an extraordinarily high rate. No other chemistry can touch the infrastructure that exists for collecting, transporting and recycling lead-acid batteries.

The rechargeable and secondary batteries category includes lead acid batteries. Despite the battery's low energy-to-volume and energy-to-weight ratios, it can deliver higher surge currents. This refers to the fact that lead acid cells have a high power-to-weight ratio. These are the batteries that transform

Chemical energy into electrical energy by using lead peroxide and sponge lead. Because of the elevated cell voltage levels and low cost, these are commonly used in substations and power systems.

Types of Lead Acid Battery: - **SEALED TYPE** – This type of lead-acid battery is merely a variation on the flooded type. About the fact that no one has access to each cell in the battery, the internal architecture is nearly identical to that of a flooded form. The biggest difference with this form is that there sufficient volume of acid to allow for a smooth flow of chemical reactions during the battery's existence.

VRLA Form – Also known as a sealed type of battery, these are known as Valve Controlled Lead Acid batteries. At the point of charging, the value controlling process allows for the stable evolution of O2 and H2 gases.

AGM Type – This is an Absorbed Glass Matte battery, which allows the electrolyte to be stopped at the plate material. This type of battery improves the discharge and charging processes' performance. These are mostly used in motorsports and engine start-up applications.

GEL Type – This is a wet type of lead-acid battery in which the electrolyte in the cell is silica-based, causing the material to stiffen. As compared to other forms, the recharge voltage values of the cell are small, and it also has more sensitivity.

Lead Acid Battery Chemical Reaction:- The chemical reaction in the battery occurs primarily during the discharging and recharging processes, and it is described as follows: When the battery is fully charged, the anode and cathode are PbO2 and Pb, respectively. As these are associated with resistance, the battery is discharged, and the electrons are charged in the opposite direction. The H2 ions pass into the anode and fuse together to form an atom. It reacts with PbO2 to produce PbSO4, which is white in color. Similar to the sulfate ion, the sulfate ion moves into the cathode, where it is converted into SO4. It becomes lead sulfate as it reacts with the lead cathode.

$PbSO_4 + 2H = PbO + H_2O$

$PbO + H_2SO_4 = PbSO_4 + 2H_2O$

$PbO_2 + H_2SO_4 + 2H = PbSO_4 + 2H_2O$

The cathode and anodes are connected to the negative and positive edges of the DC supply during the recharging process. The positive H2 ions pass into the cathode, gaining two electrons and becoming an H2 atom. It forms lead and sulphuric acid after a chemical reaction with lead sulfate.

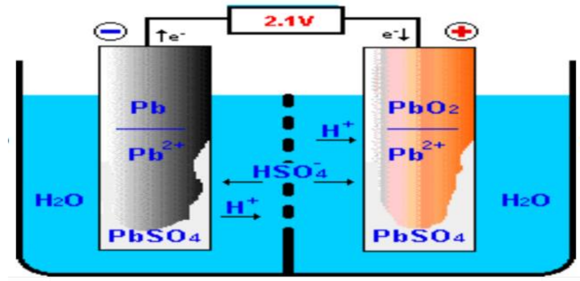

Figure 1.1 :- Lead Acid battery chemistry

Lead Acid Battery Life :- The optimum operating temperature for a lead acid battery is 250 degrees Celsius, or 770 degrees Fahrenheit. Longevity is shortened as the temperature spectrum widens. According to the law, any 80°C rise in temperature decreases the battery's half-life. A performance-operated battery with a 250C operating temperature has a lead acid battery life of ten years. And it only has a 5-year life span when maintained at 330 degrees Celsius.

Applications:-Used in electric motors , Submarines ,Nuclear submarines.

1.2 MATLAB: Matlab is a high-level language with interactive environment which enables to performing computationally intensive tasks faster than with traditional programming languages such as C , C++ and FORTRAIN . It has various components to support simulation of various complex electrical and power electronics systems .

Simulink: Simulink is a plateform for multidomain simulation and Model-Based Design for dynamic systems . It provides an interactive graphical environment and a customizable set of block libraries and can be extended for specialized applications . Simulink library Information inserts a table that lists library links in the current model , system , or block .

Simscape:

Simulink is a graphical programming environment for modelling, simulating and analysis of dynamic systems where as Simscape is a Physical modelling part in simulink environment.

Simscape:- It extends Simulink with tools for modelling and simulating basic electrical circuits and detailed electrical power systems. These tools facilitate modelling of the generation, Transmission, distribution, and consumption of electrical power, as well as its conversion into mechanical power. Sim Power System is well suited for the development of complex, self-contained power systems and power utility applications.

1.3 Battery Performance Parameters:-

The Performance Parameters of Battery are SOC(State of Charge),Depth of Discharge and Charging and Discharging rates .

1.3.1 SOC: - It gives the ratio of the amount of energy presently stored in the battery to the Nominal rated capacity. It is the fraction of the battery capacity that has been used over the total available from the battery.

1.3.2 Depth of Discharge: - The Depth of Discharge of a battery determines the fraction of power that can be withdrawn from the battery.

1.3.3 Charging and Discharging rates: - The charging rate, in Amps, is given in the amount of charge added to the battery per unit time. The charge /discharge rate may be specified directly by giving the current. The discharging rate is determined by the amount of time it takes to fully discharge the battery.

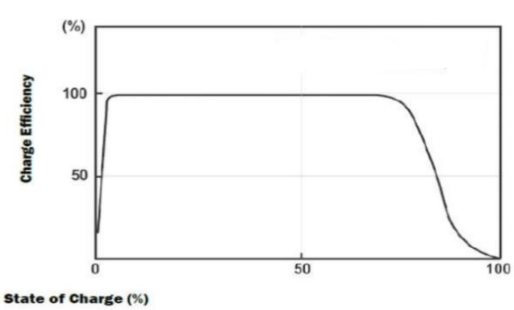

Figure 1.2 :- Graph between State of charge and charge Efficiency

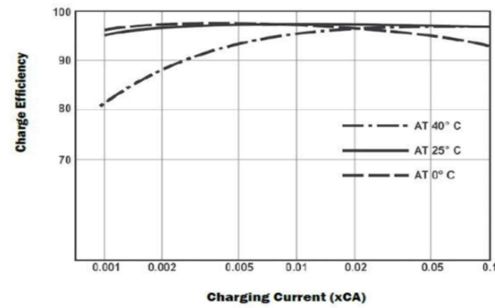

Figure 1.3:- Graph between Charging current & Charge Efficiency

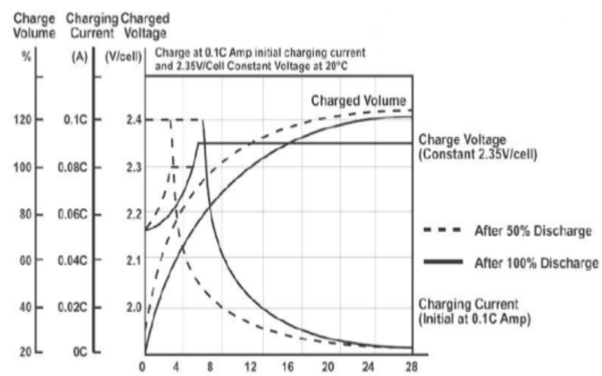

Figure 1.4:-Lead Acid battery charge characteristics taking case that charging is non continuous and peak voltage higher.

2. PROBLEM STATEMENT-

To observe the SOC and charging current of different batteries in series and parallel combination with different loads using Matlab Simulink and Simscape.

OBJECTIVE–

1. Identifying time duration while charging different batteries separately and in different combination.
2. Identifying variation in charging current characteristics of different batteries.
3. Design and develop the circuit for display of SOC and charging current for different varying loads through simulation.
4. Experimentation and validation of results.
5. Analysis of results.

3. LEAD ACID BATTERY CHARGING:

Circuit diagram of Lead Acid battery charging is shown in figure and design parameters are also shown below .Simulation results are shown both in display and waveform basis.

. DC Voltage Source = 12 Volt
. Lead acid nominal voltage:- 7.2 volt
. Rated capacity:- 55 Ah
. Initial state of charge:- 45%
. Battery response time:- 30 seconds

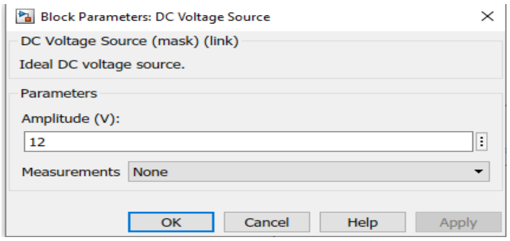

Figure 3.1. :- DC VOLTAGE SOURCE FOR LEAD ACID BATTERY CHARGING

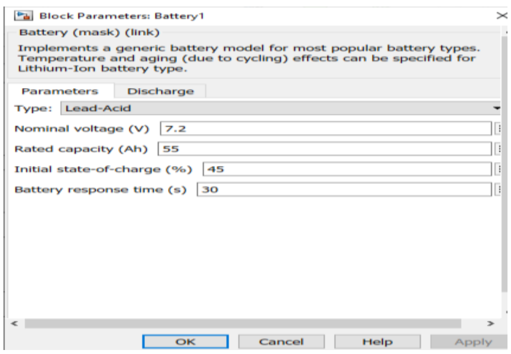

Figure 3.2:- DETAIL SPECIFICATION OF LEAD ACID BATTERY

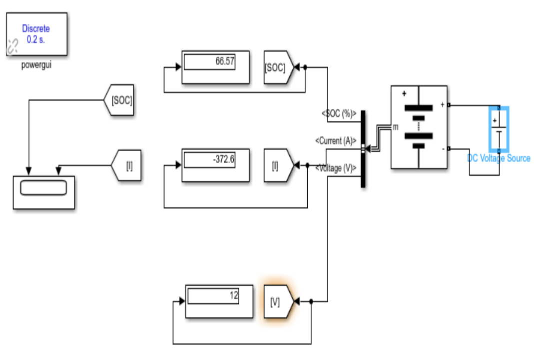

Figure 3.3 :-CIRCUIT DIAGRAM OF LEAD-ACID BATTERY CHARGING FOR 90 SECONDS

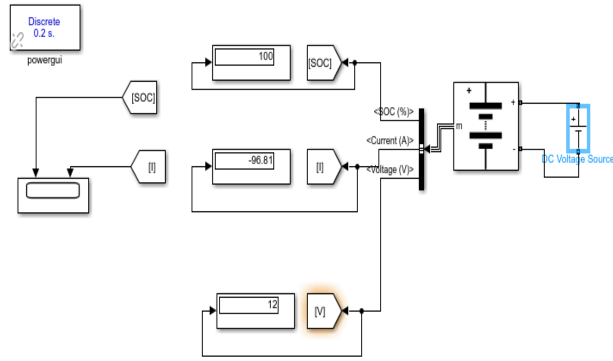

Figure 3.4:- CIRCUIT DIAGRAM OF LEAD-ACID BATTERY CHARGING FOR 180 SECONDS

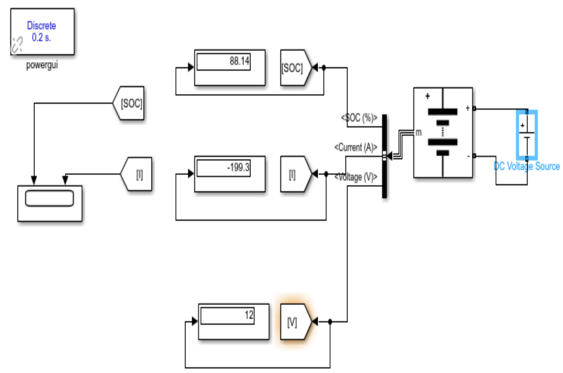

Figure 3.5:- CIRCUIT DIAGRAM OF LEAD-ACID BATTERY CHARGING FOR 250 SECONDS

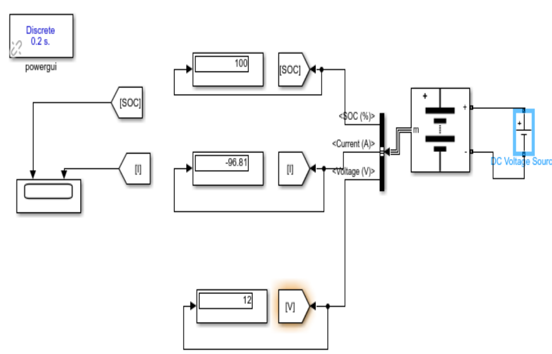

Figure 3.6:- CIRCUIT DIAGRAM OF LEAD-ACID BATTERY CHARGING FOR 425 SECONDS

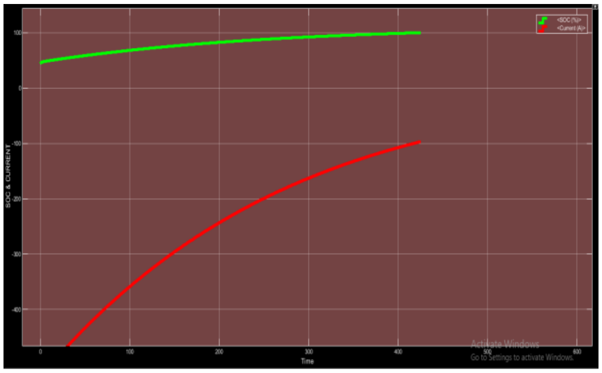

Figure 3.7:- SOC & CURRENT WAVEFORM OF LEAD ACID BATTERY CHARGING FOR 425 SECONDS

4. SERIES COMBINATION OF LEAD ACID BATTERIES CHARGING:-

Circuit diagram of Lead Acid battery series charging is shown in figure and design parameters are also shown below .Simulation results are shown both in display and waveform basis.

. DC Voltage Source = 30 Volt

. Lead acid nominal voltage:- 7.2 volt

. Rated capacity:- 55 Ah

. Initial state of charge:- 45%

. Battery response time:- 30 seconds

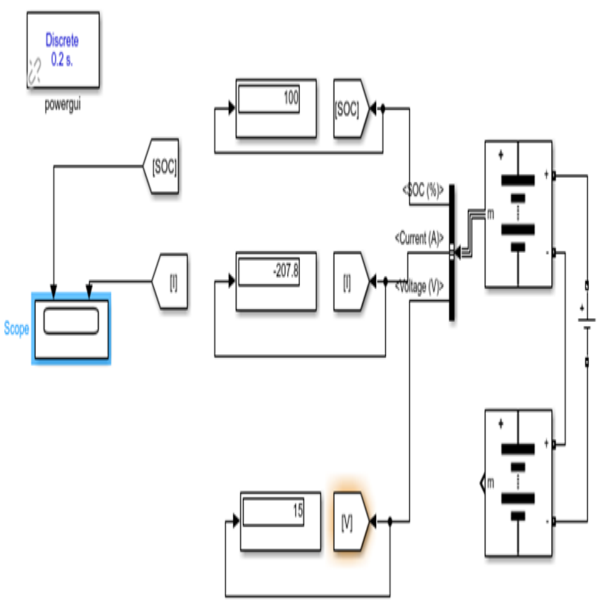

Figure4.1:- CIRCUIT DIAGRAM OF LEAD-ACID & LEAD-ACID BATTERY SERIES CHARGING FOR 1 HOUR

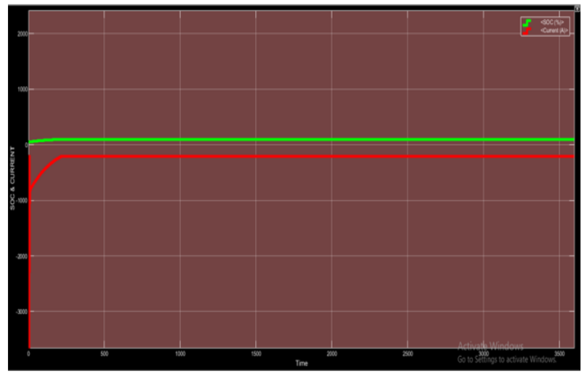

Figure4.2:- SOC & CURRENT WAVEFORMM OF LEAD ACID & LEAD ACID BATTERY SERIES CHARGING

5. LEAD ACID-LEAD ACID BATTERY PARALLEL CHARGING:

Circuit diagram of Lead Acid battery Parallel charging is shown in figure and design parameters are also shown below .Simulation results are shown both in display and waveform basis.

_. DC Voltage Source = 15 Volt

. Lithium –Ion nominal voltage:- 7.2 volt

. Rated capacity:- 55 Ah

. Initial state of charge:- 45%

. Battery response time:- 30 seconds

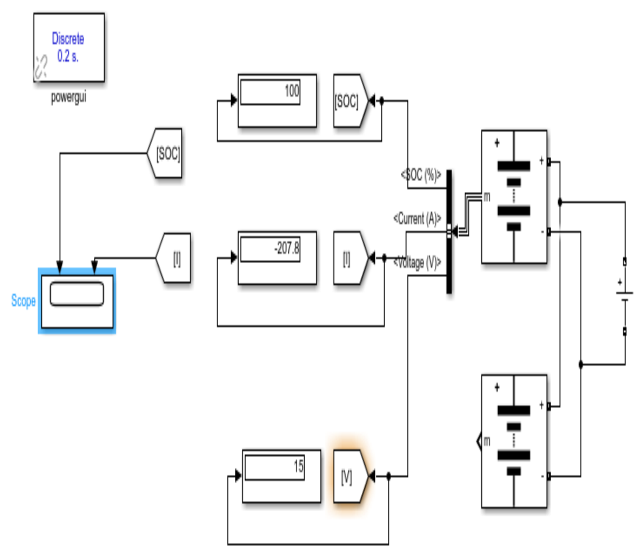

Figure5.1:-CIRCUIT DIAGRAM OF BOTH LEAD ACID BATTERY FOR PARALLEL CHARGING FOR 1 HOUR

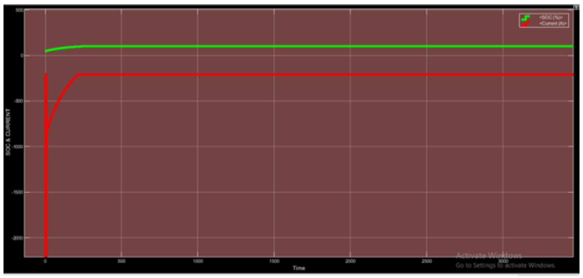

Figure5.2:- SOC & CURRENT WAVEFORM OF BOTH LEAD ACID BATTERY CONNECTED IN PARALLEL FOR CHARGING FOR 1 HOUR

6. LEAD ACID BATTERY DISCHARGE:

Initially the battery charging is taken as 100% and nominal voltage of battery is taken as 7.2 volt .

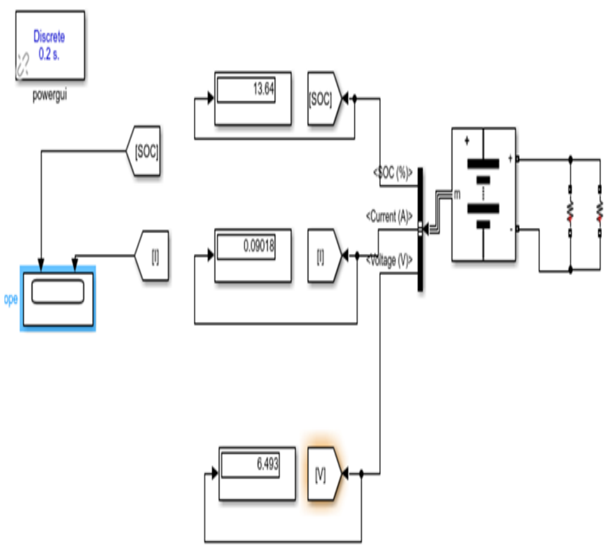

Figure6.1:- CIRCUIT DIAGRAM OF DISCHARGE OF LEAD ACID BATTERY WITH LOAD RESISTANCE 72 OHMS FOR 500 HOURS

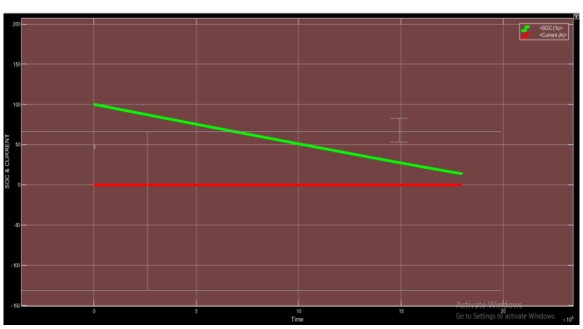

Figure6.2:- SOC & CURRENT WAVEFORM OF LEAD ACID BATTERY DISCHARGE FOR 500 HOURS

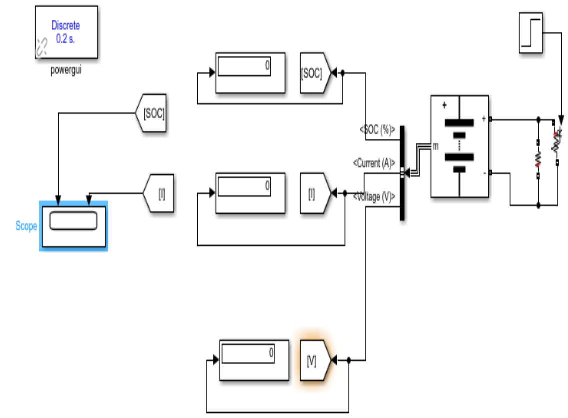

Figure6.3:- CIRCUIT DIAGRAM OF DISCHARGE OF LEAD ACID BATTERY WITH LOAD AS STEP SIGNAL FOR 25 HOURS

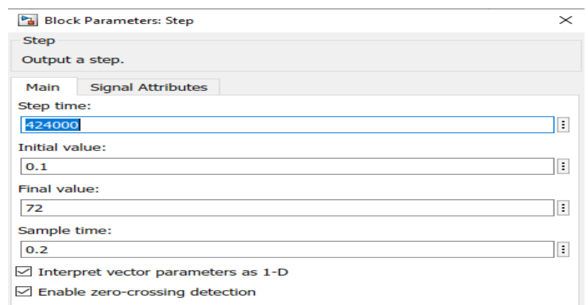

Figure6.3:- IMAGE SHOWING DETAILS OF STEP SIGNAL

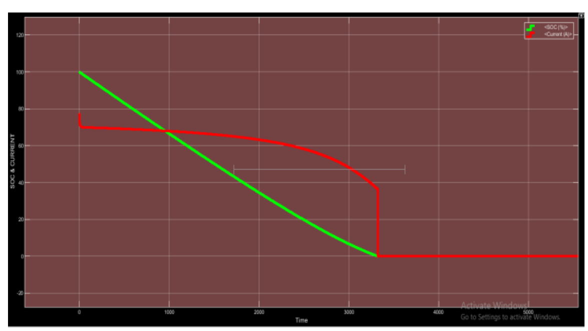

Figure6.4 :- SOC & CURRENT WAVEFORM OF DISCHARGE OF LEAD ACID BATTERY CONNECTED TO STEP SIGNAL FOR 25 HOURS

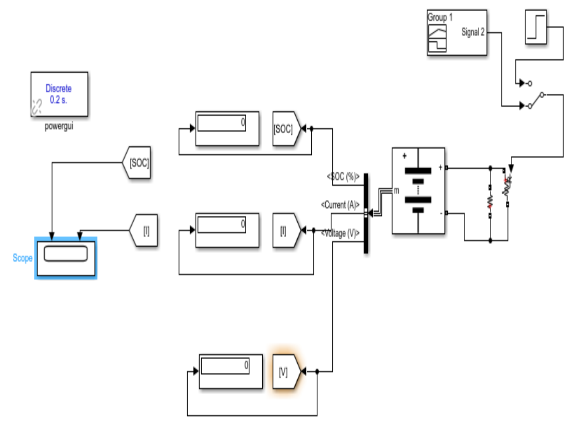

Figure6.5:- CIRCUIT DIAGRAM OF LEAD ACID BATTERY DISCHARGE CONNECTED TO LOAD OF STEP SIGNAL WITH RAMP START PROVIDED BY SIGNAL BUILDER FOR 250 HOURS

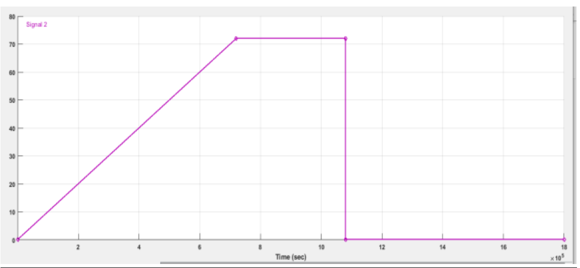

Figure6.6:- IMAGE OF STEP SIGNAL WITH RAMP START DEVELOPED IN SIGNAL BUILDER

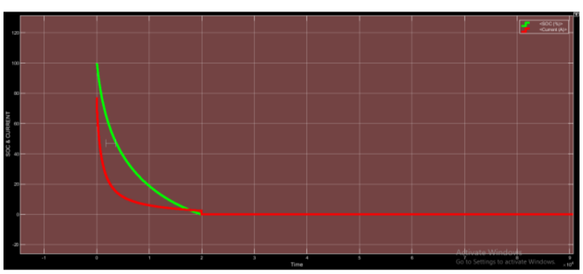

Figure6.7:- SOC & CURRENT WAVEFORM OF LEAD ACID BATTERY DISCHARGE CONNECTED TO LOAD OF STEP SIGNAL WITH RAMP START FOR 250 HOURS

7. LEAD ACID-LEAD ACID SERIES BATTERY DISCHARGE:-

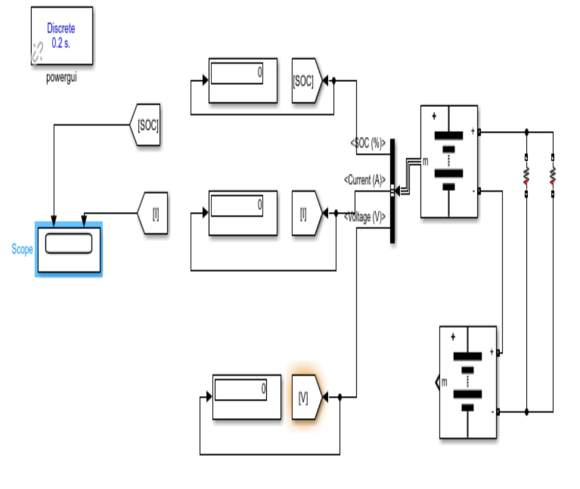

Figure7.1:- CIRCUIT DIAGRAM OF DISCHARGE OF LEAD ACID-LEAD ACID SERIES BATTERY WITH LOAD AS 72 OHM RESISTANCE FOR 500 HOURS

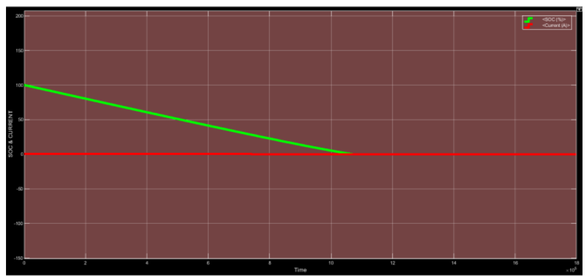

Figure7.2:- SOC & CURRENT WAVEFORM OF DISCHARGE OF LEAD ACID-LEAD ACID SERIES BATTERY CONNECTED TO LOAD RESISTANCE OF 72 OHMS FOR 500 HOURS

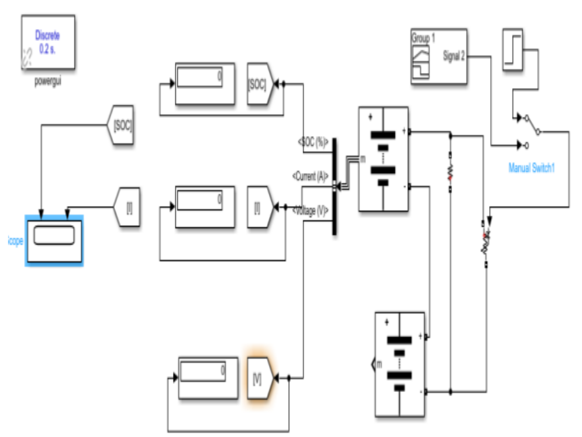

Figure7.3:- CIRCUIT DIAGRAM OF DISCHARGE OF LEAD ACID-LEAD ACID SERIES BATTERY WITH LOAD AS STEP SIGNAL WITH RAMP START FOR 500 HOURS

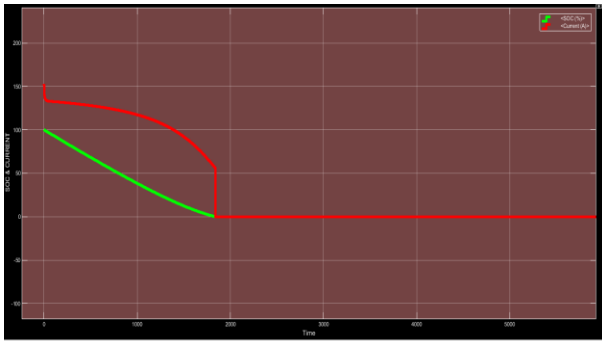

Figure7.4:-SOC & CURRENT WAVEFORM OF OF DISCHARGE OF LEAD ACID-LEAD ACID SERIES BATTERY WITH LOAD AS STEP SIGNAL WITH RAMP START FOR 500 HOURS

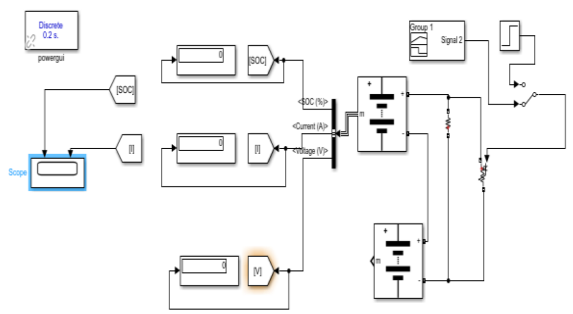

Figure7.5:- CIRCUIT DIAGRAM OF DISCHARGE OF LEAD ACID-LEAD ACID SERIES BATTERY WITH LOAD_AS STEP SIGNAL WITH RAMP START DEVELOPED BY SIGNAL BUILDER FOR 500 HOURS

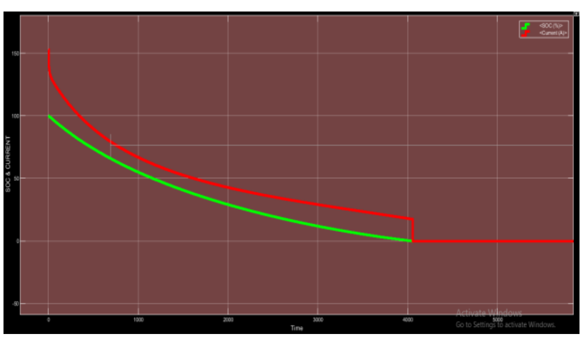

Figure7.6 :- SOC & CURRENT WAVEFORM OF DISCHARGE OF LEAD ACID-LEAD ACID SERIES BATTERY WITH LOAD AS STEP SIGNAL WITH RAMP START DEVELOPED BY SIGNAL BUILDER FOR 500 HOURS

8. LEAD ACID BATTERY PARALLEL DISCHARGE:-

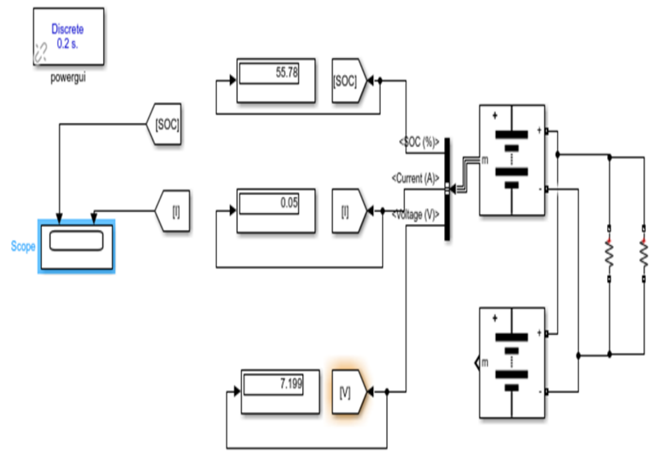

Figure8.1:- CIRCUIT DIAGRAM OF DISCHARGE OF PARALLEL CONNECTED LEAD ACID-LEAD ACID ACID BATTERY WITH LOAD RESISTANCE OF 72 OHMS FOR 500 HOURS

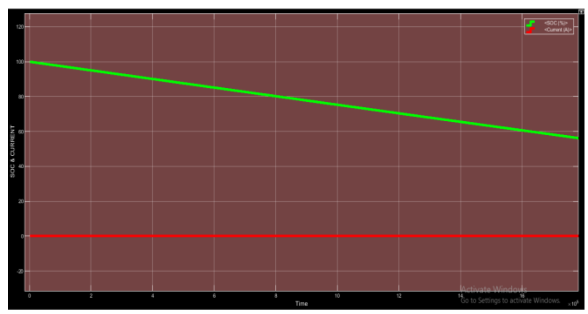

Figure8.2:- SOC & CURRENT WAVEFORM OF DISCHARGE OF PARALLEL CONNECTED LEAD ACID-LEAD ACID ACID BATTERY WITH LOAD RESISTANCE OF 72 OHMS FOR 500 HOURS

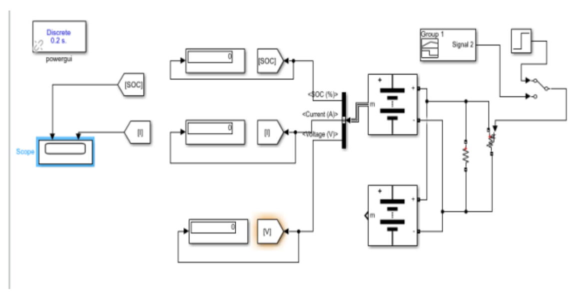

Figure8.3 :-CIRCUIT DIAGRAM OF DISCHARGE OF PARALLEL CONNECTED LEAD ACID-LEAD ACID ACID BATTERY WITH LOAD AS STEP SIGNAL FOR 500 HOURS

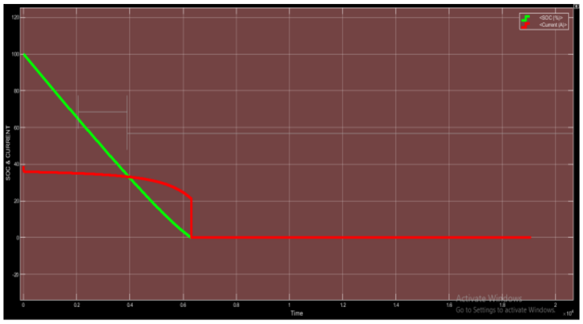

Figure8.4 :- SOC & CURRENT WAVEFORM OF DISCHARGE OF PARALLEL CONNECTED LEAD ACID-LEAD ACID ACID BATTERY WITH LOAD AS STEP SIGNAL FOR 500 HOURS

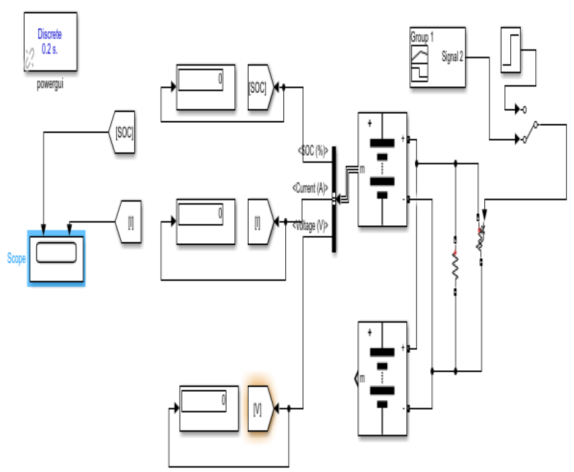

Figure8.5 :- CIRCUIT DIAGRAM OF DISCHARGE OF PARALLEL CONNECTED LEAD ACID- LEAD ACID BATTERY WITH LOAD AS STEP SIGNAL WITH RAMP START DEVELOPED BY SIGNAL BUILDER FOR 500 HOURS

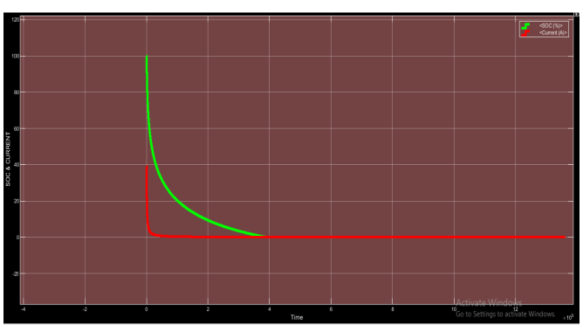

Figure8.6:- SOC & CURRENT WAVEFORM OF DISCHARGE OF PARALLEL CONNECTED LEAD ACID-LEAD ACID BATTERY WITH LOAD AS STEP SIGNAL WITH RAMP START DEVELOPED BY SIGNAL BUILDER FOR 500 HOURS

9. ANALYSIS:-

9.1 ANALYSIS OF LEAD ACID BATTERY CHARGING :-

Initially the SOC & nominal voltage of Lead Acid battery taken as 45% and 7.2 volt . The SOC reaches to 100% and charging current becomes -96.81 mille Ampere within a period of 425 seconds .The charging current was more initially and reduced by time i.e with 24 volt DC source for charging lead acid battery of initial voltage of 7.2 volt , the charging current reduces exponentially .

9.2 ANALYSIS OF LEAD ACID –LEAD ACID SERIES BATTERY CHARGING: - Initially the SOC & nominal voltage of both Lead Acid batteries taken as 45% and 7.2 volt. The SOC reaches to 100% and charging current becomes -207.8 mille Ampere within a period of 1 hour as observed. .The charging current was more initially and reduced to constant i.e. with 30 volt DC source for charging lead acid battery of initial voltage of 7.2 volt , the charging current becomes constant.

9.3 ANALYSIS OF LEAD ACID –LEAD ACID PARALLEL BATTERY CHARGING:-

Initially the SOC & nominal voltage of both lead acid & lead acid battery taken as 45% and 7.2 volt. The SOC reaches to 100% and charging current becomes -207.8 mille Ampere within a period of 1 hour as observed. The charging current was more initially and reduced to constant i.e with 15 volt DC source for charging lead acid battery of initial voltage of 7.2 volt, the charging current initially increases & then reduces and this reduced current maintains constant throughout.

9.4 ANALYSIS OF LEAD ACID DISCHARGE:- For a period of 500 hour, the lead acid discharges from 100% to 13.64% and low discharge current develops and voltage reduces to 6.49 volt from 7.2 volt when 72 ohms resistance is connected at load & with step load, the current reduces in step and the for step signal with ramp start load , the current purely reduces exponentially and then becomes constant .

9.5 ANALYSIS OF LEAD ACID-LEAD ACID SERIES DISCHARGE:-

The SOC reduces from 100% to 0% within a period of 300 hours & current almost remains constant for 72 ohms resistance at load. For step , the current reduces in a step format and finally becomes constant & SOC reduces to 0% in nearly 1800 seconds . For step with ramp start, the SOC reduces to 0 % in 4000 seconds & current droops exponentially with a step end and finally becomes constant .

9.6 ANALYSIS OF LEAD ACID –LEAD ACID PARALLEL DISCHARGE :-The SOC reduces 58% in 500 hours and current remains low constant throughput for 72 ohms resistance at load .For step load , the SOC reduces to 0 in 170 hours & reduces in a step format to a low constant current . For step load with ramp start, the SOC reduces exponentially to zero in 110 hours and current remains constant low.

10. SIMULATION RESULT OF BATTERY CHARGING

TABLE 3.1 SIMULATION RESULT OF BATTERY CHARGING

CHARGING OF BATTERIES WITH INITIAL STATE OF CHARGE = 45%		
SOC	**TIME**	
LEAD ACID BATTERY	**425 SECONDS**	**100%**
LEAD ACID-LEAD ACID SERIES BATTERY CHARGING	**140 SECONDS**	**100%**
LEAD ACID-LEAD ACID PARALLEL BATTERY CHARGING	**225 SECONDS**	**100%**

TABLE 3.2 SIMULATION RESULT OF BATTERY DISCHARGING

DISCHARGING OF BATTERIES WITH INITIAL STATE OF CHARGE = 100% WITH LOAD AS 72 OHM RESISTANCE		
SOC	**TIME**	
LEAD ACID BATTERY	**500 HOURS**	**13.64%**
LEAD ACID-LEAD ACID SERIES BATTERY DISCHARGING	**275 HOURS**	**0%**
LEAD ACID-LEAD ACID PARALLEL BATTERY DISCHARGING	**500 HOURS**	**55.78%**

10. CONCLUSION:-The analysis and design of batteries charging and discharging have been carried out for various performances parameters of voltages and loads. For charging, the fixed voltage source of 12 volt for 7.2v battery and fixed voltage source of 24 volt for series charging is used. The loads vary from purely resistive load or step load to step load with ramp at start. Namely Lead Acid, Lithium Ion and their series and parallel combination have been designed to deliver output characteristics with fixed DC voltage source for charging and also outputs of Discharging of batteries studied with load variations seen through display and waveform characteristics .This work was carried out with the help of Matlab-Simulink. The result of simulation is presented for comparison. These design concepts are validated through simulation in the Matlab and the results are presented for analysis of various batteries.

The depth of discharge and battery capacity is strongly affected by the discharge rate of the battery. The battery capacity degrades due to sulfation and shedding of extra material .The degradation of battery capacity depends most strongly on the interrelationship between the following parameters:-

1. The charging/discharging regime which the battery has experienced
2. The exposure to prolonged periods of low discharge.
3. The average temperature of the battery over its lifetime.

The initial state of charge of Lead battery set at 45% and it is found that Lead acid battery takes 425 seconds to full charge . With initial state set to full charge, it was found that Lead Acid Battery discharge to 13.64% in 500 hours with load resistance set at 72 ohms. While lead acid charging through simulation, it is seen that initially the charging current is high and the charging current reduces exponentially with time onwards. Theoretically if lead acid battery is being discharged very quickly , then the discharge current is high but practically if discharged for long period of 500 hours with load resistance nearly 100 ohms , the discharge current is constant .

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