CHAPTER NO. 3

Modeling and Simulation of Battery Performance Parameters

Modeling and simulation techniques are used for testing system conditions that might be inflexible to reproduce with hardware prototype. Modeling provides representation of a real-world system with the help of software, hardware, or its combination. In this section, the efforts are made to understand the battery performance parameters and their role in deciding the breakeven point before charging. In addition, modeling and simulation of rechargeable battery has been carried out to study its performance parameters. In this research work, scientific tools like MATLAB, SIMPLORER and LabVIEW tools are effectively used for simulation, modeling, control purposes, data acquisition, storage, estimation and monitoring.

3.1 Modeling and Simulation - Fundamentals

Modeling and simulation plays an important role in research and development. Real systems can be represented by physical models or a mathematical model which allows knowing dynamics behavior of the system through simulation. The budding discipline of modeling and simulation are based on computer areas and system theories. In early stages of the design process modeling and simulations tools are used before the availability of hardware. Iterative modeling and simulation can improve the quality of the system design, thereby reducing the number of errors in the design process. The software components of any model or system driven by mathematical input and output relationships then that designed model can be simulated under various conditions to validate the system. The modeling and simulations are important in electrical system for capacity determination and optimum component selection. The life of the battery imposes stringent constraints on its operation with active loads. During the discharge cycle of battery, the battery voltage decreases up to certain cutoff voltage. The discharge capacity and delivered energy by battery is determined with the help of empirical model. Modeling is the process of producing a system model. One of the main purposes of a model is to enable the researcher or analyst to predict the outcome of system performance parameter. The system model should be a close approximation to the actual system and incorporate most of its significant characteristics. System model should be simple and easy to understand and experiment with it. Good system model is a well judged swapping between realism and simplicity [1]

3.1.1 Importance

Simulations are accepted in a variety of areas of the technology and research. National Science Foundation report showed the great potential of simulation technology in engineering and science technology. Among the reasons there is increase interest in simulation based applications. The simulations are used because of the followings:

1. A simulation is usually cheaper and safer than conducting experiments with a prototype of the final product.
2. Simulations can often be even more realistic than traditional experiments, as they allow the free configuration of environment parameters found in the operational application field of the final product.
3. Simulations often conducted faster than real time systems.
4. Simulations allow setting up environmental conditions that allows for integration of simulated systems in the early analysis phase.

The modeling and simulations are used where system is too large or small or complex or fast or slow for direct experimentation. Various steps are involved in modeling of any general system i.e. representation of the system with mathematical intervention, select proper model, decide input and output variable of the system, system interpretation with suitable example and validation of the designed model.

3.1.2 Modeling

Generally, a model intended for a simulation study is a mathematical model developed with the help of simulation software. Mathematical model classifications include deterministic, stochastic, static and dynamic. The input and output variables are fixed values in deterministic model whereas in stochastic at least one of the input or output variables is probabilistic. In static model the time term is not taken into account where as in dynamic model time-varying interactions among variables are taken into account. Normally simulation models are stochastic and dynamic models.

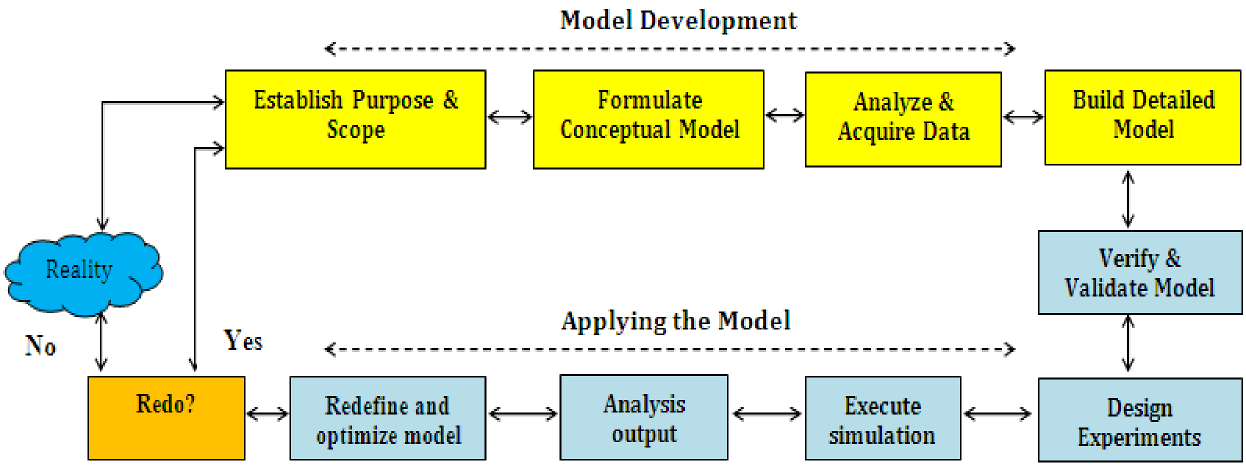

Fig. 3.1: Development and application of the model

This is the general block diagram of development and application of the model for specific purpose. The purpose and scope of the model has to be properly understood or defined in the research context. In this research work,it is planned to study the above process of development and application of model. Here, different battery models are to be studied and simulate it in MATLAB and Simplorer software to understand behaviour of the battery. The model development consists of formulation of conceptual model,analysis,acquire data and building model. Whereas in applying model includes simulation, result analysis, redefining, model optimisation and verification and validation. The mathematical formulation is needed for the planed system so that dependant and independent parameters could be identified and used in software system. After analysis the specific model is represented and used for simulation experimentation, the simulation is executed and genrerated results are again analysed. In case the simulated results are not validated with reality system in optimization or redefination then model mdification is necessary and required otherwise no modification in the prescribed model. With the help of MATLAB or SIMPLORER researcher can build mathematical models for estimation and prediction the behavior of the systems.

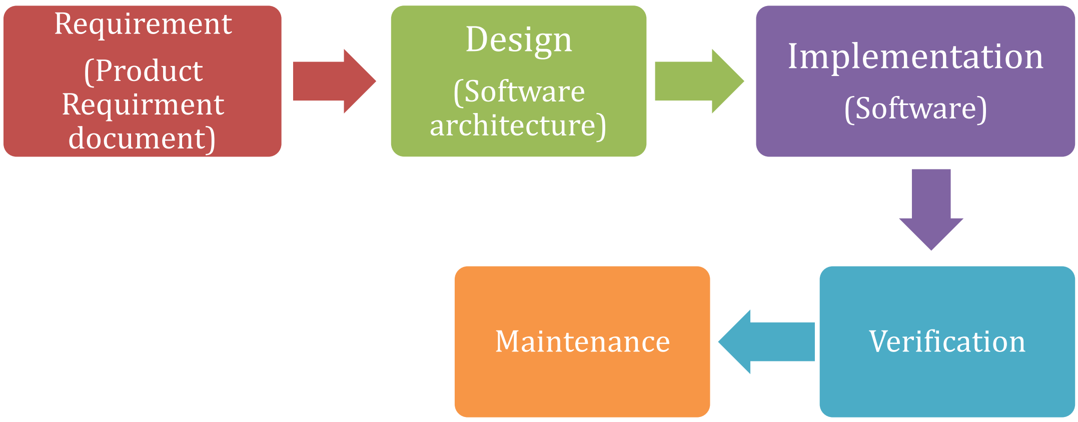

Fig. 3.2: Design steps of modeling a system

Above figure shows the flow diagram of designing system model of any system. This model flow includes initial product documentation in which user should know the coustomer requirement or specification of the system.The second stage is designing of the model according to the given specification.

The software code can be written in this stage after this implementation and verification could be carried out for the prescribed model.In case there is some ambiguity in the result then maintenance and modification of the model has to be done subsequently to acquaint expected result from the system.

3.1.3 Implementing a Model

Modeling and simulation gives information about how any system will behave without actually testing it in real life. In other words modeling is a system whose behavior can be interpreted in terms of physical /empirical /block diagram/ mathematical systems /or any equivalent by considering variable inputs and outputs. Modeling environments may include different simulation functions. Some of the most commonly used environments are LabVIEW, Matrix or system build and MATLAB/Simulation .A model is similar to the system but simpler than the system it represents. The main purpose of any model is to predict the effect of changes of parameters in the system. On the one hand, a model should be a close approximation to real system and incorporate most of its salient features.

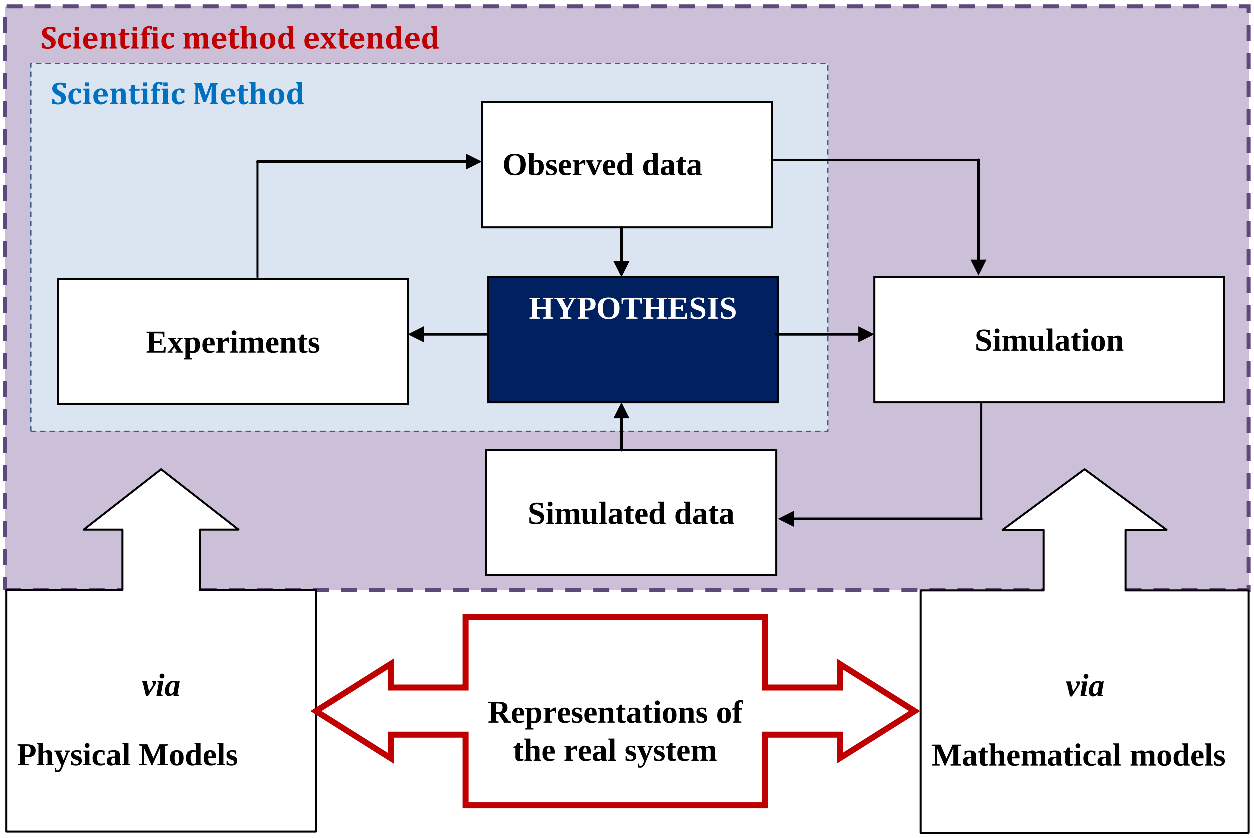

Fig.3.3: Process of Implementation

On the other hand, it should not be so complex that it is impossible to understand and experiment with it. Important part in modeling is the validity of the model. Model validation techniques include simulation of model under known conditions and comparing model output. Mathematical models are classified as deterministic, stochastic, static and dynamic. In the deterministic type of model the input and output variables are fixed values whereas in stochastic type model at least one of the input or output variables is probabilistic.

In static type of mathematical model, the time term is not taken into account whereas in dynamic type of the model time-varying interactions among the variables are taken into account. Normally, simulation models are stochastic and dynamic.

3.1.4 Simulation

Simulation is the process of solving a model on a computer. In simulation model equations are solved. Any system simulation can be completed in three steps viz. Initialization, Iteration and Termination. All visual simulation environments perform two basic functions like graphical editing and simulation. Graphical editing is used for creation, editing and retrieval of models whereas simulation gives numerical solution of the model. There are various steps involved while simulating battery model for performance determinations.

- ✓ Write mathematical equation for selected battery type
- ✓ Identify which type of battery model to be implemented.
- ✓ Select the suitable programming language for battery model implementation
- ✓ Identify variable inputs and output variables of battery model
- ✓ Draw block diagram of battery with input and output variables parameters

- ✓ Interpret with suitable example and comment on output result of the battery
- ✓ Write sample programs in different software tools
- ✓ Compare the results of different software tools with actual experiments

Followings are the steps involved in designing and developing simulation models for battery or car models.

- ✓ Formulation of the research problem of the related context
- ✓ Collect and process real system data
- ✓ Formulate and develop a research model
- ✓ Validation of developed model
- ✓ Select an appropriate experimental design
- ✓ Establish experimental conditions in the simulation and run the simulator.
- ✓ Execute simulation programs
- ✓ Interpret and present the generated results
- ✓ Suggestion for further course of action.

These are logical orders or steps to conduct simulation study and iteration at various sub-stages may be required before the simulation stud. Note that all above steps may be possible and/or required in simulation process.

3.2 Modeling and simulation tools

Modeling and Simulation of engineering systems are very much important and useful to understand behavior of the system for change in regularly or frequently used parameters. In case of battery model, the effect of changing thickness of chemical material used in battery can be predicted to understand many related battery performance parameters. Such models could be used in battery operated vehicles to predict the performance of the battery operated vehicle. There are various types of batteries and many factors affects on battery performance parameters. For estimation of battery performance different mathematical models plays an important role. The battery performance parameters are state of charge (SOC), battery storage capacity, rate of charge or rate of discharge, temperature, age or shelf life and many others. The discharge current of a battery decreases with increase in constant current discharge time. The performance of the battery depends on temperature and performance characteristics. Therefore in this research work the MATLAB, SIMPLORER and LabVIEW tools are used to perform modeling and simulation work for rechargeable battery in the context of electrical vehicles.

3.2.1 Modeling and simulation of Battery

Modeling and simulation of the battery needs to know mathematical relationship between battery input and output parameters and simulator. The simulator for battery has been developed using MATLAB and Simplorer software tool. The results of these tools are given at appropriate sections of the thesis. The mathematical battery models are explained as in the following section. The open circuit voltage (v) changes with state of charge (SOC). In case of lead acid battery, open circuit voltage is directly proportional to the state of charge of the battery. Figure 3.7 is highly useful even though it does not explain dynamic behavior of the battery and this equivalent diagram is considered for the modeling purpose. The battery capacity used in electric vehicles is usually quoted for some hours discharge. The electric cells have nominal voltages E, which gives approximate voltage when cell delivers electrical power. The internal resistance i.e. R, the current I is flowing out of the battery. The open circuit voltage V can be written

$$V = E - I \times R \tag{1}$$

Where $R = R1 + R2$

This equation gives proper prediction of the battery voltage during the electrical load. The voltage E is not constant and also affected by state of charge (SOC) and other parameters such as temperature. Mathematically, the open circuit voltage is written as

$$\mathrm{E} = \mathrm{n} \times 2.15 - \mathrm{DoD} \times (2.15 - 2.00) \tag{2}$$

Where n is considered as number of cell consist in the battery. For Nickel type of battery, this formula is not suitable because voltage or state of charge curve is not linear. In this formula temperature parameter term is not included. If temperature term is included in the formula then it would give strong impact on modeling of the battery. The equation [2] is valid for Ni-Cad traction type of battery [6]

The equation [2] is further modified and written in terms of depth of discharge (DOD) with the help of empirical formula given below.

$$\mathrm{E} = \mathrm{n} \times (-8.281\mathrm{DoD}^7 + 23.5749\mathrm{DoD}^6 - 30\mathrm{DoD}^5 + 23.7053\mathrm{DoD}^4 - 12.5877\mathrm{DoD3} + 4.1315\mathrm{DoD2} - 0.8658\mathrm{DoD} + 1.37 \tag{3}$$

To model this proposed battery MATLAB® software is used to simulate the battery behavior. The functions for calculation of E have been written in MATLAB software tool for lead acid as well as for Ni-Cd batteries. The function programs are executed before execution of main MATLAB program.

A battery with low in internal resistance delivers high current to the system as per demand of the energy. High resistance causes the battery voltage to collapse and the equipment cuts off, leaving energy behind in the system [7]

The internal resistance of most of the batteries is very low and the empirical formula for internal resistance in terms of number of cells is

$$R = No.of\ cells\ \times \frac{0.022}{C_3}\ \Omega \qquad for\ \ Lead\ Acid\ battery$$

$$R = No.of\ cells\ \times \frac{0.06}{C_3}\ \Omega \qquad for\ \ NiCd\ \ battery \tag{4}$$

The battery capacity is denoted by C and measured in Amp-Hours (AH). If battery capacity is C_3 then suffix 3 indicates the three hours of discharge. The actual battery capacity can be derived from Peukerts capacity, C_P and proved for high current [2]

$$C_P = I^k \times T \tag{5}$$

Where k is a constant, typically about 1.2 for lead acid battery called as Peukerts Coefficient. This equation assumes that battery will discharge until it is flat at a constant current I and will last T hours. Let us assume battery capacity $40C_5$ then discharge current (I) will be 8A and Peukerts capacity will be $8^{1.2} \times 5 = 60.6Ah$

The discharge time of any battery, can be written in terms of capacity-rating and initial current drawn from the battery.

$$discharge\ time = \frac{Capacity\ rating}{Initially\ drawn\ current} \tag{6}$$

The total charge removed from the battery for nth step of simulation is $CR_{\ n}$ and δt is in seconds, the time step between calculations.

$$CR_{\ n+1} = CR_{\ n} + \frac{\delta t}{3600} \times I^k \ \ Ah \tag{7}$$

It is also important to know, how much charge is removed from the plates of the battery. The supplied charge to the battery is denoted by CS and is given by the formula

$$CS_{n+1} = CS_n + \frac{\delta t}{3600} \times I \quad Ah \tag{8}$$

The depth of discharge (DoD) of battery is the ratio of the discharge removed to the original capacity. So nth step of step-by-step simulation is written as

$$DoD_n = \frac{CR_n}{C_P} \tag{9}$$

Here C_P is t he Peukerts capacity. This value of depth of discharge can be used to find the open circuit voltage. To simulate the discharge of a battery, these equations are modeled by using MATLAB software.

3.2.2 MATLAB

The acronym of MATLAB is Matrix Laboratory. It is a high-level scientific, engineering programming environment which provides many useful capabilities for plotting and visualizing data and has an extensive library of prebuilt functions for data manipulation and scientific computing. Scientific computing, also known as computational science, uses computational methods to solve science and engineering problems. The MATLAB language support large size vector and matrix operations which are fundamental to solving research problems. In MATLAB language, programs writing and algorithm developments are faster than with traditional languages. Low-level administrative tasks such as declaring variables, specifying data types, and allocating memory are avoided in MATLAB. The fast developing MATLAB software for technical computation has been giving two releases per annum with extended capabilities. The modeling of any natural systems or artificial system using numerical simulation is an important area of focus within scientific computing. Such developed models are often computationally intensive and require high-performance computing resources. In various development processes Researcher and Engineers often create models using applied mathematical methods. Fourier analysis, numerical linear algebra, and solving ordinary and partial differential equations can be used for analysis of the acquired or generated data. Various battery models are often implemented using programming languages or domain-specific modeling tools. These battery models or similar system are used for modeling and simulation purposes. Hence MATLAB, flagship software in scientific computing, is extensively used all over the world. Some factors are used for the selection of MATLAB tool for modeling and simulation and are given below.

- A flexible software structure of MATLAB comprising libraries, models, and programs enables one to integrate different model components in one package conveniently.
- Fast development with MATLAB using powerful calculation and visualization
- A wide selection of tool boxes, comprehensive collections of predefined functions for solving application-specific problems, is already available with MATLAB and is likely to grow even faster in the future.

Therefore use and demand of MATLAB software is increasing day by day in different fields of science and technology. Science and engineering student, teachers and researcher uses this software tool broadly research purposes. Graphical User Interface (GUI) is an environment available with this software that gives the option to the user developing software packages for personal and problem specific uses **[2].** Here in this research work MATLAB software is used extensively for model testing and verification of battery model and its behavior for different load conditions. With the help of MATLAB or SIMPLORER one can build mathematical models for forecasting and optimizing the behavior of complex systems. For model development following steps are considered

- Develop models using data fitting and first principle modeling techniques
- Identify parameters that optimize system performance
- Simulate models and develop custom post processing routines
- Generate reports that document model derivation and simulation results
- Share the developed models

Any model in written in MATALB follow subsequent way. The block diagram of MATLAB model has given in figure 3.4 and has to take similar efforts to write proper models of rechargeable battery in MATLAB tool.

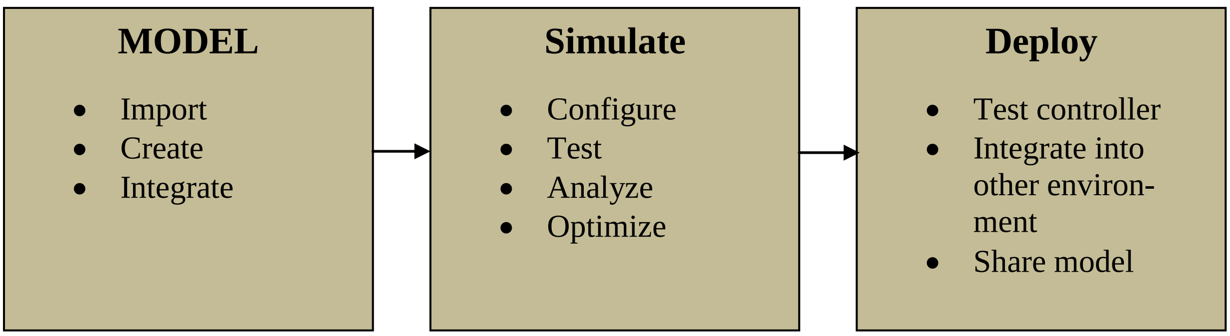

Fig. 3.4: MATLAB model

These are various step are to be carried out to model battery and simulate it for various created environment conditions in MATLAB. These steps include may include defining battery model, simulation and deployment of the developed system in controller or share the developed model [3].

Technologists and scientists are working toward an optimized design of the systems and have to develop convenient software with physical system. Therefore MATLAB software tool provides comprehensive, state-of-the-art coverage of the important aspects of modeling and simulation in battery technology and parameter determination. Thus MATLAB tool is selected for modeling and simulation of battery performance parameters purpose.

3.2.3 SIMPLORER

The simulation of an electrical, mechanical, thermal system are very much important to understand behavior of the system under prescribed conditions and accordingly changes could be suggested at the hardware side of the system.

To utilize this technology is, however, not easy since task-specific designs are usually mandatory. After verification of the result in simulator or Simplorer tool. SIMPLORER is a simulation package for electric circuit simulations that allows one to easily and quickly model. Engineers or researcher can design system model with electric and electronic components, control and mechanical components, discontinuous processes, and controls with electric circuits, block diagrams and state graph components [4]

Simplorer integrates multiple system-based modeling techniques such as circuits, block diagrams, state machines, equation level and modeling languages. This makes Simplorer the ideal tool for systems modeling. For industries where products depend on precise interaction between electromechanical components, power electronic circuits and system-based electrical and mechanical control.

Solving any general modeling problem with Simplorer tool requires certain steps to be carried out to get expected simulated result. There are minimum four different steps required for writing model in Simplorer. The given figure 3.5 below shows these steps, from creating the new projects to evaluating the simulated results. The number of the steps may vary or change or repeat according to the complexity of the problem statement. These steps are create project, create model, simulate and evaluation of the result. The steps are explained briefly in below.

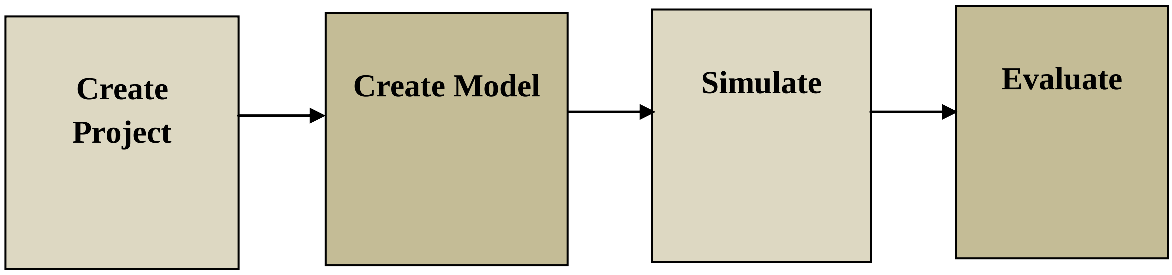

Fig. 3.5: Basic sequence for simulation problem to the result in Simplorer

Create Project- A project is a file that contains the different files of a simulation task

Create Model- A model is required to start a simulation and use the graphical inputs tool schematic or the Simplorer text editor to create the model.

Simulate- The simulator calculates the simulation model and sends the result to a display

Evaluate- Simulation results of problem can be evaluated and analyzed with the help of day post processor, Simplorer program for analyzing simulation data

In this undertaken research work the battery performance parameters of rechargeable battery is determined with the help of Simplorer® tool. The battery model is defined and simulated .These determined or simulated parameters could be used for estimation of life of the battery and other specifications of the electric car. The Simplorer® tool is one of the VHDL-AMS simulator in which schematic of the system can be drawn and simulated under specific conditions. The designed electrical system comprises the MOSFET, current sensing small value resistor and electrical load. The main parameters of the rechargeable battery like state of charge (SOC), cutoff voltage, Depth of discharge (DOD) and battery efficiency are taken in to account for deciding charge left in the battery. State of charge (SOC) is the equivalent of a fuel gauge for the battery pack in a battery electric vehicle (BEV), hybrid vehicle (HEV), or plug-in hybrid electric vehicle (PHEV).

3.2.4 Comparison of MATLAB and SIMPLORER simulators

To complement the MATLAB tool for simulation, the VHDL-AMS Simplorer tool has been used for simulations. The Simplorer® tool is one of the best VHDL-AMS simulator tools in which any schematic of the system simulated under specific conditions. The schematic of battery and electrical loads are simulated with respect to state of charge. This Simplorer based simulator system comprises of Battery, MOSFET, current sensing resistor and electrical load. The battery performance parameters of the rechargeable battery play important role in deciding many specifications of electrical vehicle like mileage, speed and other facilities inside the vehicle. The recent advances in battery technology indicate decreasing production costs and increasing energy densities to levels soon. The optimization of electrical systems based on simulations of the chain of the electric vehicle, every block of the system is simulated with a different abstraction level using the hardware description language VHDL. The comparison of MATALB and SIMPLORER is given in the following table 3.1 to understand the difference and prominent salient features. Both the software's are used for modeling and simulation of battery performance parameters. The results in MATALB and SIMPLORER have shown elegant ways of solving the system problems associated with transients in electrical circuits. It is evident from the work that in addition to a good knowledge of MATLAB® programming, the MATLAB® approach requires a sound mathematical background and knowledge of the basic laws of circuit analysis or electrical systems.

Table 3.1: Comparison table of MATALB and SIMPLORER tools

MATLAB	SIMPLORER
• High-level language for numerical , mathematical computation, visualization, and application development tool • Compilation and Linking is not required hence gives fast performance Interactive environment for iterative exploration, design, and problem solving • MATLAB provides tools to acquire, analyze, and visualize data • Tools for building applications with custom graphical interfaces (GUI) • MATLAB add-on products provide built-in algorithms for signal processing and communications, image and video processing and control systems • MATLAB provides Simulink tools along with add-on tools for simulation purpose • Functions for integrating MATLAB based algorithms with external applications and languages such as C, Java, .NET, and Microsoft® Excel® • MATLAB access data from files, other applications, databases, and external devices.	• Simulation models can be created easily and quickly • Simulations are processed accurately • Simulations in Simplorer is reliable with simulator backplane technology (electrical connector in parallel with each other) • Simplorer results can be transferred to other applications • Provides Equivalent circuit extraction (ECE) Maxwell interface • Provides $RMxprt^2$ interface • Provides SPICE interface • MATLAB/SIMULINK interface • C interface for linking user defined model in c code • Provides IEEE interface • Simulate frequency analysis (Optional programs) • Simplorer provides analog and mixed signal analysis • Simplorer provides readily VHDL code for deployment • Mixed or combined types system can be simulated • Experiment tools with optimization • Add on model Libraries for power, automotive, mechanical, hydraulic, machines, non linear and linear transmission components.

The SIMPLORER® approach requires only a good understanding of the SIMPLORER® package, the ability to select and appropriately initialize circuit components and achieve good connections for successful simulation. Although a faster response time was achieved with the MATLAB® approach, the two approaches satisfactorily showed the battery responses for different electrical loads [5]. It is, therefore, recommended that system engineers and researchers who are tackling with problems involving transients in battery charging and discharging should utilize these modern tools in their analysis.

3.3 Modeling and Simulation of Battery Performance Parameters

Battery performances and characteristics at diverse operating conditions are critical in its applications particularly in Electrical Vehicles (EVs) and Hybrid Electrical Vehicles (HEV). With a precise and competent battery model it can be predict and optimize battery performance mainly under practical runtime usage such as Battery Management Systems (BMS). An accurate method for estimating the battery parameters is needed before constructing the reliable battery model. There are three famous battery models; battery equivalent circuit, Thevenin and second order Battery modes are commonly used for battery modeling.

The measurement of battery performance parameter is matter of apprehension, and hence understanding of battery parameters is necessary. There are various battery parameters in the context of electrical vehicle. Measurements of the internal resistance of each cell or module side, capacity testing, density measurement etc. in batteries are not straight forward. This essentially requires sophisticated hardware and software, which is capable of handling complex systems and provides meaningful information to the user in a scientific way. Here MATLAB software tool is used for modeling and simulation of Battery Performance Parameters (BPP) with different electrical loads. In this chapter modeling of the rechargeable battery and simulated results are given to understand battery behavior for different types of electrical loads. A simple, fast and effective equivalent circuit model of battery is implemented to facilitate the battery model as a part of the system model. The equivalent circuit model of the battery has been proposed for modeling and simulation and simulated results are presented here for better understanding of battery behavior in various conditions. The battery model parameters are simulated for different battery conditions using MATALB software .These steps are further described as follows with the help before flow. The steps or algorithm for simulating these parameters of battery is given in the followings. Initially all constant terms of the modeling of the battery equivalent circuit are defined at the beginning of the MATALB code i.e.no of cells, capacity of the battery, internal resistance, Peukerts constant (k), discharge current, delta etc. The battery equivalent circuit consists of circuit elements and each one has precisely predictable behavior which is already explained in the previous section of battery modeling. In this battery modeling concept, it is necessary to understand that the values of circuit parameters are not constant i.e. E and R. The open circuit voltage (V_{oc}) and internal resistance varies with state of charge (SOC). In lead acid battery, open circuit voltage is directly proportional to the state of charge of the battery. This variation of the battery parameters are introduced in figure 2.13 (reference. chapter no 2) hence this model is highly useful even though it does not explain any dynamic behavior of the battery. In this research work modeling of battery equivalent circuit has been considered and used for modeling and simulation purpose for parameter estimation.

The battery equivalent circuits of figure 2.13 (Previous Chapter) is assumed for battery modeling purpose. The algorithm and flowcharts are prepared for writing battery model using MATLAB software tool. This model writing process two different MATALB functions are written separately. These functions are called as user defined functions and saved MATALB tool and these functions are called whenever required in the program.

After initialization certain parameters of the battery, the open circuit voltage of the battery is formulated and these functions are called whenever required in the MATLAB program execution. In the program number of steps, CR (n), depth of discharge has to be defined according to the formulae. The formula is written for knowing terminal voltages across battery and assigns certain conditions for depth of discharge. After formulating terminal voltage under certain conditions the supplied charges of the batteries are defined under some condition with V (n) and different parameters. After these steps or procedures the last is to analyze the generated result by the MATLAB simulator. In the software part the last step is to plot the various graphs for different active loads conditions.

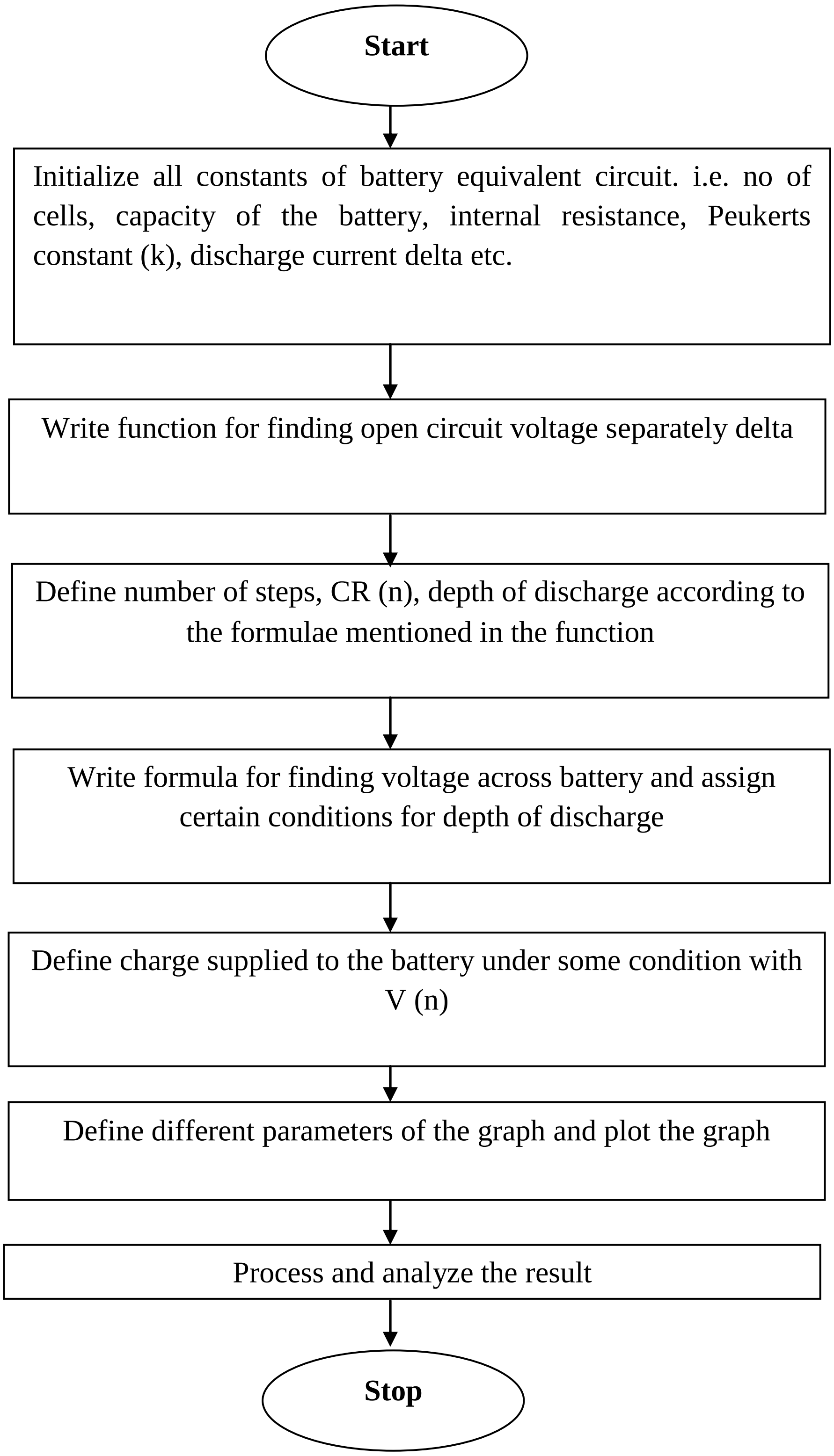

Fig. 3.6: The steps of simulating battery parameters

The analysis of the simulated data gives battery discharging time and discharging current. This simulation has helped in verification of secondary data which are gathered from different sources. The algorithm of the modified battery modeling is given in figure.3.6.

3.3.1 Effect of active load on battery performance parameters

To understand effect of an active load on rechargeable battery for various load current, battery equivalent circuit has to be considered for simulation. The battery equivalent circuit consists of circuit elements and each one has precisely predictable behavior. This is the proposed battery equivalent circuit for modeling and simulation using MATLAB. This battery equivalent circuit shows dynamic behavior for charging and discharging of the battery. For modeling the battery, it is necessary to understand that the values of circuit parameters are not constant i.e. E and R.

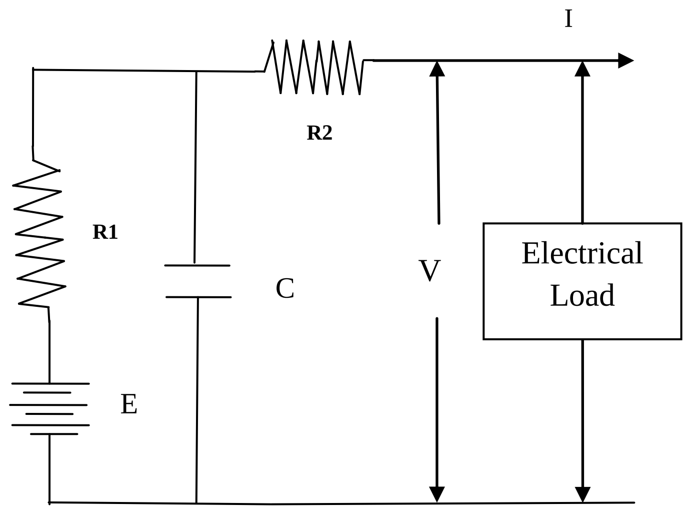

Fig. 3.7: Proposed battery model for modeling and simulation

- **MATLAB based simulator result**

MATLAB software based battery simulator with constant current source has been developed and used for knowing battery capacity and battery discharging time for different active loads. In active load the discharging current of the battery is kept constant and battery voltage is decreased according to load and discharging time.

In almost in case of experimental research, it is necessary to deal with variety of data. Data acquisition, analysis and visualization are the basic steps in handling the experimental parameter of particular system. Modeling of any experimental conditions and verifying the dependence of output parameters on experimental parameters can be simulated.

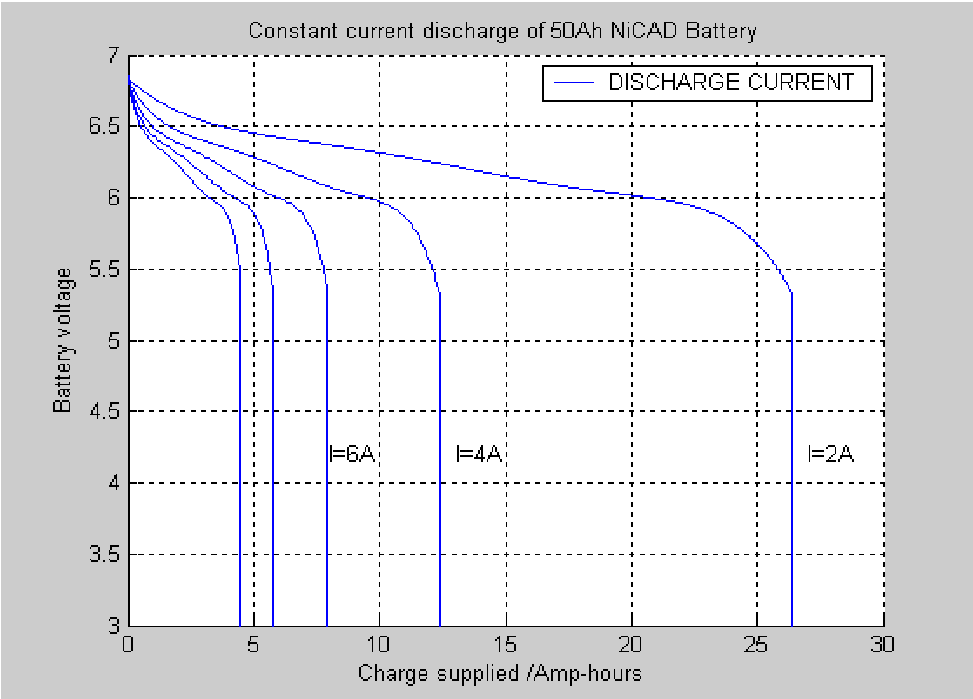

Fig. 3.8: Ni-Cd Battery discharging for different currents

MATLAB has been used as a modeling and simulation tool for harnessing data representation and analysis skills of the researcher. Here in this section lead acid battery is modeled and simulated using MATLAB tool. The constant current sources are used to discharge the battery and simulations are carried out for different discharge currents for NiCad 6V Battery.

Following graph shows discharge curves are given for different discharging current 2A, 4A, 6A, 8A and 10A.

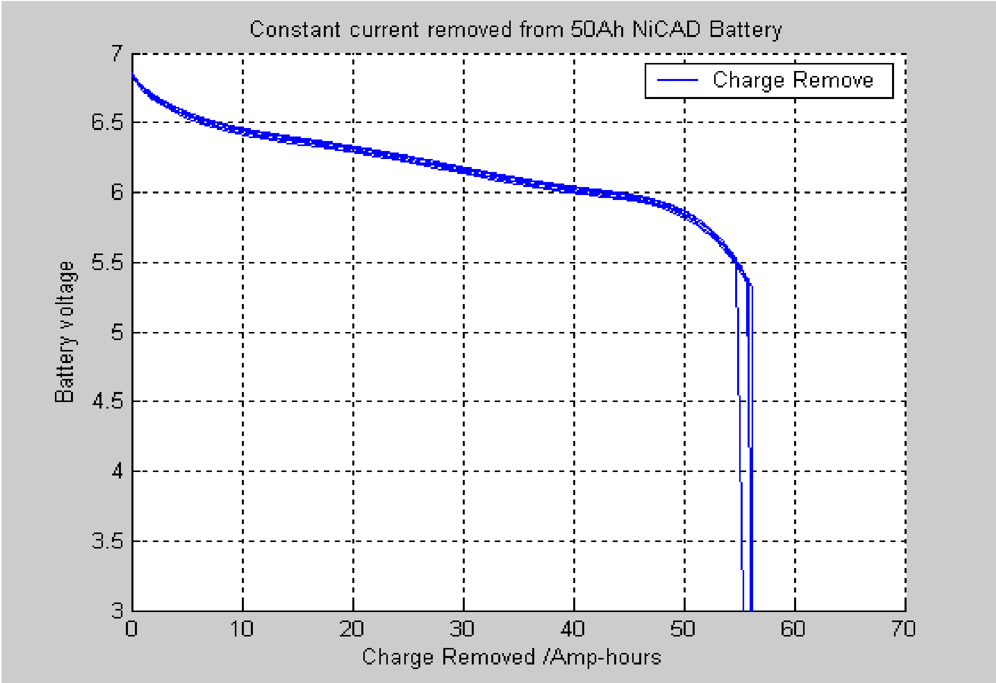

Fig. 3.9: Charge removed from the battery by 5th step simulation

Similarly an additional MATLAB simulated results for charge removed from the battery is also given figure 3.9.This graphs comments on charge removed from the battery for five different active loads with currents 2A, 4A, 6A, 8A and 10A.

Hence MATLAB tool is useful software tool for writing mathematical model of any battery and simulate it for different battery conditions. The writing functions for lead acid battery and Ni-Cad is also simple for the experimentation. The algorithm is also been developed for main program and this main program can be debugged for changing battery parameters of the battery. The battery model written in MATLAB is a dynamic battery model whose parameters are changes according to the terminal voltage and discharging current of the battery.

3.3.2 Determination of Battery capacity using MATLAB

Any model represents the system itself, whereas the simulation represents the operation of the system over time. Simulations techniques are used in many contexts, such as simulation of technology of any system for performance optimization, safety engineering, testing, training, education, and video games. Simulations are used in scientific modeling of natural systems or human systems to gain insight into their functioning. Simulation shows the eventual real effects of alternative conditions and courses of action.

Any battery, determination of battery capacity is an important issue therefore battery simulator is developed to find actual battery capacity using peukerts exponent technique. The simulation work is concentrated on development of battery simulator and estimation of battery parameters using Peukerts law. The Peukert coefficient is estimated from the real time observations carried with the help of active load battery discharge experiment. Various methods are available to estimate the battery efficiency and the life time of the battery.

This simulation work deals with the use of computers to test the battery parameters using scientific tool as a MATLAB. The graphical user interface (GUI) has been developed for battery model to represent the behavior of the selected system and represents the battery system over time.

Thus this developed battery system gives real effects on battery under test. In this process of simulation, the Peukerts law played a significant role. Every battery system has a specific Peukerts exponent and this exponent is used to estimate the battery performance parameters. This method also used for finding battery capacity and actual capacity of the battery.

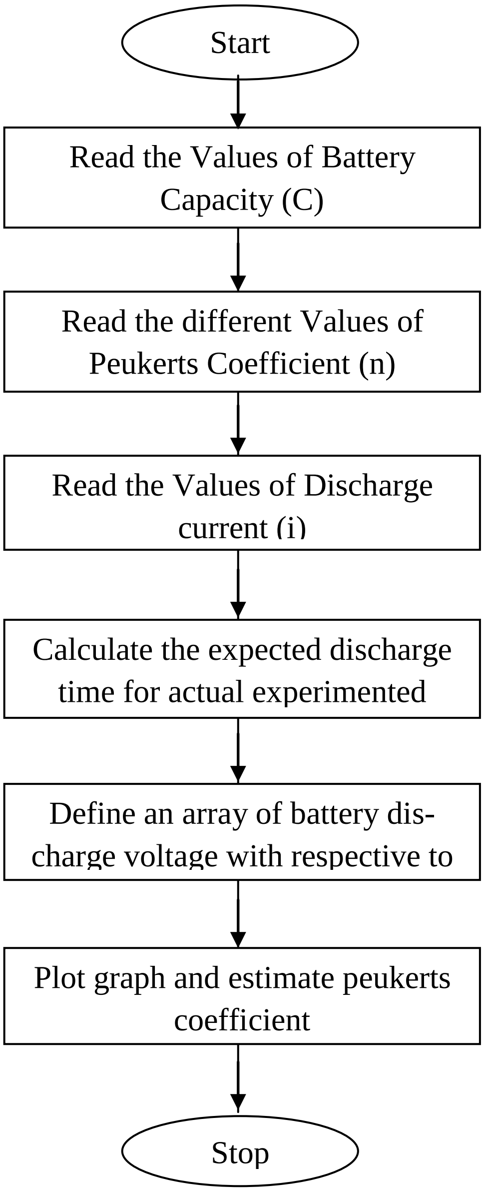

Fig.3.10: Flow chart for finding peukerts coefficient

The above flowchart figure 3.10 of the battery simulator is developed for prediction of state of health SOH of the rechargeable battery. The important number i.e peukerts number is unique to each battery type that is put into peukerts formula in order to perform the calculations. The above flowchart gives total development procedure of battery simulator. Accordingly the battery simulator is developed and experimented for different values of discharge current and different battery capacity.

The peukerts formula is

$$t = C/I^n \tag{10}$$

Where, n= Peukerts exponent, C = Battery capacity and I = discharge current

Using Peukerts law the battery discharge time can be calculated thus the input parameters for this purpose are Peukerts exponent which is a unique number for every battery generally for lead acid battery it is between 1.1 to 1.4 with the other parameter is battery capacity and the discharge current.

After these input parameters to the simulator, the mathematical calculations are performed in order to calculate the discharge time using the peukerts formula. This battery discharge time is then used to find actual capacity of the battery and to plot the graph of battery terminal voltage versus discharge time.

- **MATLAB based simulator Result**

With the help of all the information gathered and referring to many books, internet, and MATLAB manual the layout was created for the simulation of the battery using Peukert law. In the simulator the discharge current is set through the edit text field, the value of battery capacity is given and the Peukert coefficient is entered.

The graph of battery voltage versus time is seen on the screen it also has one more facility to plot the excel sheet which has the readings of battery testing. After entering all the fields required the start simulation button is pressed and the graph is plotted accordingly. When all the parameters are entered and the start button is pressed the graph is viewed, which gives the behavior of the battery.

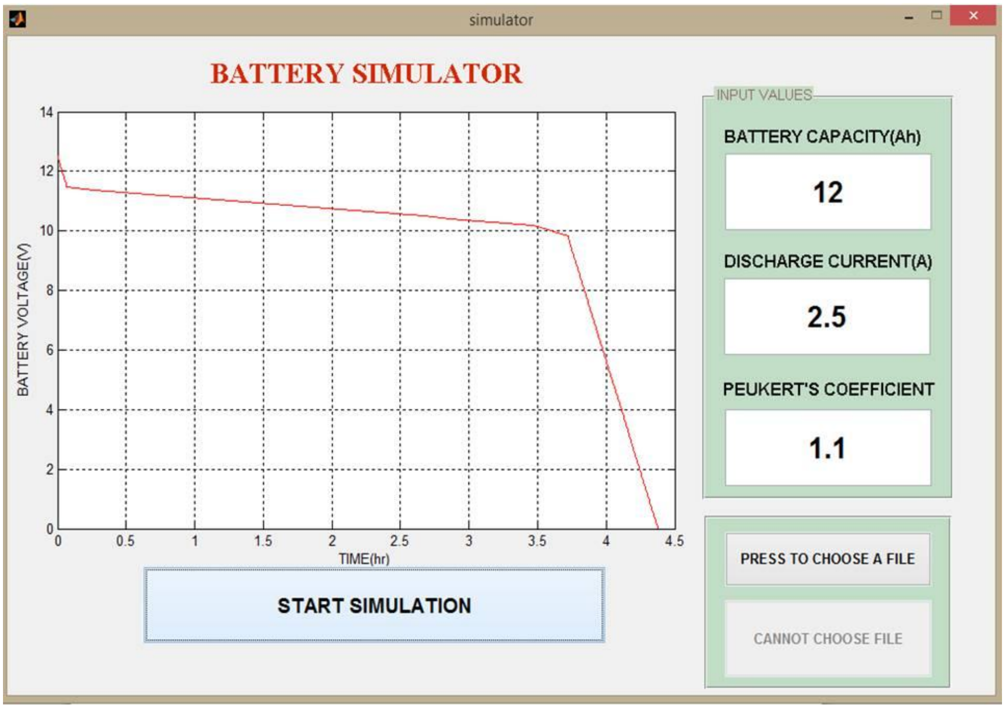

Fig. 3.11: Battery simulation for finding peukerts coefficient

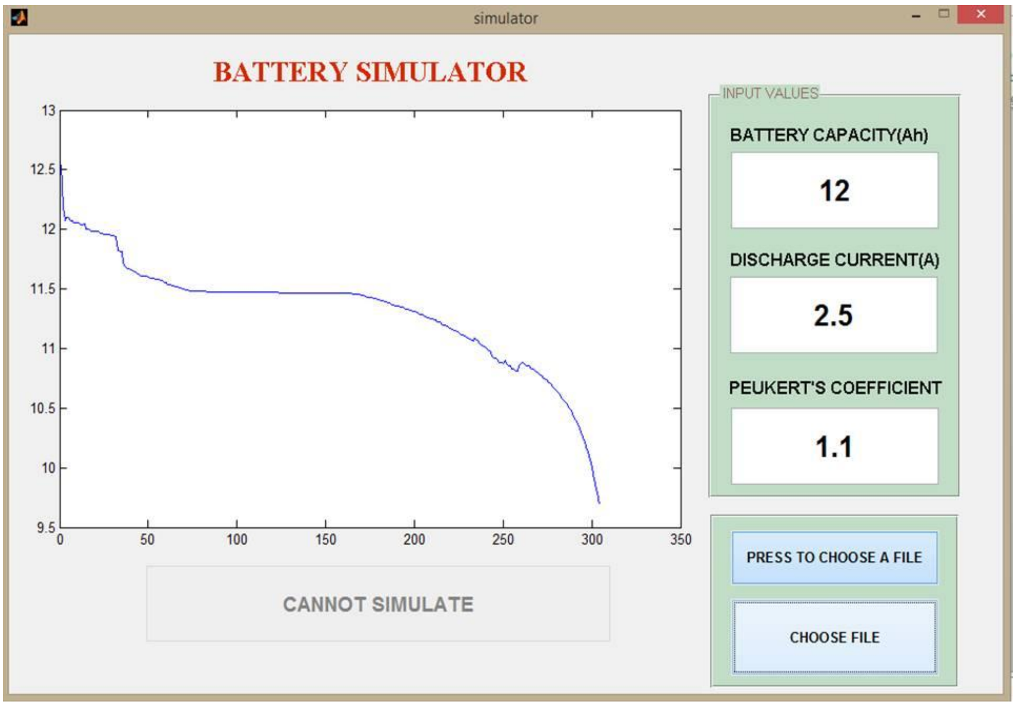

Fig. 3.12: Actual experimented result

The above figures no. 3.11 and 3.12 shows the simulations of the battery with its capacity 12Ah, discharge current 2.5 A and Peukerts coefficient 1.1 in same way if the excel file is available the graph can be as shown in the figure below. When any external file in MATLAB is to be used it is necessary to study the file handling capability of MATLAB. Here the function xlsread () in MATLAB is used. Xlsread get data and text from a spreadsheet in an excel workbook. After using this function the two columns of the excel sheet are separated and the graph is plotted as shown in the figure 3.12. This simulator helps in prediction of battery discharge time with connected load or discharge rate and hence state of health of the battery.

These simulated results are compared with actual experimental results using active load discharge experiment and then predictions are possible using comparison can be seen in figure 3.1 and figure.3.12. The graph on figure 3.11 is simulated and graph on figure 3.12 is experimental result of the discharging curve of the same battery. If these two graphs are superimposed then actual discharge time of the battery can be estimated easily from the graphs. After discharge time knowing of the battery the Peukert exponent can be compared with standard one from the simulated results. The peukerts constant gives approximation about remaining life of the battery.

To validate the results generated shown by the simulator, hardware is designed to discharge the battery using active load. For the experimentation 35AH battery is discharged with the constant current of 6.5A and shown in the figure 3.13.

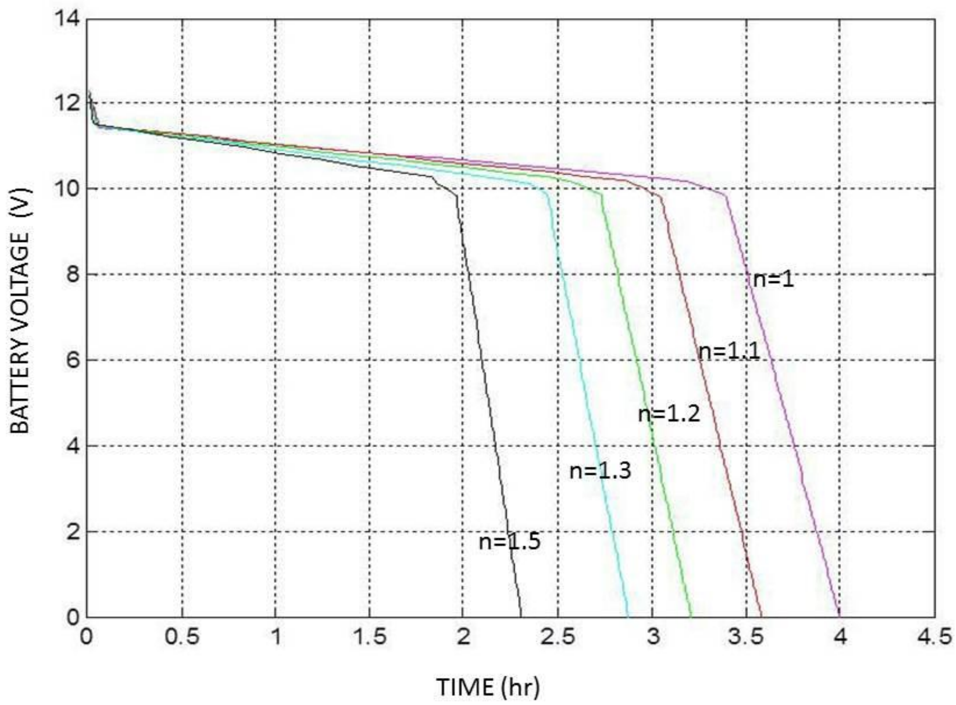

Fig 3.13: Discharge curves for 26 Ah battery and discharge current 6.5A with different peukerts exponent (n).

The figure.3.14 shows the various discharging curves for different values of Peukert's coefficient. After comparing two graphs it has been observed that value of Peukert's coefficient is around 1.1 which is showing battery efficiency approximately as 80 %. Battery Efficiency is assumed as100% when coefficient n value is 1. The table 3.2 gives the idea about efficiency of the battery and Peukert's coefficient number, thus the value of n can be estimated in this manner.

Table 3.2: Battery efficiency and peukerts coefficient

Peukerts coefficient	Battery Capacity (%)
1	100
1.1	80
1.2	60
1.3	40
1.4	20

Thus the Peukert's coefficient can be used to find the efficiency of the battery and the life estimation of the battery. Therefore using this experimentation the estimation of battery life and discharge behavior using battery simulator for HIL setup is studied and experimented for different batteries.

3.3.3 Simulation of state of charge (SOC) using SIMPLORER

The task of simulation using SIMPLORER involves creation of project using SSC Commander, creation of model using the graphical input tool schematic or the SIMPLORER text editor, evaluation and analysis of result using the simulator data and Day Post Processor applications respectively.

The schematic of determination of battery performance parameters is given below as shown in figure 3.10. This consists of sensing resistors, potential divider, MOSFET and electric load as a DC motor along with model of battery. The load is driven by MOSFET and sensing resistor. The current value of the electric load is decided by gate voltage of the MOSFET. Initially bias voltage is set by the resistors R1= 80Ω and R2 =20Ω.The potential drop across gate terminal decides current passing through the MOSFET and subsequently drives motor.

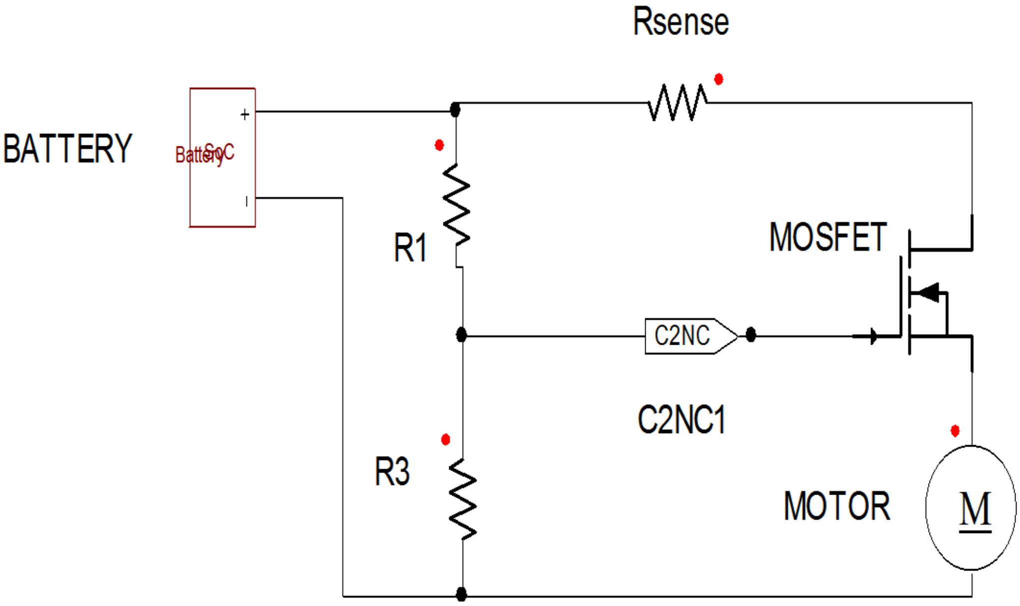

Fig. 3.14: Battery Performance Parameters testing Setup

The R_{sense} is the small value (0.5Ω) resistor sensing resistor connected in series of MOSFET and Battery to limit the circuit current. The circuit is drawn in Simplorer® tool. It is one of the VHDL-AMS simulator in which schematic of the system can be drawn. The prescribed battery performance circuit is simulated under specific conditions like initial time, ambient temperature, end time etc. In the schematic some typical values of the components are considered for simulation purpose. The typical battery model parameters are capacity factor (1), initial voltage (V_{int}=5V) and maximum voltage (V_{max}=6V) considered for simulation of the following circuit. The current of dc motor is decided by voltage between gate and source of the MOSFET and accordingly battery will drain. The model parameters of the DC motor considered for simulations are armature current of 2A, armature resistance of 1Ω, armature inductance of 10mH and inner rotor speed of 2000rpm. The model in Simplorer represents a lead-acid battery model for the design and optimization of electrical on-board systems of automobiles and other stand-alone and mobile applications. The model is suited to model the voltage-current characteristics of these batteries in charge and discharge operation. Several loss effects during charging are included to model the mismatch between charged electrical and stored chemical energy.

Apart from this, the internal resistance varies with temperature and state-of-charge to yield a realistic voltage behavior under load. The battery model is a behavioral model of a lead-acid battery. It is designed to generate reasonable results in a temperature range from -20°C up to +50°C and currents up to ten times the rated current.

- **Simplorer based results and conclusion**

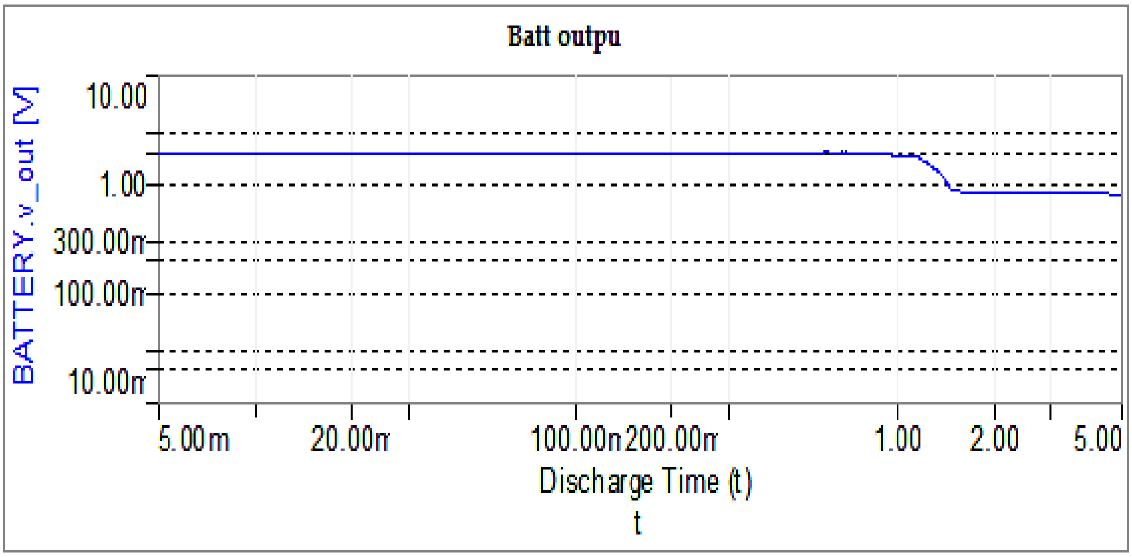

Fig. 3.15: Battery Terminal Voltage verses discharge Time

As battery drains due to dc motor current, state of charge (SOC) of the battery varies means it decreases. The simulated values of state of charge (SOC) is determined using Simplorer® tool and shown graphically. The current value of SOC gives the amount of charge present in the battery. The rechargeable battery model with active load / DC motor is simulated in Simplorer for transient state of analysis. The schematic of battery performance parameters setup is simulated in the student version of Simplorer® tool.

The simulated results are given in the form of graphs as shown in figure 3.15 and figure 3.16. From the graph figure 3.16 it is seen that how the battery state of charge changes with discharge time and can be determined from this graph. The closed circuit current decides the potential of gate terminal of the MOSFET. When the circuit MOSFET turns on then same MOSFET current flows through the DC motor with default parameters and accordingly speed of DC motor varies. After over period of time the battery gets fades off or detoriates due to high current dischrge and battery potential of gate terminal of MOSFET drops.This Lead DC motor decreases and subsequently its speed decreases.

The transient analysis of the circuit ia aslo studied and plotted the graphs of current verses discharge time of the battery model..

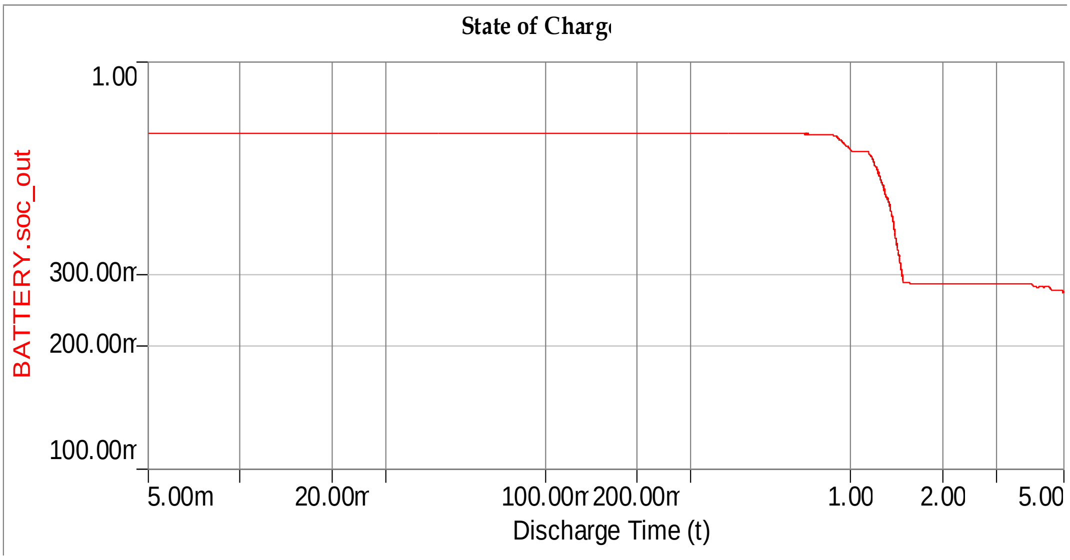

Fig. 3.16: Battery SOC verses discharge time

The various simulation steps are executed for more than 500 seconds and different simulated graphs are plotted and battery performance parameters like state of charge and terminal voltage are studied .The figure. 3.12, shows how SOC changes with output voltage of the rechargeable battery. From these determined values of SOC it is easy to understand how much battery charges left in the battery at this instant of time.The SOC range shown in the simulated graphs are 0 to 1 and it is understood as 0% to 100%. With the help of these SOC values estimatation of other battery performance parameters are posssible. Through this system simulation it is possible to find how long distance could travel by electrical vehicle.Hence this simulation is useful for electrical vehicle. The VHDL code for this schematic is possible for professional version of Simplorer® tool.

3.3.4: Conclusion

Modeling and simulation of battery performance parameters are studied and experimented successfully with the software tools of MATALB and Simplorer. Initially the fundamentals of the modeling and simulations are explained theoretically and understood properly This understanding is important for modeling of any static or dynamic system..The different modeling and simulations software's are compared according to the battery modeling perspective. Approximate mathematical battery model are explained for lead acid battery and nickel cadmium battery. This battery model is simulated in MATALB and results are represented for different currents. Charge supplied to the battery and charge removed from the battery is also formulated and used effectively in the MATLAB based simulator. The respective parameters like terminal voltage against discharging current and number of simulation steps are given in figure 3.8 and figure.3.9. Determination of battery capacity using MATLAB simulator is also developed and experimented. In this development graphical user interface is also developed for battery life estimation. This developed MATLAB based GUI gives approximate values of peukerts coefficient. These peukerts coefficient values are compared with actual experimented values of peukerts coefficient.The experimental data is taken from actual discharge profile of the battery. The actual experimented results are plotted on the simulated results from this peukerts number is estimated. This helped to know number of cycle's battery have been used before. The effect of active load on the rechargeable battery is also simulated with an AMS (analog mixed signal) software tool. In AMS Simplorer tool, state of charge of the battery is estimated for inductive DC motor load. The battery parameters are modeled and used in the proposed experimental setup diagram is shown in figure 3.14.The MOSEFET based active load circuit has been used for simulation purpose. Battery state of charge and terminal voltage of the battery are estimated for generated simulated results. Simplorer software based simulated results are shown in figure.3.15 and figure.3.16. Therefore this modeling and simulation of battery performance parameters plays important role in deciding further research work for comparison of actual result with expected results of the battery.

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