Battery Modeling and its Dynamics for the application in Renewable Energy Systems

Anil Kumar

Department of Electrical Engineering
National Institute of Technology Rourkela
Rourkela-769 008, Odisha, India

Battery Modeling and its Dynamics for the application in Renewable Energy Systems

Thesis submitted in partial fulfilment of the requirements for the degree of

Master of Technology

in

Electrical Engineering

(Specialization: Industrial Engineering)

by

Anil Kumar

(Roll No. 212EE5396)

under the supervision of

Prof. Somnath Maity

Department of Electrical Engineering
National Institute of Technology Rourkela
Rourkela, Odisha, 769 008, India

June 2014

Electrical Engineering Department
National Institute of Technology Rourkela
Rourkela-8, Odisha, India.

Certificate

This is to certify that the work in the thesis entitled ***Battery Modeling and its Dynamics for the application in Renewable Energy Systems*** by ***Anil Kumar*** is a record of an original research work carried out by him under my guidance and supervision in partial fulfilment for the degree of Master of Technology with the specialization of ***Industrial Engineering*** in the ***Electrical Engineering department***, National Institute of Technology Rourkela. Any part thesis has not been submitted for any academic award or degree elsewhere.

Place: NIT Rourkela
Date: June 2, 2014

Prof. Somnath Maity
Asst. Professor, EE Department
NIT Rourkela, Odisha, India

Author's Declaration

I, **Anil Kumar** (Roll No. **212EE5396**) comprehend that plagiarism is characterized as any one or the blending of the accompanying

1. Un-credited directly duplicating of individual sentences, sections or representations, (for example, diagrams, charts, and so on.) from any source, distributed or unpublished, including the Internet sources.
2. Un-credited dishonorable summarizing of pages or sections (changing a couple of words or expressions, or modifying the first sentence request).
3. Credited directly duplicating of a real partition of a paper (or theory section) without clear depiction of who did or composed what.

I have verified that all the thoughts, articulations, charts, outlines, and so forth., that are not a consequence of my work, are appropriately credited. Long expressions or sentences that must be utilized directly from distributed writing have been plainly recognized utilizing quotes.

I attest that no segment of my work could be considered as plagiarism and I assume ownership such an objection happens. I see completely well that the guide of the theory may not be in a position to check for the likelihood of such frequencies of plagiarism in this group of work.

Place: NIT Rourkela
Date: June 2, 2014

Anil Kumar
Roll: 212EE5396
EE Department (Industrial Engg.)
NIT Rourkela, Rourkela, Odisha

Acknowledgment

I am grateful to different neighborhood and overall co-partners who have helped towards forming this hypothesis. At the begin, I may need to express my bona fide because of Prof. Somnath Maity for his suggestion all around my hypothesis work. As my task guide, he has constantly influenced me to stay focused on finishing my goal. His discernment's and comments helped me to manufacture the general heading of the investigation and to make progress with examination in significance. He has helped me staggeringly and been a wellspring of data.

I extend my thanks to our HOD, Prof. A.K.Panda for his valuable advices and encouragement.

I am truly grateful to my friends Shubham, Ranjeet, Nilesh, Sumit and Mayank. My sincere thanks to everyone.

I would like to thank specially Pradeep Sahu sir for standing beside me all the time and support me morally and ethically.

I must perceive the educational possessions that I have got from NIT Rourkela. I may need to thank administrative and particular staff parts of the Electrical Department who have been minding enough to provoke and help in their different parts.

Last, but not the least, I may need to dedicate this work to my family, for their veneration, diligence, and cognizance.

Anil Kumar
Roll: 212EE5396

Abstract

In this thesis document presents recommended battery design for stand-alone photovoltaic (PV) systems. In this report, a new model of battery is developed. The developed battery model is based on battery characteristics and its behavior. It includes battery dynamic behavior like SOC, battery capacity, battery current. Batteries are getting to be progressively vital to our life as they are connected in an extent of different regions. Now a day for Photovoltaic system battery is more important especially in Stand-alone PV system where grid facility is not present where we have to store the power which is produced by PV array. In this way the unwavering quality of battery is a discriminating issue in these battery provisions. By and large, framework parts, other than PV modules, in the same way as batteries, charge controller and so forth (additionally eluded as an offset of framework) are obliged to understand a dependable source of energy. The exploration center must be given on battery demonstrating and its measuring for Stand-alone PV systems. There will be investigation of non-linear elements of battery and its displaying also. The goal is to model the battery based on circuit approach and in this way joins together the battery model with a resistive load, and external DC voltage source and thus analyzes the charging and discharging behavior of proposed battery model. .

Keywords: *Battery; SOC(State of charge); PV(Photovoltaic) system)*

Abbreviation

Some notations are as follows :

- C_{CAP}= Overall Capacity of battery.
- S_0= Initial state of charge of battery.
- V_{batt}= battery terminal voltage.
- i_{batt}= current of battery, negative sign shows the discharging of battery current.
- Z_{eq}= Equivalent of two RC-networks.
- V_{batt}= battery terminal voltage.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

Motivation
Thesis Contribution
Project Overview
Thesis Organization

Chapter 1

Introduction

1.1 Motivation

In 21st century vitality emergencies, drag each analysts fixation towards the renewable energies, renewable vitality is a wellspring of clean and efficient power vitality. Around all renewable energies photovoltaic (PV) and wind are acknowledged to be great wellsprings of vitality. Numerous looks into are going ahead in the territory of PV framework, huge test around there is to track maximum power point(MPP) in the element climatic conditions and shading condition in light of the fact that MPP shifts with change in temperature and insolation.

This report introduces an outline of battery engineering which is generally utilized as a part of stand-alone Photo-voltaic (PV) systems. Renewable energy sources have been attaining the maximum concern of interest today to compensate the conventional power generation through fossil fuels. Among all the available renewable sources, Solar Photovoltaic has been proving to be the promising energy source to generate electrical power as it is abundant and conversion process is simple and direct.

In numerous sorts of stand-alone Photo-voltaic (PV) systems, batteries are obliged to level out irregularities in the sun oriented light and concentrate the sun powered vitality to higher force. Today, leadacid and nickelcadmium batteries are regularly utilized as a part of PV systems. Some developing battery advances might additionally be suitable for capacity of renewable vitality, for example, distinctive sorts of redox flow batteries and high temperature sodiumsulphur batteries. ID of the essential parameters in PV requisitions might be utilized to coordinate exploration and item upgrades, and correlation of distinctive battery innovations could be utilized to guide battery decision for particular client conditions.

Points of interest are given about the regular sorts of overflowed lead-corrosive, valve controlled lead-corrosive, and nickel- cadmium cells utilized within PV frameworks, including their outline and development, electrochemistry and operational execution aspects. Examinations are given for different battery advances, and contemplations for battery subsystem outline, assistant frameworks, upkeep and security are talked about.

The Battery for Stand-alone PV System must be displayed and broke down both scientifically means mathematically and additionally by accepting with the assistance of simulation works.

1.2 Thesis Contribution

This work was carried out to address a huge need inside the PV business in regards to the provision of batteries in stand-alone systems. A percentage of the more discriminating issues are recorded in the accompanying.

- Batteries encounter an extensive variety of operational conditions in PV orders, including shifting rates of charge and release, recurrence and profundity of releases, temperature variances, and the systems and breaking points of charge regulation. These variables make it extremely troublesome to precisely foresee battery execution and lifetime in PV systems.
- Untimely disappointment and lifetime forecast of batteries are significant concerns inside the PV business.

- Battery execution in PV frameworks could be ascribed to both battery outline and PV framework operational variables. A battery which is not planned and developed for the operational conditions accomplished in a PV framework will in all likelihood fizzle rashly. In any case, injurious operational conditions and absence of fitting support will bring about disappointment of even the more sturdy and strong profound-cycle batteries.
- Battery makers' details frequently don't give sufficient data to PV provisions. The execution information displayed by battery makers is commonly focused around tests directed at specified, consistent conditions and is regularly not illustrative of battery operation in real PV frameworks.
- Wide varieties exist in control controller plans and operational attributes. Presently no benchmarks, rules, or measuring practices exist for battery and charge controller interfacing.

1.3 Project Overview

To model the battery with the help of accurate and efficient circuit, so that we can predict and optimize battery runtime and circuit performance.

- The battery for Stand-alone PV system has to be modelled and analysed both mathematically as well as by validating with the help of simulation works.
- To overview the features and parameters of battery and analyse the characteristic of it.
- To model the battery in such a way that it will work in each and every conditions under constant temperature conditions.

1.4 Thesis Organization

The thesis is organized as follows:

Chapter 1 describes the project motivation, organization and overview of the project.

Chapter 2 reviews the literature on various mechanism of PV systems and mechanism of battery. Literatures are also reviewed on various battery models which are based on mathematical and circuit oriented model. Various papers proposed such kind of battery which is actually capable of to observe the dynamic characteristic of electrical battery and nonlinear effects under different condition, the proposed battery model can easily follow an accurate SoC of electrical battery and runtime prediction.

Chapter 3 describes the function Photovoltaic systems, in this chapter describes the features any various types of PV system and the deals with the importance of battery. In this chapter describes the characteristics and various types of battery and use of them in PV system.

Chapter 4 describes the features of various battery model, studied the various circuit and mathematical oriented battery models and finally proposed the battery model for PV system. Test the Proposed model with the help of Simulation/MatLab platform. Simulation results are shown in this chapter

Chapter 5 finally summarizes the results obtained in each chapter and future scope of work is discussed in brief.

Chapter 2

Background and Literature Review

Chapter 2

Background and Literature Review

This chapter gives an idea about the importance of battery in photovoltaic system especially in standalone system where grid facility is not present.

2.1 Paper review

This section briefly describes the outcome of various standard literature and through this try to figure out the problem statements.

Many literatures gives an idea on the modelling of battery for solar photovoltaic (PV) system

IN [1] G A.Rincon-Mora et.al,proposed a one kind of battery model which is accurate , and comprehensive. The primary objective of this paper was to find out the dynamic features of electrical battery from nonlinear open circuit voltage and capacity time subordinate ability to transient reaction. In this paper effects of self-discharge is neglected.

IN [2] Shuhui Li. et.al, proposed a methodology of Battery Modelling based on Mathematical and Circuit Oriented Approaches. The primary focus of this paper is to compare the circuit based battery and mathematical battery models. For circuit based model, the impact of State of charge (SoC) with circuit parameters is shown. Whereas in mathematical based model it represents the Voltage and Current relationship with state of charge (SoC) of electrical battery, here mathematical equation of proposed model is based on Shepherd relation.

[3]T.Kim et al. In this paper proposed the kind of battery which is actually capable of to observe the dynamic characteristic of electrical battery and nonlinear effects under different condition, the proposed battery model can easily follow an accurate SoC of electrical battery and runtime prediction.

In [4] IEEE Recommended paper, studies the fact about standard battery, types of battery and its parameters. In this paper studies the battery sizing tips for various applications like use of Lead-acid batteries in Standalone PV system.

In this paper studies the battery management system ,its actually controls the amounts of flow of electrical power from PV array to storage battery and electrical load. The battery management system is based on value of SoC which is estimated by this system.

In [5] S.Martinez, studies the cost optimization techniques, in this paper problem is to find out the size of battery storage in PV system. Here Optimization technique is being used for battery for cost optimization. In this paper an algorithm is introduced for calculating an critical value which is unique, this value is associated with battery size, this critical value is used to minimized the cost related with total electrical power purchase from the electrical grid.

In [6], this paper explains the battery management algorithm for improvement of the battery performance at different situations.

In [7], Charging and discharging behaviour of electrical battery with implementation of different kind of loads. This paper shows the battery sensitivity with circuit impedance.

In [8], shows the behaviour of multiple power sources to the system. Here analysed the behaviour of Li-ion battery at various test conditions.

In [8] [9] [10] [11], shows the mathematical model of battery. Here analysed the dynamic behaviour of electrical battery.

In [12], shows the detection and prediction of terminal volatge collapses in Li-ion batteries.Here knows the complete features of battery and studied one simplified battery model for Li-ion battery, by using universal adaptive stabilization (UAS) track the output voltage curve of a physical Li-ion battery.

In [13], studied one battery model which is based on equivalent electric circuit and studied the behaviour of V-I on SOC and temperature.

Chapter 3

Solar Photovoltaic System

Chapter 3

Solar Photovoltaic System

3.1 Introduction Solar PV System

PV system is outline to give the electric supply to load and burden could be AC sort or DC sort. Supply might be required in day time or night-time time or both time. PV system can give supply just in day time for night hours we required supply for that we have batteries, where electrical power can store and use it whenever required.

Renewable energy is for the most part characterized as vitality that hails from assets which are regularly renewed on a human timescale, for example, daylight, waves, wind, tides, rains, Bio-mass, Bio-fuel. Renewable energy replaces conventional resources in to four different regions: power era, heated water/space warming, engine fuels, and provincial (without-grid) energy services.

Solar Photovoltaic system ia actually under solar energy which is under Renewable energy sources. Photovoltaic change over sunlight into its electric current form utilizing the photoelectric effect. PV systems are an essential and generally cheap wellspring of electrical energy where power (grid) is not much convenient, absurdly exorbitant to associate, or basically distracted.

Sunlight based photovoltaic is presently, after wind and hydro control, the third most paramount renewable energy source as far as all inclusive introduced limit. Establishments may be ground-mounted (and now and again incorporated with cultivating and brushing) or incorporated with the roof or dividers of a building (either building-coordinated photovoltaic or essentially rooftop).

3.2 Types of PV System

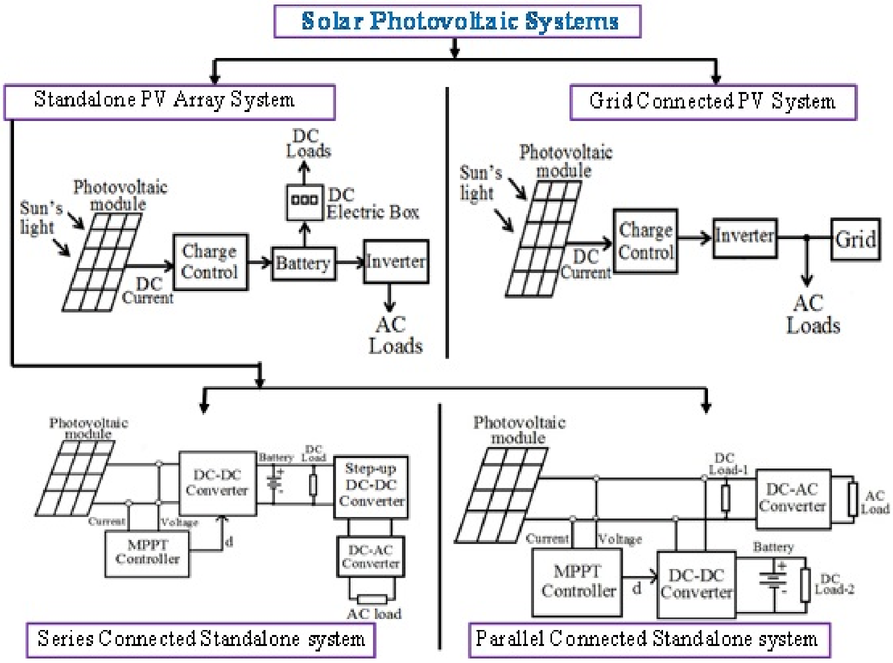

Figure 3.1: Solar Photovoltaic System.

3.2.1 Stand-alone PV System

Contingent upon the kind of load, expense, assets availability and necessity of the load. Stand-alone isolated into are portray a few classifications, which beneath:

(a) Unregulated standalone system with DC load. Generally this sort of system is for low power requisitions. A PV system is specifically associated with the load with the absence of MPPT controller, during night it won't give any supply as a result of the unlucky deficiency of the battery.

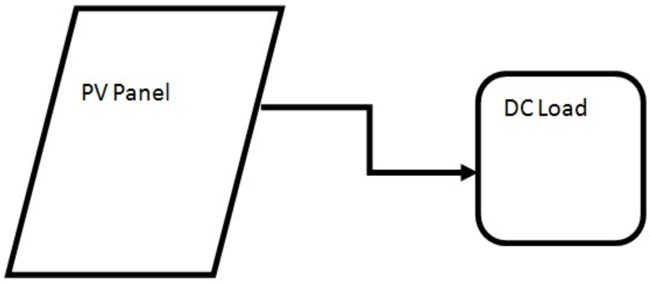

Figure 3.2: Unregulated Stand-alone PV System with DC load.

(b)Regulated standalone system along with DC load. It is like unregulated standalone system with DC load however fundamental distinction between this and past one that this system obliges a MPPT procedure. Typically system with MPPT ought to have one battery otherwise additional power will be waste.

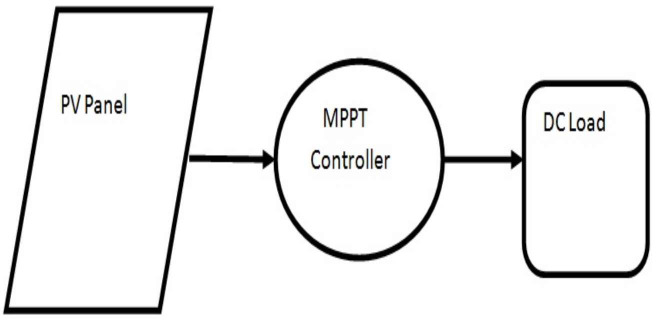

Figure 3.3: Regulated Stand-alone PV System with DC load.

(c)Battery in Regulated standalone system with DC or AC load or both. It is like the previous one (b) only difference is the addition of electrical battery.

In this type of system battery plays the the vital role. Whatever be the extra electrical power produced from PV panel is being stored in this battery for future purpose.

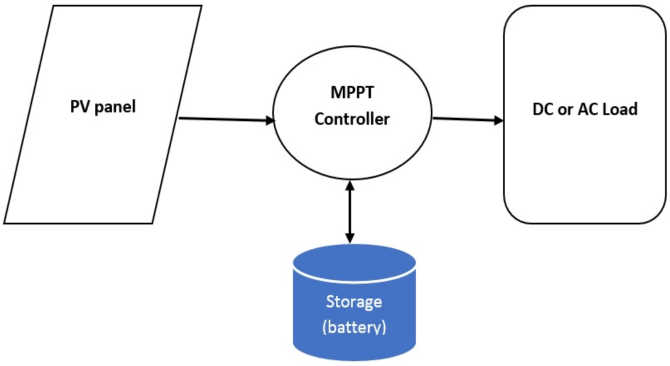

Figure 3.4: Battery in Regulated standalone system with DC or AC load.

This type of standalone PV system is mainly implemented in remote area or used in the local environment. Battery management scheme and charge controllers are required for battery for improvement of battery life.

3.2.2 Grid based PV System

Grid connected PV system is mainly use for high power applications, in this whatever be the high power which is produced by PV panel is transfers through grid, this much amount of high electrical power is very difficult to store in battery.

This type of system consists of PV panel, charge controller and Inverter is mainly use for AC based appliances.

Note: Here in this project we works mainly with the standalone PV system, and we analyze that battery requirement is much more essential for this kind of a system.

As we know battery have some limited life which is actually fixed by the manufacturer, battery life in PV system is based on its operating temperature, duty cycle, cell construction and the charge control.

In next section, explaining the design and construction of battery and its types and explains the features of different kind of batteries.

3.3 Overview of Battery Technologies

In order to select batteries for standalone PV system, it is imperative that we have to know about their configuration execution aspects, features, operating temperatures, cycle life and necessities. Data in the accompanying segments is planned as an audit of essential electrical battery qualities and phrasing as is generally utilized as a part of the outline and provision of batteries in systems.

3.3.1 Battery

For stand-alone PV systems, the selection of battery is very important because in this conditions the more life and strength of battery is required so that electrical power is stored for longer time of period. In this systems, electrical vitality prepared from PV exhibit cannot generally be utilized when power is transformed. Since the interest for vitality does not generally harmonize with its processing, electrical batteries are ordinarily utilized within systems. Essential capacities of a stockpiling battery in PV systems are to:

(i) Electrical power Storage Capacity: To store electrical vitality when it is prepared by the PV systems and to supply electrical power to electrical loads as required.

(ii) Supply Surge Currents: Supply surge working flows or say power to an electrical burdens.

(iii) Stabilization of Current and Voltage : Stable current and voltage is essential when supplying to appliances (load), by stifling transients that may happen in systems.

3.3.2 Construction of Battery

Batteries are for the most part mass generated, consolidating a few successive and parallel courses of action to build a unit. Beginning charge and discharge cycles are directed on batteries before they are sent to shoppers after processing.

Battery developers have varieties in the points of interest of their battery development, yet some regular development characteristics might be portrayed for all batteries.

These critical parts of battery development are depicted underneath:

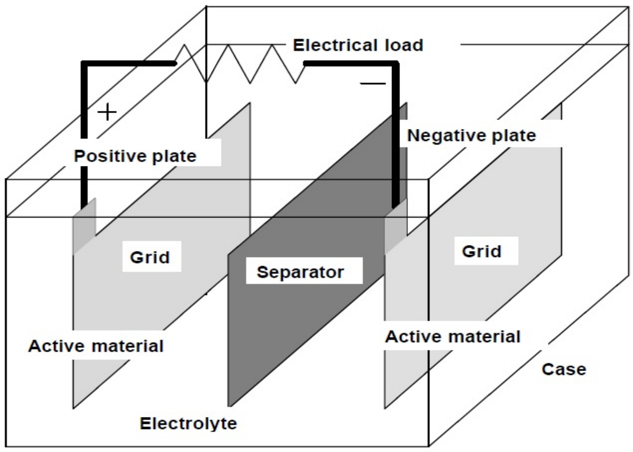

Figure 3.5: Composition of battery.

3.3.3 Types of Battery

Many sorts and groupings of some kind of batteries are made today, everyone have some particular configuration and execution attributes suitable for specific provisions. Every battery sort or configuration has its distinct qualities and shortcomings. For PV systems, the most normal batteries is lead-corrosive batteries because of their various accessibility in numerous sizes, minimal efforts. For low temperature conditions nickel-cadmium type of batteries are utilized, since initial price of these batteries are high so these batteries are not generally use in PV systems. Since we know not a single battery is more accurate, so for this we choose such kind of battery where we can extract the good features and then use in PV systems.

As a rule, electrical capacity batteries might be separated into to significant classes, essential and optional batteries.

(i) Essential battery: These kind of batteries cannot be recharge and can be used in some specific applications.so we can directly say that we cannot use these batteries in our PV systems. Lithium and carbon-zinc batteries are under this category. These batteries can store and supply energy.

We want such kind of batteries those who recharging capability.

(ii) Optional battery: These kind of batteries have recharging capability and can be used in various applications.so we can directly say that we can use these batteries in our PV systems. Lithium and carbon-zinc batteries are under this category. In this batteries recharges simply passing the current it in reverse direction to discharge current.

Lead-acid batteries, Li-ion batteries [14] [15] etc. are under this category.

Table 3.1: Battery Characteristics

Sl.no:	Types of Battery	Advantages	Disadvantages
1	Lead-Antimony(Lead-Acid)	cost is low, easily available, deep cycle is good and performance is good in high temperature	high maintenance
2	Nickel-Cadmium	easily available,performance is excellent in low and high temperature, maintenance is not required	accessible in low limits, expense is high, experience the ill effects of "memory" impact
3	Captive Electrolyte Lead-Acid	medium expense, next to zero support, less vulnerable to freezing, introduce in any introduction	reasonable profound cycle execution, bigoted to overcharge and high temperatures, constrained accessibility
4	Ni-Cd	easily available , performance is good in both low and temperature, maintenance free	just accessible in low limits, high cost, experience the ill effects of "memory" impact

3.3.4 Battery Performance

Battery Terminology:

(i) Ah: Ampere-hour is represented in Ah. Electrical batterys storage capacity is measure by this unit, which is actually obtained by integrating the battery discharging current over some specific time period. X-Ah means transfers X ampere current over 1 hour.

E.g: Suppose a battery delivers 10 Amp current for 10 hour is actually represented in 100 Ah.

(ii) Charging/discharging rate: Represented as the ratio of nominal battery capacity to the discharge/charge time periods in hours.

E.g: A 4-Amp charge for nominal 100-Ah battery would be represented as C/20 charge rate.

(iii) OCV [16]: Open circuit voltage of battery is represented as OCV, this is occurs when battery is in steady state conditions and not during charge/ discharge conditions. According to design the OCV value is 2.1 volts for Lead-Acid battery, depends upon battery design, temperature etc.

(iv) Battery Capacity: It is represented in KWh (Kilowatt-hour), which is actually a multiplication of rated capacity of battery in Ah with nominal battery voltage and further the combined value is divided by 1000.

E.g: Suppose a Nominal battery voltage= 20 V,

Electrical battery storage capacity= 50 Ah, then

Energy storage capacity of battery = (20V*50Ah)/1000 = 1.0 kWh.

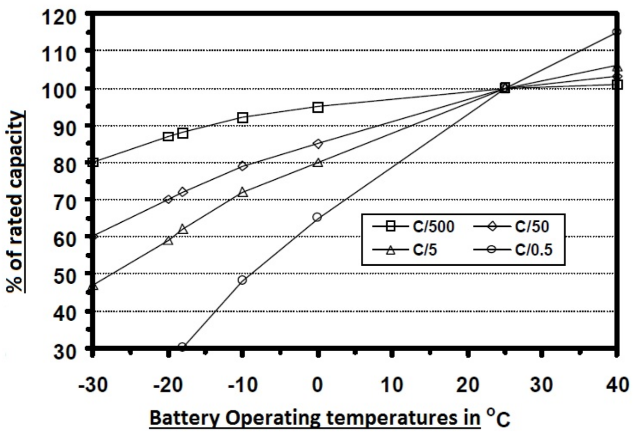

Figure 3.6: Effects of temperature and discharge rate on Lead-Acid battery capacity.

When batteries are regularly used in PV systems, we are not able to get the exact rated capacity of battery. However, battery rated capacity choose as a baseline on which to compare the battery performance on various conditions. We used the Same discharge rate or comparing the rated capacity of batteries.

(v) Charge/discharge: During Charge conditions battery receives current and during discharge conditions battery release current.

(vi)SOC [16]: State of charge of battery is represented as SOC. This is very important parameter for battery, it defines as the amount of energy present in the battery represented in percentage of energy available in electrical fully charged battery.

Facts about SOC :

1. SOC increases when battery is in charging process, and

2. SOC decreases when battery is in discharging process.

At any particular time, amount of capacity remaining in battery.

(vii)DOD: Depth of discharge of battery is represented in DOD, DOD = 1-SOCmin.Compared to fully charge capacity of battery DOD defines the percentage of capacity taken from battery.

From definition of DOD and SOC we can say that, SOC(percentage)+DOD(percentage)= 100 percentage.

There are two types of DOD in PV systems which are as follows:

(I) Max DOD: Max DOD means maximum DOD, also known as allowable DOD. Max DOD implies the greatest sum in percentage of completely evaluated capacity of battery could be taken from a battery. For standalone PV systems, at a given release rate the low voltage load disconnect (LVD) set purpose of the battery charge controller manages the suitable DOD limit. Also, the Max DOD is actually depends upon weather, from less insolation, less temperatures or more load requirement. DOD may be as 80 percenatge which is high and is purely depends upon the types of battery used in Stand-alone PV systems. It is related to the autonomy, operates the load for a certain number of days without any PV array output.

(II) Daily DOD (Average): With the average daily load profile, averageDOD is the percentage of the full-rated limit which is taken from a battery. At the point when load is fluctuates season savvy say in a PV lighting framework, the average daily DOD will be all the more exposed to the harsh elements days because of the more extended daily load operation period. With a steady day by day load , average daily DOD is all the more exposed days in view of easier battery temperature and evaluated limit. Contingent upon the rated capacity and the average daily load energy, to autonomy, it is related reversely; so we can say that the systems is designed for more capacity have definitely have lower daily DOD.

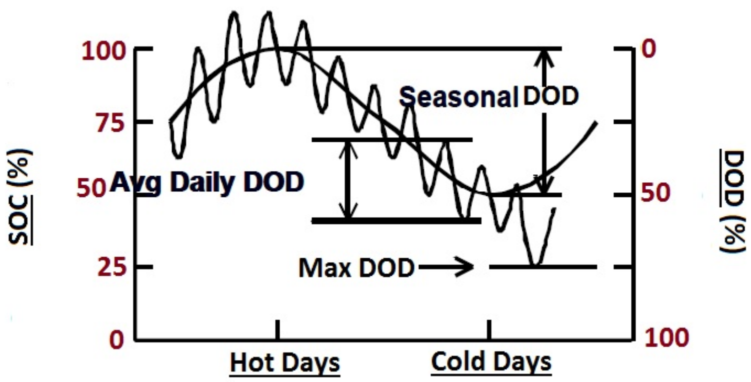

Figure 3.7: Seasonal variation in battery's SOC and DOD.

(viii)Self-discharge rate of battery: When battery is in open circuit means loads are not connected for longer period of time, battery's SOC degrades after some time due internal composition and due to inner losses.

(ix)Battery lifetime (Cycles): It is very difficult to predict the exact lifetime of battery because battery depends upon various parameters such as DOD, charge/discharge rates, cycles, and variations of temperatures in batteries. In PV systems Lead-Acid types of batteries last longer than 16yrs as compare to other type of batteries. whereas under similar under conditions other type of battery like NI-Cd batteries last longer than 16 yrs.

(x) Polarization Capacitance (C): This is the capacitance due to the chemical diffusion within the battery and does not necessarily represent a purely electrical capacitance. It depends on SOC,temperature and also the device design.

Regular Maintenance: Every kind of batteries requires the regular maintenance; maintenace-free batteries should also be check on regular basis such as to check the connections, body parts. In case of flooded batteries levels of specific gravity, voltage and electrolyte should be checked for some specific value. [17]proper measurement of battery parameters are also required.

In winter conditions , for Lead-acid batteries electrolyte may freeze.so for this try to maintain the environment temperature at room temperature by burying the batteries under ground, as we known that ground is the good for maintaing the temperatures.

Selection of a Battery for PV sytems: This is very important points for choosing correct battery for a system, it is not the easy task to select a battery whose performance will be good for each and every conditions. Since different batteries have different kind of features, here we have to decide the batteries. Here some selection criterias are given below:

(i) charging/discharging characteristics,

(ii) battery lifetime(cycles),

(iii) requirement of daily DOD,

(iv) effects of temperatures [13],

(v) analyses the self-discharge rate at steady state condition,

(vi) can sustain at different environment conditions,

(vii) low maintenance cost

3.4 Summary

This chapter gave a review of PV system and characteristics of battery and the various features of battery's components.Here we studied the factors and characteristics of battery.

These kind of batteries are generally useful for Stand-alone PV systems.

Chapter 4

Proposed model and implementation

Chapter 4

Battery Modeling using Mathematical and Circuit Oriented Approach

4.1 Introduction of Battery Modeling

Because of the complex charging/discharging characteristics and relative damageable feature of battery, it is important to make faultless battery models which can help the configuration of charging station all the more effectively and dependably. There are two essential displaying procedures are mathematical and circuit-oriented methods.

Generally, mathematical related model [2] created built principally with respect to the Shepherd relation to anticipate framework level conduct, for example, battery runtime, productivity, or capacity limit.

Circuit-related battery models are models which utilizing a combination of voltage sources, resistors, and capacitors and these combinations are typically utilized and used by researchers for other electrical systems where these kind of mixture is required because these conditions deals with the all necessary features of circuit. There are numerous circuit-related battery models which were explained by many researchers. Like the mathematical based model improvement, circuit-based models have likewise experienced diverse stages from right on time low correctness Thevenin-based and impedance-based models [2] to more exact runtime-based RC system models created as of late.

Because of the battery model advancement in the two separate bearings, it gets critical to explore the relations, contrasts, and computational complexities utilizing the two displaying methodologies.

4.2 Battery Quality for Model

As we know for a rechargeable battery, through a charge process it transform the electrical energy into its chemical energy whereas during discharge process it transform the chemical energy into its electrical energy, this are internal compositions of a rechargeable battery.

Facts about battery are given below:

Factors affecting battery models : The imperative variables influencing battery execution and models: rate of charge and discharge of a normal battery, the total battery capacity thats means how much battery can store energy and for how longer period of time battery can retains that energy, State of charge of a battery.

SOC, For any kind of battery state of charge estimation is essential, battery manufacturer fixed the intial state of charge of the battery, during charge or during discharge cycles, time varying characteristics of a particular battery depends upon the state of charge of the battery. SOC value generally deals in percentage from 0 to 100 per, and in numerical value varies from 0 to 1.

DOD, Depth of discharge is also the important factor for a battery, DOD= 1- (min)SOC, DOD explains the charge/discharge process of battery. Larger amount of DOD during discharging process means more amount of energy is taken from battery, larger value of DOD reduces the battery lifetime.

Charging/releasing rates influence the evaluated battery capacity. As indicated by the Peukert's mathematical statement, if the battery is, no doubt released immediately, then the measure of energy that could be concentrated from the battery is lessened.

Past history and age of a battery effects on the capacity of a battery. Actually while taking after makers' DOD details, the battery limit stays up to at the appraised limit for a certain number of cycles. If during process if we take battery under extreme DOD, the capacity of a battery rashly lessened.

Temperature variations in battery also affects the life and capacity of a battery, and it affects the energy taken from the battery. Usually at higher temperatures the capacity of any battery increases but if we forcefully increase the temperature that may affect the lifetime of a battery.

So generally we taken an inner temperature of battery is constant.

4.3 Various models available for battery modeling

There are many models available for battery modeling, and a few of them are mentioned here in this section. The merits and demerits of those models and the reason for choosing the modified equivalent model in this thesis is also given.

4.3.1 Circuit Oriented Model(I)

This circuit based model is taken from [2], which explains the features of circuit-oriented model. When we are dealing with circuit oriented model it always combine the capacitors, some resistances and voltage and current sources.

The vast majority these kind of models have these fundamental classifications:

- Model is based on Thevenin, shown in Figure 4.1 (a) and
- Model is based on Impedance, shown in Figure 4.1 (b).

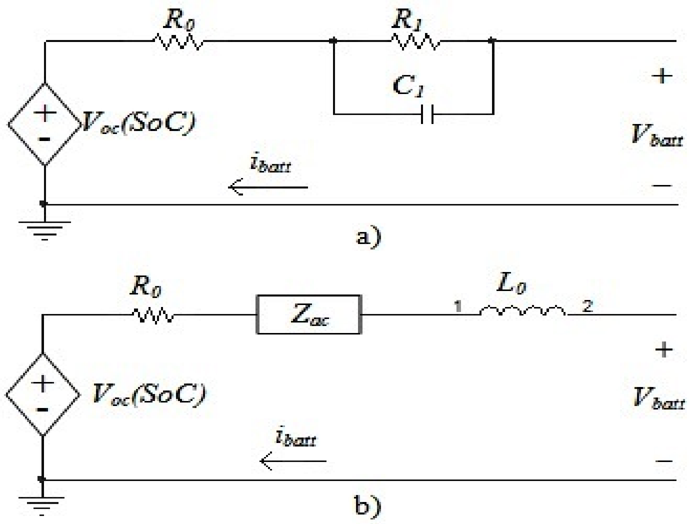

Figure 4.1: Circuit-oriented battery model.

Typically, very difficult to change the given battery parameters as we know the different parameters of battery have different features. At some specific SOC, In Fig 4.1(a) which is actually based on Thevenin, have the combination of Voc(SoC), internal resistance which is then combine with the parallel combination of resistor and capacitor (RC) to predict battery reaction to transient load occasions , by accepting the Voc(SoC) is consistent.

Here in this model Voc(SoC) assume to be constant, Accordingly, this type of model is not able to show the SOC impact on the battery conduct legitimately.

In Fig 4.1(b) which is actually based on Impedance, use the complex elements like Zac which is actually a AC- equivalent circuit, it can only give response to a AC response only not able to give any response to Dc response due to fix SOC. It follows the electrochemical impedance spectroscopy method for this AC equivalent model, it is in frequency domain.

We need such kind of a circuit model which reduces the circuit complexity and gives the proper response for a various SoC value, which can eliminates the disadvantages of above two models.

4.3.2 Simple Battery Model(II)

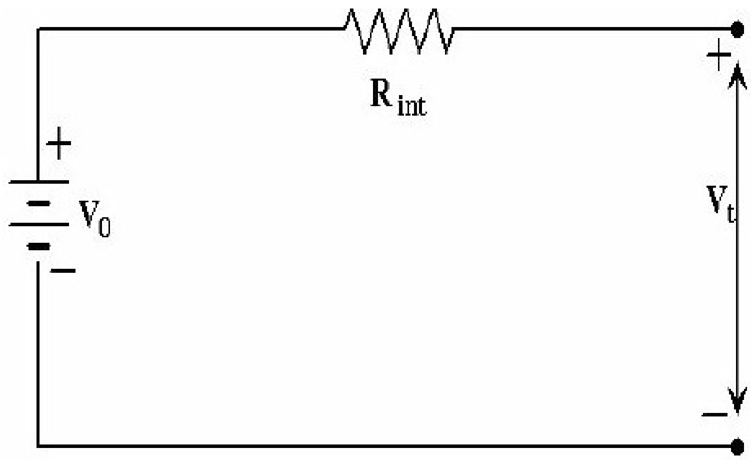

Figure 4.2: Simple battery model.

The most commonly used battery model is shown in Figure 4.2. It consists of an ideal battery with open-circuit voltage V0, a constant equivalent internal resistance Rint and the terminal voltage represented by Vt. The terminal Voltage Vt can be obtained from the open circuit measurement, and Rint can be measured by connecting a load and measuring both the terminal voltage and current, at fully charged condition. While this model seems to be very simple, it does not take into consideration the varying nature of the internal resistance due to temperature, state of charge, and electrolytic concentration.

This kind of model can only be used for certain circuit simulation, and it cannot be used for PV applications.

In next section describes the function and detail configuration of proposed electrical circuit model.

4.4 Proposed Battery Model

4.4.1 Equivalent circuit model of battery :

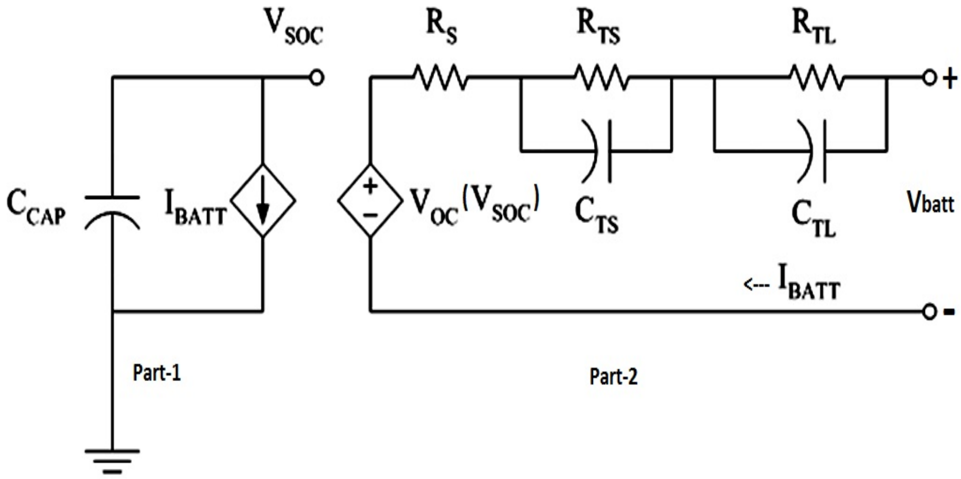

Figure 4.3: Equivalent Circuit model of Battery.

Description : This circuit describes the relationship between current controlled current source to the nonlinear voltage controlled voltage source. The above circuit falls under two parts which are as follows:

(i) Part-1 : This part describes the life cycle of the battery, part of circuit contains current controlled current source represented as Ibatt and capacity of battery represented as Ccap. Ccap is very large which actually represents the characteristics of state of charge of battery model.

(i) Part-2 : This part describes the dynamic behavior of the model, this part of circuit contains discharging current Ibatt through open terminal of the battery, voltage controlled voltage source, resistance Rs and the two RC-networks. In this part of circuit the two RC-network are uses for the prediction of battery characteristics to the SoC values, here we used the voltage controlled voltage source to relate the SOC to the open-circuit voltage.

This proposed model eliminated the some disadvantages of Figure 4.1(a) and (b), like this proposed circuit model can work with variable SOC values whereas this was not possible with previous circuits, also Voc(SoC)changes with time whereas Voc(SoC)in previous circuits open circuit voltage assumes constant.

In this proposed circuit model the two RC-networks(time constants) are used for transient response, without using 1 or 3 RC-networks, in order to attain accuracy, two time constants sustains an errors within 1 mv when using curve fittings method.

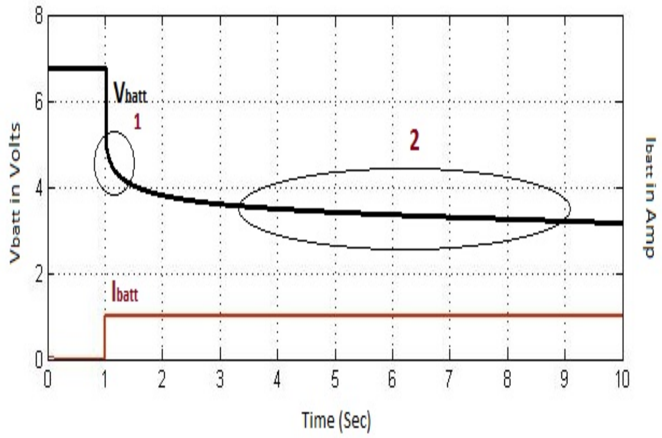

Figure 4.4: Step Load current event.

In the above figure see that for step load current performance there is a sudden voltage drops of battery this is due to the series resistor R_S, this occurs for short period of time then due to the two RC-network, battery response slow down. We consider for step response, R_{TL}, C_{TL} used for longer time constants and R_{TS}, C_{TS} used for shorter time constants. Here R_S is used for sudden voltage drop. Here point 1 represents the shorter time constant and point 2 represents the longer time constant.

4.5 Mathematical Equations for Proposed Battery Model

Here in this section explains the mathematical expression of the proposed model.

$Z_{eq} = R_S + \frac{R_{TS} * sC_{TS}}{R_{TS} + sC_{TS}} + \frac{R_{TL} * sC_{TL}}{R_{TL} + sC_{TL}}$ ——— (1)

$SOC(t) = SOC_0 - [\frac{1}{C_{CAP}} * \int_0^t i(t)\, dt.]$ — (2)

$V_{batt} = V_{OC} + [(-i)_{batt} * Z_{eq}]$ ————- (3)

The above equation (3) shows the open circuit voltage of the battery.

As we know that that SOC is the function of various parameters of battery which are as given below,

$Voc = -154.5 * exp(-0.5055 * SOC) + 2.677 + (0.3873 * SOC) - (0.01494 * SOC^2) + (0.000207 * SOC^3);$

$Rs = 4.782 * exp(-9.329 * SOC) + 0.007625 + (0.0001517 * SOC) - ((2.67 * exp(-006)) * SOC^2) + ((1.615 * exp(-008)) * SOC^3);$

$R_{TS} = 0.7187 * exp(-0.9142 * SOC) - 218.8;$

$C_{TS} = -12.44 * exp(-0.7863 * SOC) - 0.232;$

$R_{TL} = 0.5325 * exp(-0.7216 * SOC) + 220.5;$

$C_{TL} = 8.641 * exp(-5.715 * SOC) + 0.1582.$

All the expressions are then implemented into Simulink model.

4.6 Simulation Model

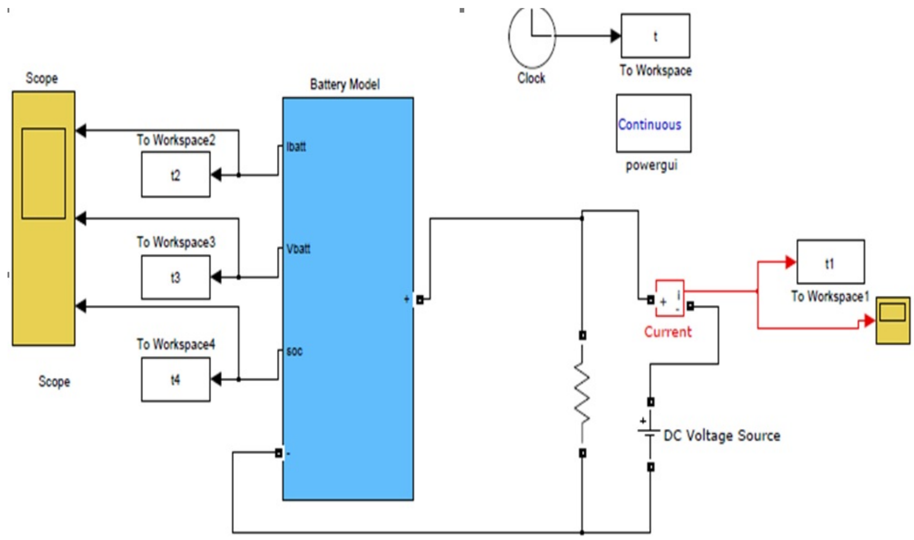

Figure 4.5: Simulink model part 1

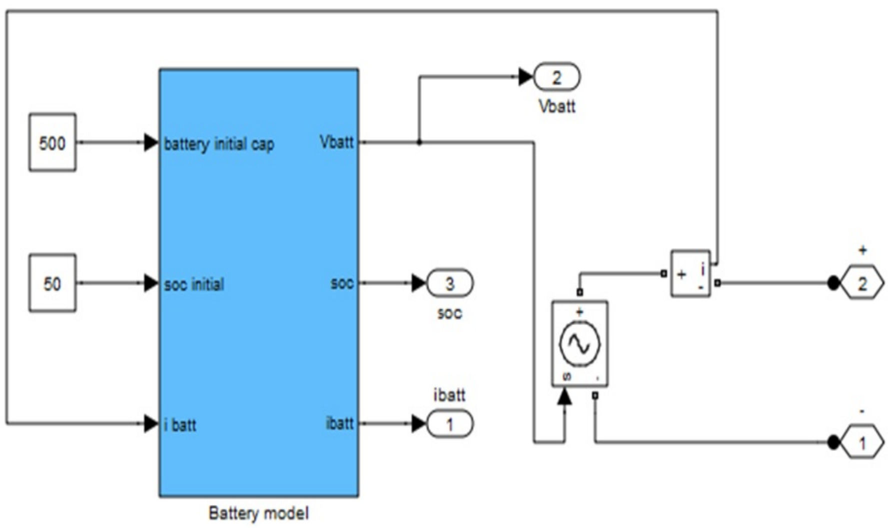

Figure 4.6: Simulink model part 2.

Discuss: Taken SOC initial value = 50 %, and

Battery initial capacity = 500.

We can take any values according to our requirement.

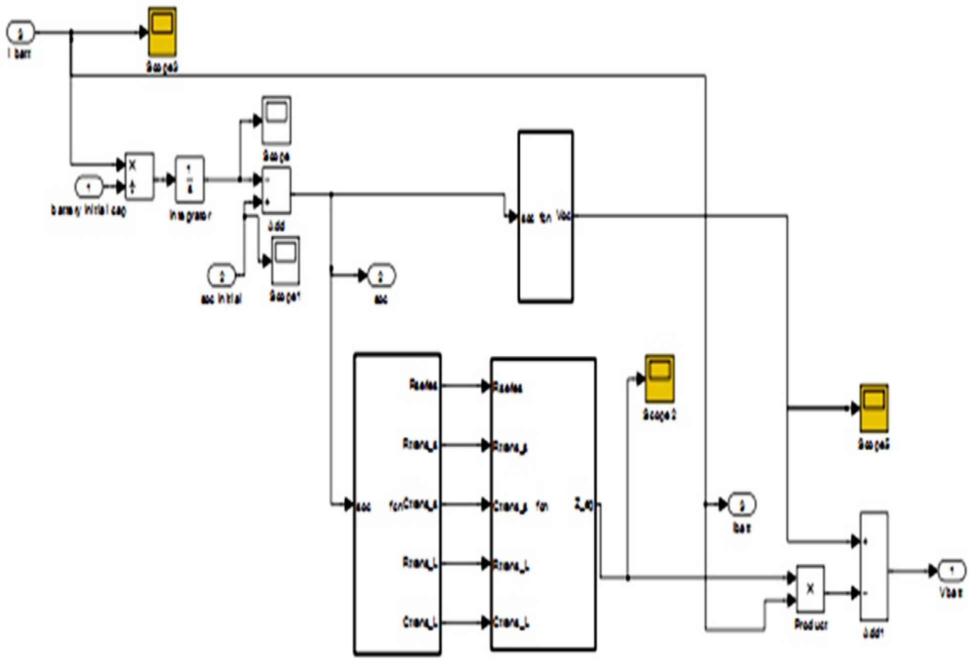

Figure 4.7: Simulink model part 3.

4.6.1 Modal Assumptions:

(i): Internal resistance is gathered constant throughout the charge and the discharge cycles and doesn't shift with the amplitude of the current.

(ii): The model doesn't consider the effect of temperature.

(iii): The Self-discharge of the battery is not considered. It might be considered to by including a large resistance in parallel with the battery terminals.

(iv): The battery has no memory impact, it does not consider the bad history of DOD.

4.7 Results and Discussions

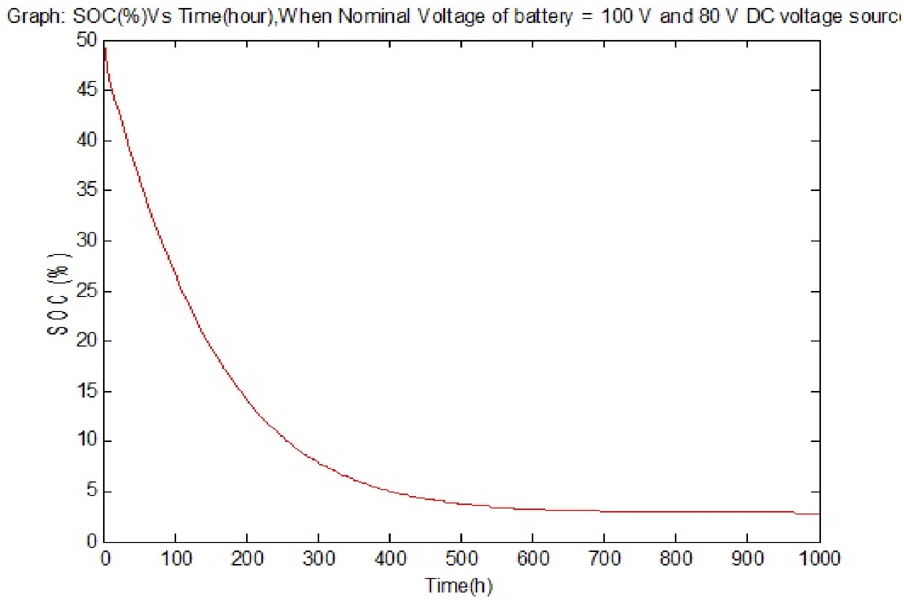

Figure 4.8: Graph: SOC in percentage Vs Time.

Result [Fig 4.10]: When Nominal Voltage of battery is 100 V and 80 V DC voltage source .SOC decreases as DC Voltage is less than the nominal voltage of battery.

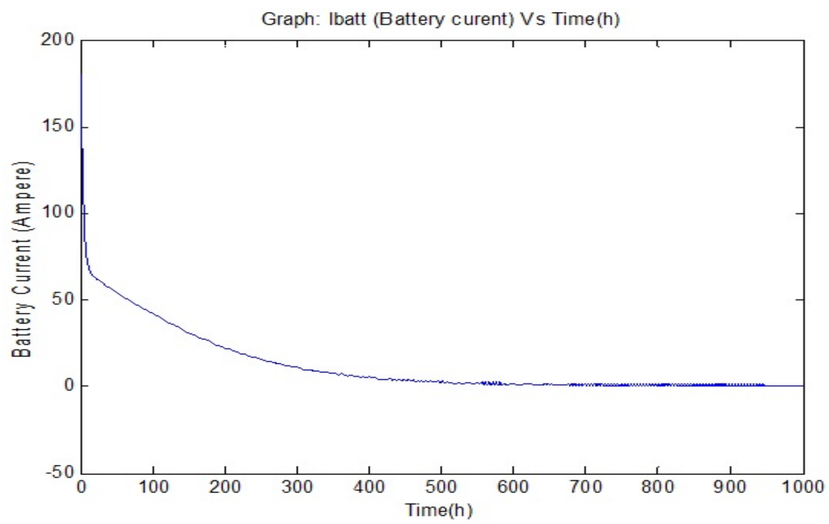

Figure 4.9: Graph: Battery Current(Ibatt) Vs Time.

Result [Fig 4.11]: When Nominal Voltage of battery is 100 V and 80 V DC voltage source .SOC decreases as DC Voltage is less than the nominal voltage of battery.

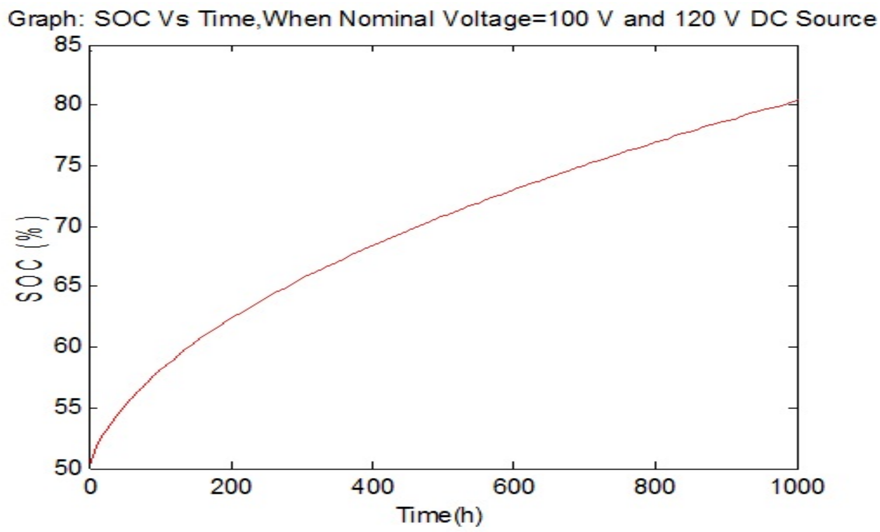

Figure 4.10: Graph: SOC in percentage Vs Time.

Result [Fig 4.12]: When Nominal Voltage of battery is 100 V and 120 V DC voltage source. SOC increases as DC Voltage is more than the nominal voltage of battery.

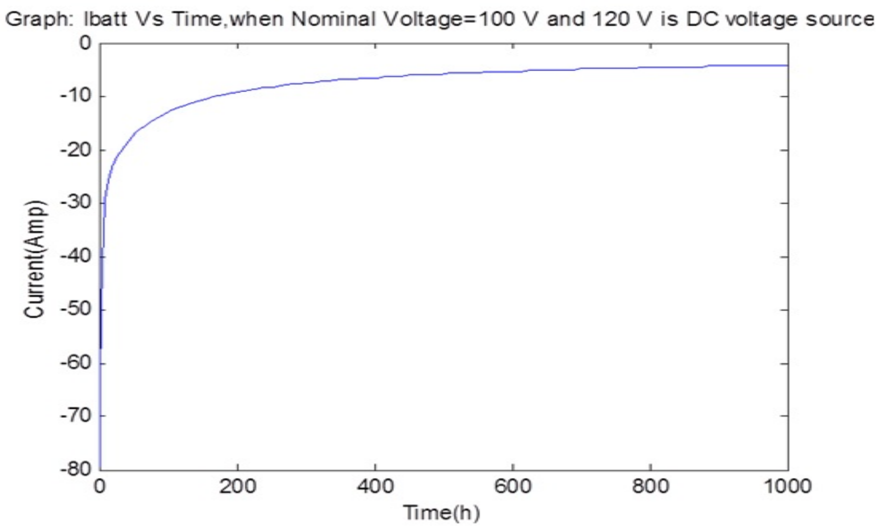

Figure 4.11: Graph: Battery Current(Ibatt) Vs Time.

Result [Fig 4.13]: When Nominal Voltage of battery is 100 V and 120 V DC voltage source .SOC increases as DC Voltage is more than the nominal voltage of battery.

4.7.1 Some Results related with the batteries behavior

Here in this section observe the discharging characteristics of batteries like Lead-Acid and Ni-Cd battery.

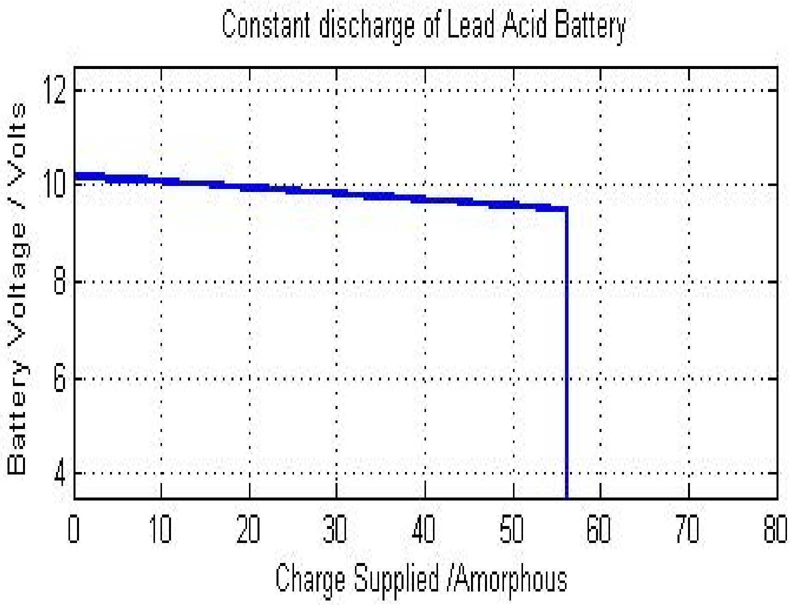

Figure 4.12: Graph: Constant discharge of Lead Acid Battery .

Result [Fig 4.12]: Here observed the characteristic of Lead Acid battery's terminal voltage with time.

Parameter used for Lead-Acid battery : No of Cells =5; $Capacity = 100; Rin = 1m\Omega$

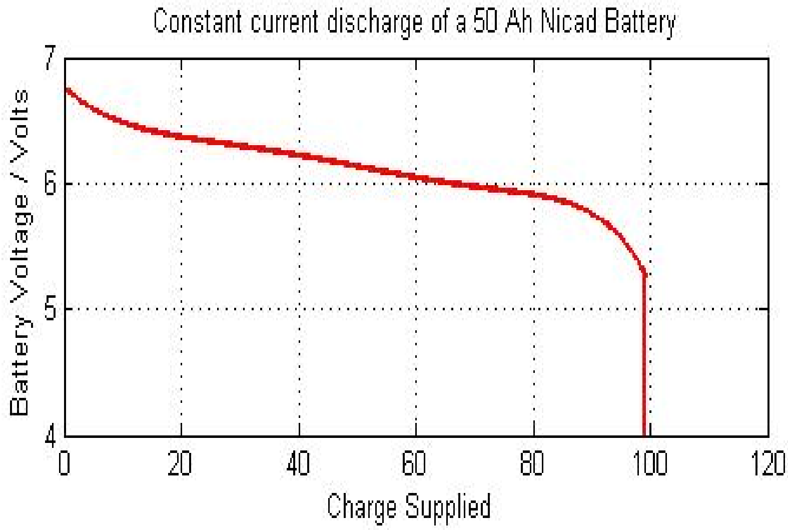

Figure 4.13: Graph: Constant current discharge of a 50 Ah NiCad Battery .

Result [Fig 4.13]: Here observed the characteristic of NiCad battery's terminal voltage at constant current discharge of 50 Ah rate.

Parameter used for Lead-Acid battery : No of Cells =5; $Capacity = 100; Rin = 3m\Omega$

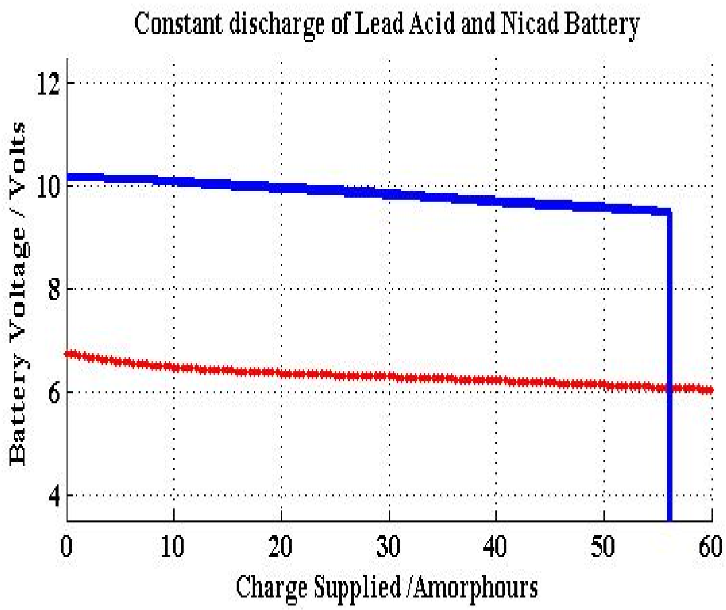

Figure 4.14: Graph: Constant discharge of a Lead Acid and NiCad Battery .

Result [Fig 4.14]:Comparison between Lead Acid and Nicad battery.

Chapter 5

Conclusion and Future Scope of work

Chapter 5

Conclusion and Future work

5.1 Conclusion:

The Battery is modelled and simulated using MATLAB/SIMULINK environment. Battery model with a constant power load, the total system behaviour should be studied. Component wise and as a whole some Battery systems are simulated. Performance is studied with different batteries parameter configurations.The comparison of the constant discharge of Lead-Acid and Nickel-cadmium is shown and analyse the characteristics of batteries.

Simulation of Battery model and its design based on state space modelling is to be studied. Mathematical approach for the battery model will study. Optimization technique will be used for Battery Sizing.

5.2 Future Scope of Work :

1. In this work only two we consider the circuit based model and test that model with the help of external Dc voltage source, in further we can test the batterys performance with the help of mathematical oriented battery model.

2. Battery sizing and its optimization is also important so with the help of optimization technique, can increase efficiency and battery lifetime.

Bibliography

[1] M. Chen and G. A. Rincon-Mora, "Accurate electrical battery model capable of predicting runtime and iv performance," *Energy conversion, ieee transactions on*, vol. 21, no. 2, pp. 504–511, 2006.

[2] S. Li and B. Ke, "Study of battery modeling using mathematical and circuit oriented approaches," in *Power and Energy Society General Meeting, 2011 IEEE*, pp. 1–8, IEEE, 2011.

[3] T. Kim and W. Qiao, "A hybrid battery model capable of capturing dynamic circuit characteristics and nonlinear capacity effects," *Energy Conversion, IEEE Transactions on*, vol. 26, no. 4, pp. 1172–1180, 2011.

[4] "Ieee recommended practice for sizing lead-acid batteries for stand-alone photovoltaic (pv) systems - redline," *IEEE Std 1013-2007 (Revision of IEEE Std 1013-2000) - Redline*, pp. 1–58, July 2007.

[5] Y. Ru, J. Kleissl, and S. Martinez, "Storage size determination for grid-connected photovoltaic systems," *Sustainable Energy, IEEE Transactions on*, vol. 4, no. 1, pp. 68–81, 2013.

[6] C.-F. Chiasserini and R. R. Rao, "Energy efficient battery management," *Selected Areas in Communications, IEEE Journal on*, vol. 19, no. 7, pp. 1235–1245, 2001.

[7] R. Rynkiewicz, "Discharge and charge modeling of lead acid batteries," in *Applied Power Electronics Conference and Exposition, 1999. APEC'99. Fourteenth Annual*, vol. 2, pp. 707–710, IEEE, 1999.

[8] M. Knauff, C. Dafis, D. Niebur, H. Kwatny, and C. Nwankpa, "Simulink model for hybrid power system test-bed," in *Electric Ship Technologies Symposium, 2007. ESTS '07. IEEE*, pp. 421–427, May 2007.

[9] Z. Salameh, M. Casacca, and W. A. Lynch, "A mathematical model for lead-acid batteries," *Energy Conversion, IEEE Transactions on*, vol. 7, pp. 93–98, Mar 1992.

[10] H. Khafagy and A. Makki, "Mathematical modeling and simulation of lead acid battery," in *Information and Communication Technologies: From Theory to Applications, 2004. Proceedings. 2004 International Conference on*, pp. 137–, April 2004.

[11] M. Casacca and Z. Salameh, "Determination of lead-acid battery capacity via mathematical modeling techniques," *Energy Conversion, IEEE Transactions on*, vol. 7, pp. 442–446, Sep 1992.

[12] S. Mukhopadhyay and F. Zhang, "Adaptive detection of terminal voltage collapses for li-ion batteries," in *Decision and Control (CDC), 2012 IEEE 51st Annual Conference on*, pp. 4799–4804, Dec 2012.

[13] B. Schweighofer, M. Recheis, T. Gallien, and H. Wegleiter, "Fast and accurate battery model including temperature dependency," in *Industrial Electronics Society, IECON 2013 - 39th Annual Conference of the IEEE*, pp. 6740–6745, Nov 2013.

[14] S. Barsali and M. Ceraolo, "Dynamical models of lead-acid batteries: implementation issues," *Energy Conversion, IEEE Transactions on*, vol. 17, pp. 16–23, Mar 2002.

[15] L. Gao, S. Liu, and R. Dougal, "Dynamic lithium-ion battery model for system simulation," *Components and Packaging Technologies, IEEE Transactions on*, vol. 25, pp. 495–505, Sep 2002.

[16] X. Tang, X. Mao, J. Lin, and B. Koch, "Li-ion battery parameter estimation for state of charge," in *American Control Conference (ACC), 2011*, pp. 941–946, June 2011.

[17] B. Schweighofer, H. Wegleiter, M. Recheis, and P. Fulmek, "Fast and accurate battery model applicable for ev and hev simulation," in *Instrumentation and Measurement Technology Conference (I2MTC), 2012 IEEE International*, pp. 565–570, May 2012.

Appendix

Program Files:

MATLAB FILES:

I : Nicad Battery

```
%Nicad Battery
%Author: Anil Kumar (212ee5396), NIT Rourkela
%.........................
% INITIALIZATION


T=(0:50:50000);
CR=zeros(1,1001);
DoD=zeros(1,1001);
V=zeros(1,1001);
CS=zeros(1,1001);
I=30;
NoCells=5;
Capacity=100;
k=1.045;
deltaT=50;
Rin=(0.06/Capacity)*NoCells;
PeuCap=((Capacity/3)^k)*3;
V(1)=open_circuit_voltage_Nicad(0,NoCells)-I*Rin;
for n=2:1001;
    CR(n)=CR(n-1)+((I^k*deltaT)/3600);
    DoD(n)=CR(n)/PeuCap;
    if DoD(n) >1
        DoD(n)=1;
    end
    V(n)=open_circuit_voltage_Nicad(DoD(n),NoCells)-I*Rin;
    if DoD(n)>0.99
        V(n)=0;
    end
    if V(n)>0
        CS(n)=CS(n-1)+((I*deltaT)/3600);
    else
        CS(n)=CS(n-1);
    end
end
plot(CS,V,'k');
axis([0 200 3.5 25]);
xlabel('Charge Supplied /Amorphours ');
ylabel('Battery Voltage in Volts ');
Title( 'Constant current discharge of a 50 Ah Nicad Battery');
```

II : Lead Acid Battery

```
%Author: Anil Kumar (212ee5396, NIT Rourkela)
%........................
% INITIALIZATION


T=(0:10:10000);
CR=zeros(1,1001);
DoD=zeros(1,1001);
CS=zeros(1,1001);
V=zeros(1,1001);
% CS=zeros(1,1001);
% I=30;
NoCells=5;
Capacity=100;
k=1.12;
deltaT=50;
p=5000;
Rin=(0.022/Capacity)*NoCells;
PeuCap=((Capacity/10)^k)*10;
E=open_circuit_voltage_LA(0,NoCells)-I*Rin;
I=(E-(E*E-(4*Rin*p))^0.5)/(2*Rin);
V(1)=E-I*Rin;
for n=2:1001;
    E=open_circuit_voltage_LA(DoD(n-1),NoCells);
    I=(E-(E*E-(4*Rin*p))^0.5)/(2*Rin);
    CR(n)=CR(n-1)+((I^k*deltaT)/3600);
    DoD(n)=CR(n)/PeuCap;
    if DoD(n) >1
        DoD(n)=1;
    end
    V(n)=open_circuit_voltage_LA(DoD(n),NoCells)-I*Rin;
    if DoD(n)>0.99
        V(n)=0;
    end
    if V(n)>0
        CS(n)=CS(n-1)+((I*deltaT)/3600);
    else
        CS(n)=CS(n-1);
    end
    end
plot(CS,V,'b.');
axis([0 60 3.5 12.5]);
xlabel('Charge Supplied /Amorphours');
ylabel('Battery Voltage in Volts ');
Title( 'Constant discharge of Lead Acid Battery');
```