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Modeling and Simulating Battery Charging Testing for Electric Vehicle applications using Simulink

Kinjarapu Bhagya Sri

Subject faculty, EEE Dr.B.R. Ambedkar University kinjarapu.bhagyasri2822@gmail.com

ABSTRACT:

Sustainability in global setting is a key question, to decrease the reliance on fossil fuels, there is transition to electric vehicle, It is causing a sharp increase in the global sales of electric cars (EVs), and the cost of buying an EV is falling due to its efficiency, extended battery life, and quality. Configurations for charging are essential for electric vehicles. Level 1, Level 2, and Level 3 are the three tiers of charging systems. This thesis defines the topology that will be needed for an interphase between the two charging systems, i.e., slow charging and fast charging. The Li-ion battery model is regarded as a specification example and both types of charging will comprise of CUK (DC/DC converter with zero ripple factor) converter to charge the battery. The battery charging models are simulated, using the MATLAB/Simulink software, and then provide the charging of the lithium-ion battery model.

Keywords: Li-ion Battery; DC/DC converter; CUK converter.

Introduction:

The contemporary world is dependent on the fossil fuel-based transportation system in terms of its economic and social progression and the free flow of goods and persons. Only 30% of the fuel is used in a combustion engine; the remainder is wasted. In contrast, an electric motor may achieve an efficiency of over 80%. According to the fact that the electric vehicle (EV) is driven assisted by electric-powered motor, powered by rechargeable battery packs as opposed to a gasoline engine [1]. Battery-electric-run cars include cars, buses, forklifts, bicycles, railcars, as well as scooters. The positive examples observed in the battery productions of the energy storage have, additionally, had the certain effects of the electric car battery marketplace [2]. Electrical automobiles (EVs) sales are rapidly rising across the globe due to the efficiency of the EVs and a higher level of battery technology that is making EVs cheaper to purchase. Electrical cars are relying on the electric battery to deliver the primary or the secondary power. The market for electric car batteries may be impacted by this flow as it influences the demand for electric vehicles [3].

An electric-powered vehicle utilizes mixture energy in remote rechargeable battery packs which is used to manage it. Since the latter makes use of all of the capacity on-board of batteries, hence, this does not require any combustion engine to do it faster. Mostly, the lead-acid & lithium-ion batteries are used. In addition, the lithium-ion battery offers many advantages over the lead-acid battery, including being smaller than the latter. The only place where it can be changed around to be more efficient is in charging the batteries and similarly the charge per distance will also get enhanced. The Society of Automotive Engineers (SAE) has classified charging modes into three tiers. Both onboard and offboard charging are available for EVs [4-7].

Intends to develop a system that integrates on-board AC slow charging with DC rapid charging, and uses MATLAB/Simulink software to model the converter at different charging time values. MATLAB/Simulink is used in the provided study to calculate battery charging and discharging in a very basic model. to establish links using drag and drop, to contextualise diagrams with requirements, to assess requirements traceability, and to move between requirements, designs, produced code, and tests. Additionally, it helps when related requirements, designs, or tests change, and it calculates the implementation and verification status in accordance with specifications [8-12].

Monitoring current and voltage, estimating the State of Charge (SOC), and employing supervisory logic are all included in the battery system model and simulation technique that uses Simulink and State flow.

Restricting power intake and output to prevent overcharging and discharge, among other things.

Table 1: Charging levels

Charging	Current (Amp)	Voltage (Volt)	Power (kW)
Level-1 charging	12 to 16	120	1.3 – 1.9
Level-2 charging	Up to 80	240	Up to 19.2
Level-3 charging	Up to 80	480	Up to 130

Principle and structure of battery charging / discharging characteristics:

The initial stage in the development process would be to build and parameterise an analogous circuit that would properly replicate the behaviour of the battery. This is estimated with the help of MATLAB and estimation techniques and measured data on lithium-ion, Ni-MH, or lead-acid batteries.

Because of its many benefits, including high specific energy densities, high energy densities, and extended cycle lives, the lithium-ion battery is used in this paper.

Parameterization is achieved by discharging and charging current pulses. With the help of MATLAB, it is possible to construct mathematical models of predicting and optimizing the performance of the complex system. The following procedures are involved in model development: Using first principal modelling and data fitting techniques, fit data and create models; determine the parameters that optimize the model in the system; simulate and create custom post-processing procedures; and generate reports outlining the model's development and simulation outcomes. Distribute the created models.

Various processes are depicted in accordance with the block diagram of the MATLAB-based rechargeable battery model. Model definition, simulation, deployment of the produced system in a controller, and model sharing are some examples of these phases. To ascertain the impact of the load and its character charging/discharging, additional data collected during the project or research's simulation will also be utilized in conjunction with the MATLAB model. The following describes the steps involved in creating each subsystem: State of Charge (SOC) and Open Circuit Voltage (OCV) calculations.

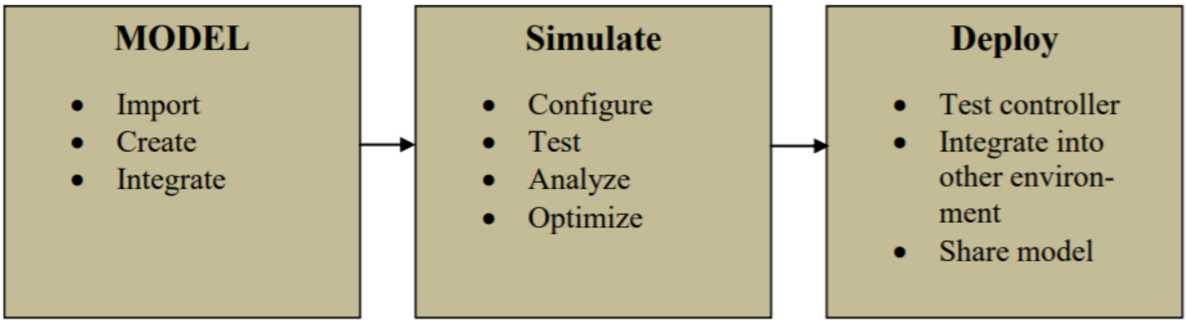

Fig.1: MATLAB Model

OCV Calculation:

Electrical potential difference (voltage) between any pair of terminals (points) is related, and when no circuit is connected to the device, then the voltage is referred to as open circuit voltage. When no external load is connected as indicated in fig. 2: V (t) = OCV, since there isn't an external load attached, there isn't any external electric current flowing between the terminals.

OCV is a significant parameter of characterization of the lithium-ion batteries. It was applied to the study of the variations of the electronic energy. The ideal voltage source model is the most basic representation of an ideal battery. With this concept (Fig. 2(a)), the voltage is (ideally) constant and is not influenced by the current or usage history. Therefore, terminal voltage is the voltage across the battery terminals when a load is applied. On the other hand, OCV (open circuit voltage) is the voltage across the battery terminals when there is no load. When it comes to battery open circuit voltage, as seen in Figure 3, we use a multimeter to measure the voltage across the battery's terminals; even though we have measured the OCV, no current is flowing in the circuit.

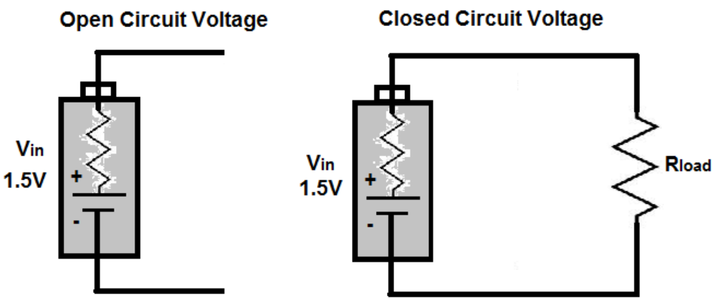

Fig.2: (a) circuit without load (b) circuit with load

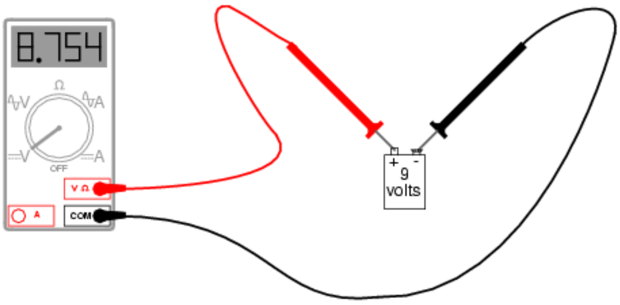

Fig.3: Example of OCV

State Of Charge (SOC):

Charge states the electric battery's level of charge relative to its capacity. One of the key factors that determine strategy is the SOC, or remaining capacity in a battery. Battery charging or discharging is determined by the level or range, and the SOC's properties show this. A high voltage indicates that the battery is completely charged, whereas a low value indicates that the battery is empty. The two main and most straightforward methods for testing a battery's state of charge are (a) the SOC estimating OCV method and (b) the SOC estimating coulomb counting method.

SOC Calculation for the battery model:
SOC (t)= Q_t / Q_n

The SOC of a battery is the ratio of its nominal capacity (Q_n) to its current capacity (Q_t), and it is the most important battery characteristic. The nominal capacity (Q_n), or maximum charge that a battery can hold, is supplied by the manufacturer. To determine how capacity might affect the battery cell's current, capacity was evaluated in relation to current. Next comes the SOC calculation.

$$SOC = SOC\Big|_o - \frac{1}{C_n}\int_0^t I(t)\,dt$$

Where, C_n is capacity I is the current SOC$\big|_0$ is the initial SOC

Battery Capacity:

Battery capacity is the amount of energy that a battery can hold. It is expressed in watts (Wh), kilowatt-hours (kWh), or ampere-hours (Ah). Battery capacity is one of the battery's parameters. We might clarify it using the following example:

Let us have a voltage vb, and flowing current is ib. then the energy is
∫v b.*ib*.dt = Energy capacity in Wh
or ∫*ib*.dt = Charge capacity in Ah

Consequently, the amount of energy sources that the battery can store or deliver to the load is known as its capacity. Wh capacity, sometimes referred to as the battery's energy capacity, shows the battery's true capacity. Charge-capacity (C) or Ah offers a measure of Wh if an enduring quantity of V_b is maintained.

The most common commercial use of charge capacity (C) or Ah battery is the most common. A battery is discharged by decreasing the charge applied to a fully charged battery at a rated value of current and at a known value of applied load.

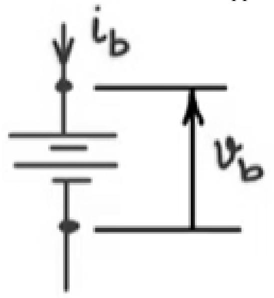

Fig 4: If i_b is positive, it means that the battery is being charged and that the current is going into a positive terminal. The computed energy will then be used for charging. In addition, if current i_b is exiting the terminal and reversing in the other way, energy is being lost.

Modeling and Simulation of Battery:

The mathematical model between battery input and output parameters, as well as the simulator, can only be obtained through battery modelling and simulation. This is a controlled voltage source that is dependent on the real state of charge (SOC).

In addition to being important for estimating battery performance and design, simulations and modelling are required to determine the electrical system's capacity and best part selection. Every facet of the parameters extraction of manufacturers' discharge characteristics is described in relation to battery modelling.

The fast, precise, and effective solution such character provides will be helpful to the batteries. The charge and discharge behaviour is in general as follows:

$E_{charge}=f_1$(it, i*, Exp, Batt Type) and $E_{discharge}=f_2$(it, i*, Exp, Batt Type)

Where its functions are E_{charge} and $E_{discharge}$ (Capacity Extracted (Ah)) Current at low frequency (i) = A Exp=Exponential zone (V) of dynamics Battery type = battery kinds (at the moment, lithium-ion batteries are utilised) Therefore, the battery model is necessary to track battery parameters like SOC.

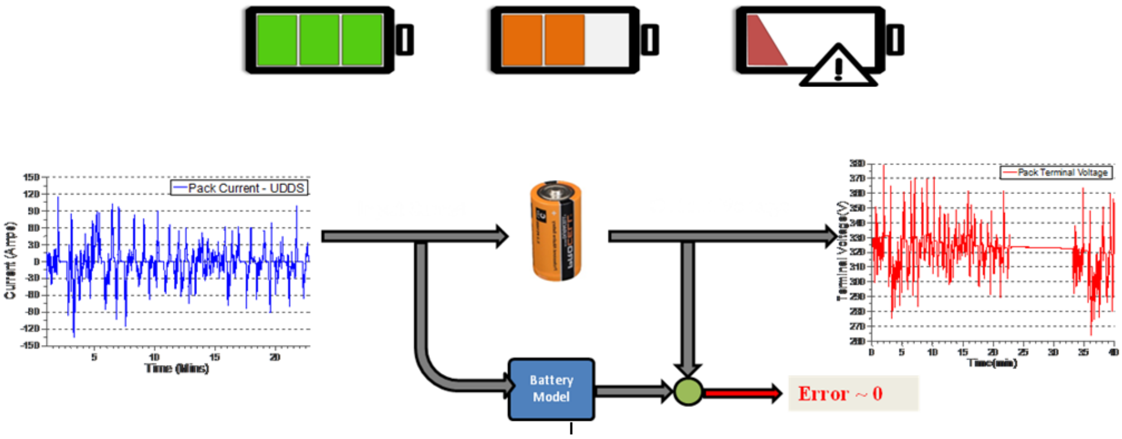

Fig.5: Battery Model: used to track battery characteristics

Design of batteries designing a battery management system (BMS) should begin with a high-fidelity battery model. To estimate the essential properties of a battery, such as its health and state of charge, a BMS needs a suitable battery model and a sufficient estimation approach.

A battery model is a list of mathematical functions that describe the physical actions that take place in the battery. Simply put, the image below illustrates that if the battery and battery model are fed the same current profile, they should have the same voltage profile and the model-to-battery signal discrepancy should be close to zero. This indicates that the model can predict how the battery would behave, which implies that by using an estimator, one may predict crucial quantities like the SOH and the battery's remaining usable life.

Simulation of Battery Model:

MATLAB/Simulink is used to create a battery simulation model, which includes a cell parameters module for looking up the charging and discharging process.

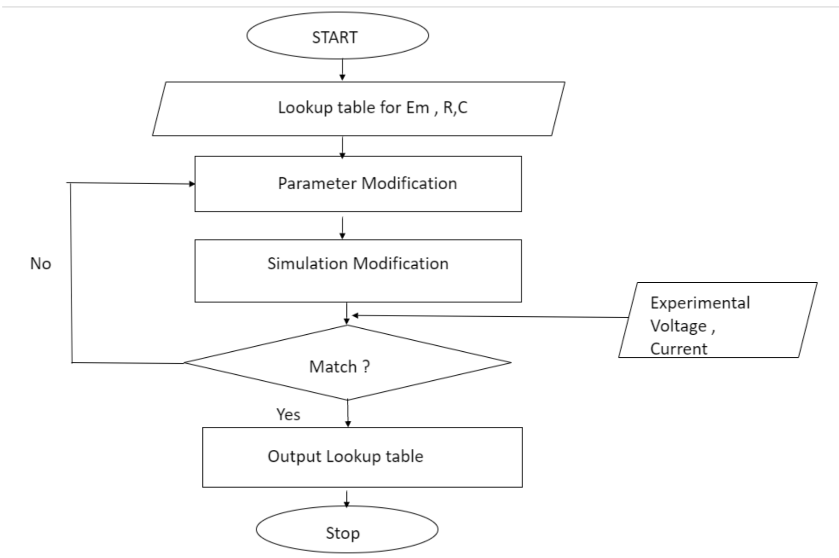

Fig.6: Flow chart to get the comparable circuit components' simulated parameters.

Mathematical Model of the battery:

Numerous mathematical methods of estimate have been categorized based on methodology, and the estimation measures in the diverse literature have been divided into four groups:

Direct measurement: In this case, direct measurement is predicated on the battery's physical attributes, such as its impedance or terminal voltage. The following list contains the most popular techniques: Methods of open circuit voltage, terminal voltage, impedance, and impedance spectroscopy

Bookkeeping estimation: The method assumes that the battery is charged or discharged as input. The precision of measuring the battery system's current is correlated with the precision of counting coulombs. There are two types mainly; Coulomb counting method; modified Coulomb counting method.

Adaptive systems: Because it takes into account the nonlinearities of battery systems, the adaptive systems may also be referred to as an indirect way to measurement. It may be divided into five categories: support vector machines, fuzzy neural networks, RBF neural networks, BP neural networks, and Kalman filters.

Hybrid Method: This is based on how many times different scientists from different nations have made mistakes when solving the equations. This battery model falls into three main categories: per-unit system and EKF combination; Coulomb counting and EMF combination; and Coulomb counting and Kalman filter combination.

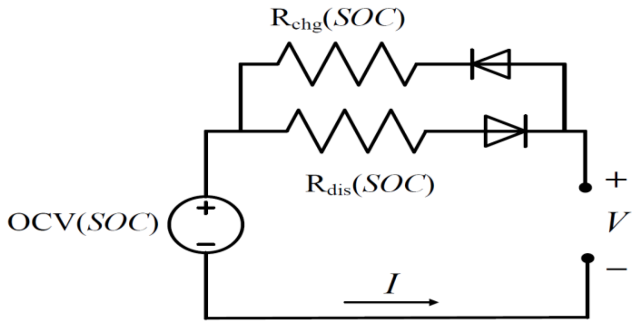

Fig.7: Equivalent circuit

Here, we explain how terminal voltage (V_t) and state of charge (SOC) are related.
V_t = OCV (SOC) – I * R_{dis} (T, SOC) at time of discharging
V_t = OCV (SOC) + I * R_{chg} (T, SOC) at time of charging
V_t is actual terminal voltage where actual load is connected.

The open circuit voltage depends on SOC. In any battery, there exist a certain amount of internal resistance that resists the current during charging and discharging the batteries. Time of behavior of resistance during charging does not match at the time during discharging. Heating of battery is also cause of this internal resistance.

Table2: Example of Li - ion model

EV model	Battery	Range	Wh/km
Li - ion	60kWh	275 km	220

Calculation of load power:
P=890A*320V =285 Kw (1)
Battery capacity selection = 890A * T = 890 * 0.21 (2)
= 190Ah
Charging time of the battery:
T=$batterypowerrating\ /loadpower$ =60∗103/285∗103 (3)
T=12.6 min

Design of converter:

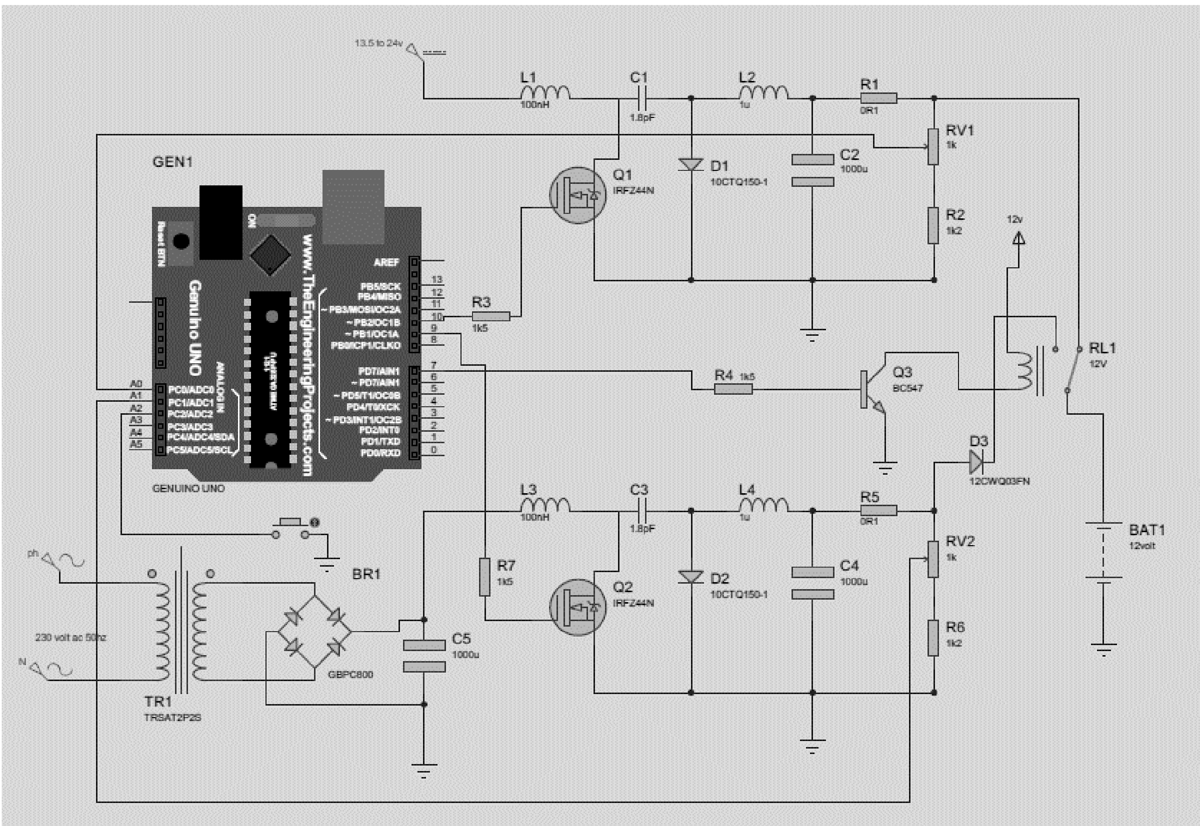

Fig. 9: Circuit diagram of the converter

Usually, the CUK converter is chosen to reduce the voltage to about the nominal voltage of the battery. The output voltage and inductor values of the given circuit are designed. The values of the inductor and capacitor are established using the corresponding design formula.

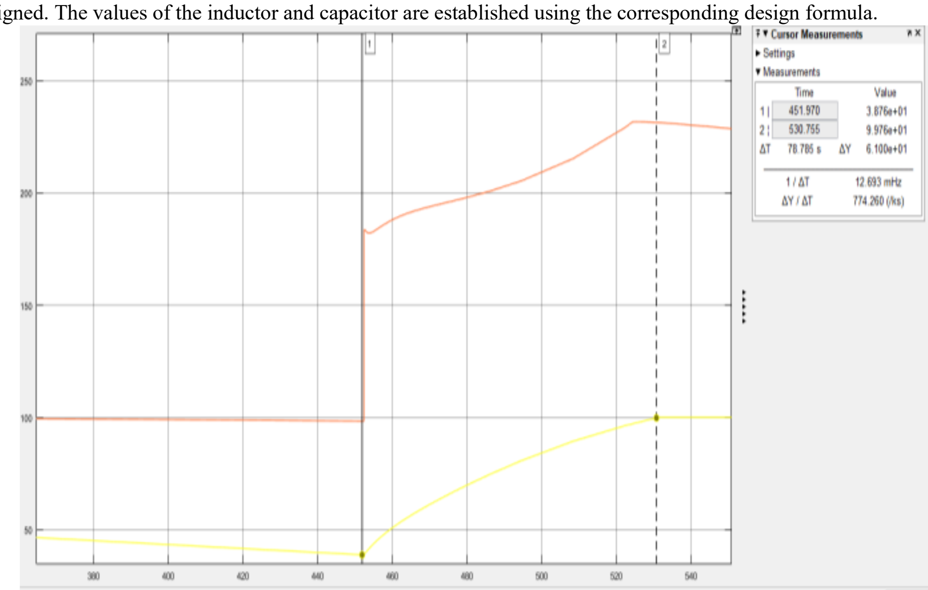

Fig. 10: Waveforms are against the fast charging of battery that consumes 190A and charges at 1h.

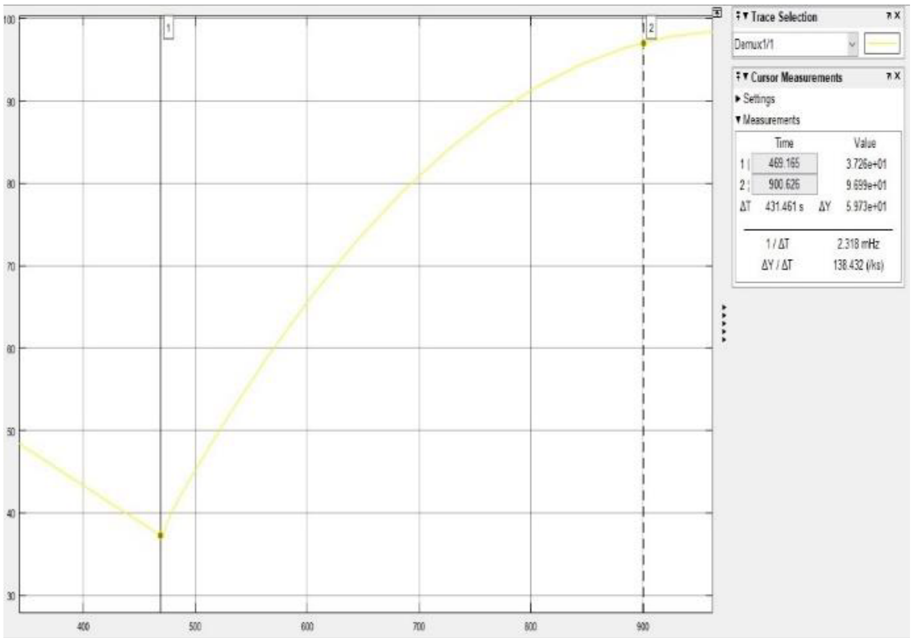

Fig.12: Waveform is in relation to the slow charging of the battery which consumes 20 A and charges in 5.5 h.

Conclusion:

The paper discussed the analysis, design, and MATLAB/Simulink simulation of a dual-mode battery charging system that can both be charged slowly and quickly. The design has built-in inter- phased circuitry which easily switches the inter-phase on and off riding on the operation requirements or availability of energy. The effectiveness and adaptability of the system are proved by results made during simulations. During sanctuary charging (low current) the battery accepts charge at 20 A current and takes about 5.5 hours, so is suited to areas where the battery will not be in demand such as low demand periods or overnight charging and is battery-life and energy efficiency friendly. Fast charging mode, however, achieve a high current of 190 A to bring down the charging time to only 1 hour, which is ideal in case of electric vehicles which need quick turnaround in case of commercial use or emergency cases. The combination architecture is not required to have dedicated infrastructure, which makes it compact, adaptable, and expandable. This two-mode charger promises very well in terms of residential and commercial usage where super fast charging as well as optimum utilization of energy is crucial.

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