Battery Modeling and IPT Charging Infrastructure for Electric Vehicles

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Abstract **-** The automotive industry has become one of the most important world-wide industries, not only at economic level, but also in terms of research and development. Electric vehicle is presently a well established technology. The acceptability is hindered by operating levels of battery which needs to survive long runs. In this study, a discussion on batteries suitable for vehicular application will be done, along with mathematical modeling useful for simulation purpose. A perfect battery needs a proper charging infrastructure that supports the process, where Inductive power transfer technology is an essential medium, which will be detailed

Keywords– *Electric Vehicle system, Battery Parameters, Modeling of Battery, Charging Infrastructure, Inductive power transfer*

I. INTRODUCTION

Electric vehicles (EV) are evolving fast in current times, and there are numerous motives for the scenario. The most significant one is their exposure to reducing emissions of greenhouse gases (GHGs). Increasingly, there are more technological elements that are being introduced on the vehicles towards the improvement of both passengers and pedestrians' safety. More specifically, they promote sustainable and efficient mobility through different initiatives, mainly through tax incentives, purchase aids, or other special measures, such as free public parking or the free use of motorways. EVs are expected to reduce this number, with adequate penetration in the transportation system, but this wasn't the only explanation for introducing together again this millennium old and once-dead idea, as a financially successful and affordable material. An EV is smooth, pleasant to run, which does not have the cost of fuel associated with conventional automobiles. It is extremely useful as a metropolitan mode of transportation. It is sufficient of regular start-stop running, generates the complete torque from the start-up, and does not need trips to the filling station.

II. BATTERY ELECTRIC VEHICLE (BEV)

EVs are referred to as BEVs with just batteries to offer the drive train capacity. BEVs ought to rely solely on the electricity placed in their power packs; thus, the focus of certain vehicles relies straightforwardly upon the battery perimeter. Commonly they can wrap 100 km–250 km on one charge, though the top-level sculpts can go greatly advance, from 300 km to 500 km [5]. These achieves rely upon driving circumstance and approach, van designs, lane situation, atmosphere, battery type and age. When drained, charging the battery pack takes a considerable amount of time contrasted with refueling a regular ICE vehicle. It can take up to 36 h totally renew the batteries [6], there are far less tedious ones too, yet none is similar to the brief period needed to top off a fuel tank. Charging time relies upon the charger devise, its foundation and working power level. Favorable circumstances of BEVs are their straightforward development, activity and comfort.

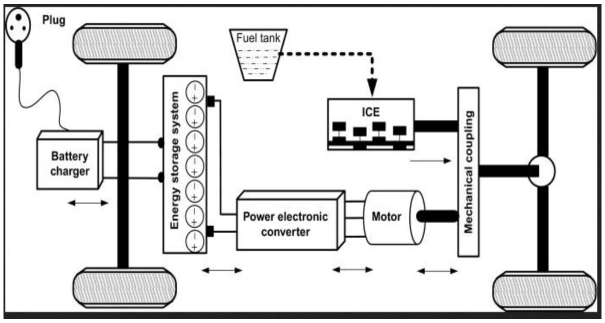

Figure 1- BEV setup [5]

III. BATTERIES FOR ELECTRIC VEHICLE

EV batteries are quite different from those used in consumer electronic devices such as laptops and cell phones. They are required to handle high power (up to a hundred kW) and high energy capacity (up to tens of kWh) within a limited space and weight and at an affordable price. Extensive research efforts and investments have been given to the advanced battery technologies that are suitable for EVs all over the world. The current two major battery technologies used in EVs are nickel metal hydride (NiMH) and lithium ion (Li-ion). Nearly all HEVs available in the market today use NiMH batteries because of its mature technology. Due to the potential of obtaining higher specific energy and energy density, the adoption of Li-ion batteries is expected to grow fast in EVs. Various terms have been defined for batteries to characterize their performance. Commonly used terms are summarized below:

a. Battery Pack: A pack of batteries is composed of modules and placed in a thermally stable chamber.

b. Ampere-hour Capacity: It is the total charge that can be discharged from a fully charged battery under specified conditions.

c. C (nominal C-rate) is used to represent a charge or discharge rate equal to the capacity of a battery in one hour.

d. Specific energy is defined as how much energy a battery can store per unit mass. It is expressed in Wh/kg.

$$\text{Specific Energy} = \frac{\text{Rated Wh Capacity}}{\text{Battery Mass in Kg}}$$

e. Specific power is the peak power per unit mass. It is expressed in W/kg

f. Energy density, also referred as the volumetric energy density, is the nominal battery energy per unit volume (Wh/l).

g. SOC is defined as the remaining capacity of a battery and it is affected by its operating conditions such as load current and temperature.

$$\text{SOC} = \frac{\text{Remaining Capacity}}{\text{Rated Capacity}}$$

If the Ah capacity is used, the change of SOC can be expressed as:

$$\Delta SOC = SOC(t) - SOC(t_0) = \frac{1}{Ah\ capacity} \int_{t_0}^{t} i(\tau)\, d\tau$$

h. Depth of Discharge is used to indicate the percentage of the total battery capacity that has been discharged. For deep-cycle batteries, they can be discharged to 80% or higher of DOD.

IV. BATTERY TECHNOLOGY FOR EV

A battery is composed of a positive electrode and a negative electrode with an ion-conductive but electrically insulating electrolyte in between. During charging, the positive electrode is the anode with the reduction reaction, and the negative electrode is the cathode with the oxidation reaction. During discharge, the reaction is reversed, and so the positive and negative electrodes become cathode and anode electrodes, respectively. In a sealed cell, the liquid electrolyte is held in a separator to prevent the direct short between the two electrodes. The separator also serves as a reservoir for extra electrolyte, a space saver allowing for electrode expansion, an ammonia trap (in NiMH battery), and a safety device for preventing shortage due to Li-dendrite formation (in Li-ion battery).

a) Ni – MH Battery technology

A schematic of the Ni-MH rechargeable battery is shown in figure. The active material in the negative electrode is metal hydride (MH), a special type of inter-metallic alloy that is capable of chemically absorbing and desorbing hydrogen. The most widely used MH in Ni-MH today is the AB_5 alloy with a $CaCu_5$ crystal structure, where A is a mixture of La, Ce, Pr, and Nd, and B is composed of Ni, Co, Mn, and Al. The active material in the positive electrode is $Ni(OH)_2$, The separator is typically made from grafted polyethylene (PE)/polypropylene (PP) non-woven fabric. The commonly used electrolyte is a 30 wt.% KOH aqueous solution with a pH value of about 14.3. In some special designs for particular applications, certain amounts of NaOH and LiOH are also added into the electrolyte. During charge, water is split into protons (H+) and hydroxide ions (OH-) by the voltage supplied from the charging unit. The whole process is reversed during discharge. The complete reaction for charging is as follows:

b) $M + NI(OH)_2 \rightarrow MH + NIOOH$

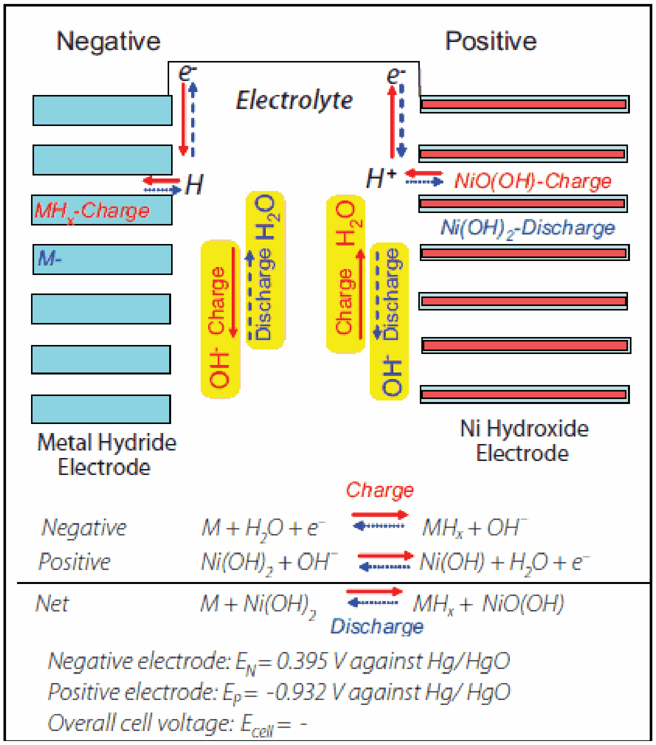

Fig 2 – NiMH charging scheme through chemistry

b) Li – ion Battery Technology

The most commonly used active material in the negative electrode is graphite. During charging, Li ions, driven by the potential difference supplied by the charging unit, intercalate into the interlayer region of graphite. The arrangement of Li+ in graphite is coordinated by the surface–electrolyte–interface (SEI) layer, which is formed during the initial activation process. The active material in the positive electrode is a Li-containing metal oxide, which is similar to Ni(OH)2 in the Ni-MH battery but replaces the hydrogen with lithium. During charging, the Li+ hops onto the surface, moves through the electrolyte, and finally arrives at the negative electrode. The oxidation state of the host metal will increase and return electrons to the outside circuitry. During discharge, the process is reversed. Li ions now move from the intercalation sites in the negative electrode to the electrolyte and then to the original site in the LiMO2 crystal.

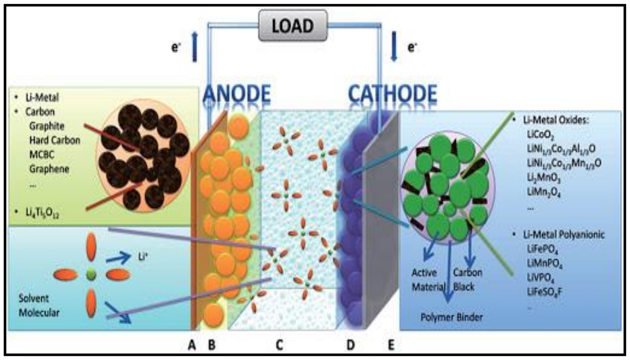

Fig 3 – Li-ion battery chemistry

V. BATTERY MODELING AND CHARGING

Battery modeling forms the basis of and stands as an effective tool for battery design, manufacturing, and control. It is particularly important for battery and battery management since the model development is logically the first step in developing any system identification and state estimation algorithms. Extensive research has been carried out on battery modeling and a variety of models have been developed from different aspects and for different purposes.

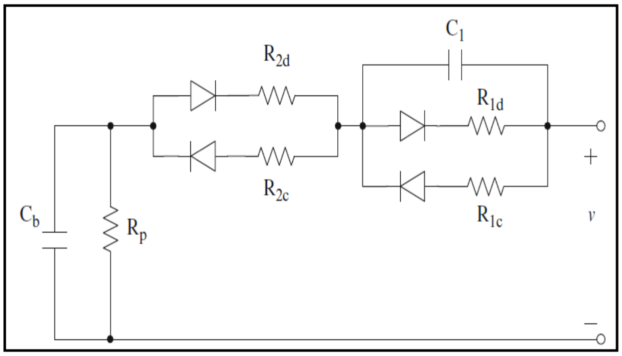

Fig 4 Equivalent circuit model of battery of EV

Here, C_b = battery capacitance
R_p = self-discharge resistance
R_{2c} = internal resistance for charge
R_{2d} = internal resistance for discharge,
R_{1c} = overvoltage resistance for charge
R_{1d} = overvoltage resistance for discharge,
C_1 = overvoltage capacitance

VI. IPT CHARGING SIMULATION AND RESULT

The series-series capacitor compensation based IPT topology is one of the most preferred network arrangement adopted by industries because of its structure simplicity and operational stability for varying coils distance. This network presents a low-cost solution but compromises its efficiency, power transfer capability, high resonant peaks, and control accuracy for variant loading. An algorithm for phase control is presented to enhance efficiency bandwidth.. The control solutions only supports clam to provide higher efficiency by maintaining zero voltage switching (ZVS) for IPT system. The control system topology that is selected for our study of IPT utilizes classical series L–C compensation with small size auxiliary components to make ZVS along with zero current switching (ZCS).

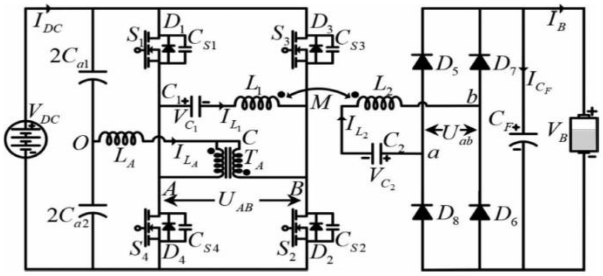

Fig 5- ZVZCS topology implementation

Active switches S1 − S4 at primary side and diodes D5 − D8 at secondary side forms an H-bridge (conventional). Moreover, Ca1 and Ca2 act as potential divider at the input with ancillary, LA and TA to maintain the soft-switching feature of the circuit with BC. The primary and secondary side of the circuit is coupled with L1 and L2 with C1 and C2, respectively. The operation of the converter is controlled by using MPWM. The following assumptions are considered to understand the operating principle of the proposed converter:

1) All active and passive devices consisting of transformer, dc source, switches, diodes, and capacitors are ideal including internal switch diode and capacitance.
2) Electrical series resistance of inductor and inter-winding capacitance of transformer are neglected.
3) Voltage divider capacitors (Ca = Ca1 = Ca2) and CF are large enough to maintain constant voltage at input and output terminals of the converter.
4) The effects of the magnetizing inductance of TA are neglected.

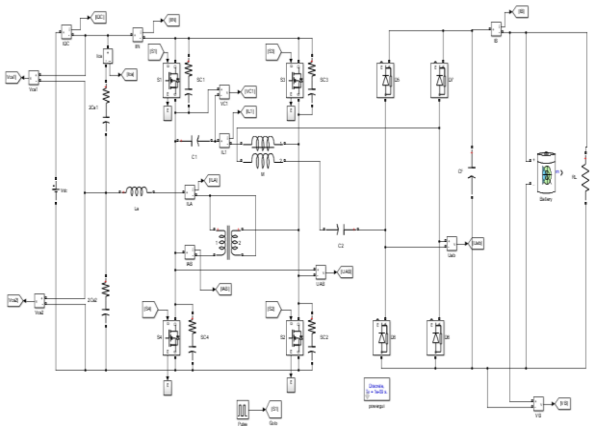

Fig 6 – MATLAB simulation of system

The simulation of a recommended topology has been done in MATLAB/Simulink by using principal components, as shown in figure below. The components used are rated as given in figure 5.3 above.. The ideal dc source is placed in series with resistor (nΩ) and inductor (nH). MOSFET switches from Sim-Power System Library with 0Ω resistance and 870 pF capacitance as snubber have been used to simulate H-bridge part of dc–dc converter. The auxiliary transformer is contracted by linear transformer and transmitter, receiver coils from mutual inductance.

Fig. 7 shows the ZVS turn-ON of switches S1 to S4, as the voltage across the switch reaches to zero, the gate pulse is given to that particular switch to turn it ON. In Fig. 8, the ZCS turn-ON for switches S2 and S4 is indicated. The current from the switch becomes zero before the gate pulse finishes. Therefore it is said that the proposed wireless converter maintains ZCZVS. The compensation capacitor voltage peak value is selected by observing the performance of V_{C1}

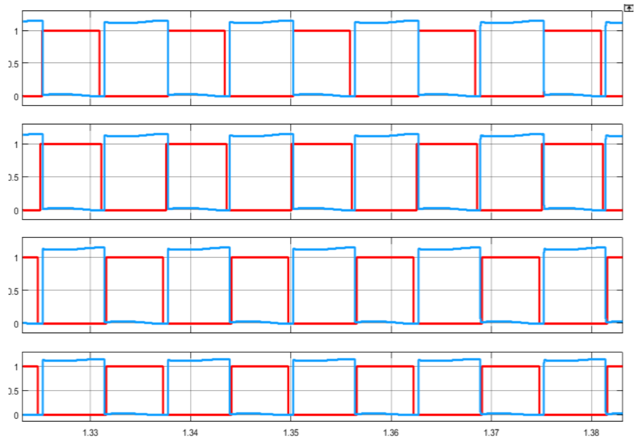

Fig 7 - ZVS turn-ON of switches S1 to S4

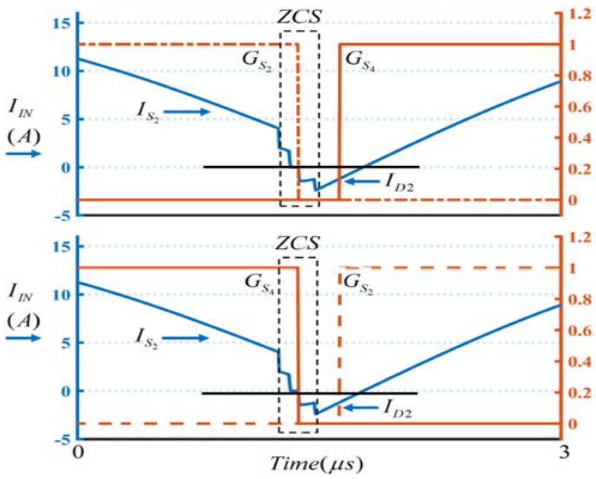

Fig 8 - ZCS turn-OFF for S2 and S4

The performance of the converter for BC is shown in Fig. 9. Graph shows that the disturbance is very less, whereas the conventional charger having disturbance in BC voltage and current, which reduces the life of the battery and degrades the charger efficiency, whereas the nature of battery voltage and current shown in graphs is without using the auxiliary circuit. The circuit performance provides 93.5% efficiency with parameters depicted in figure. The output efficiency for fixed parameters is controlled by updating the switching frequency and output power is controlled by changing input voltage.

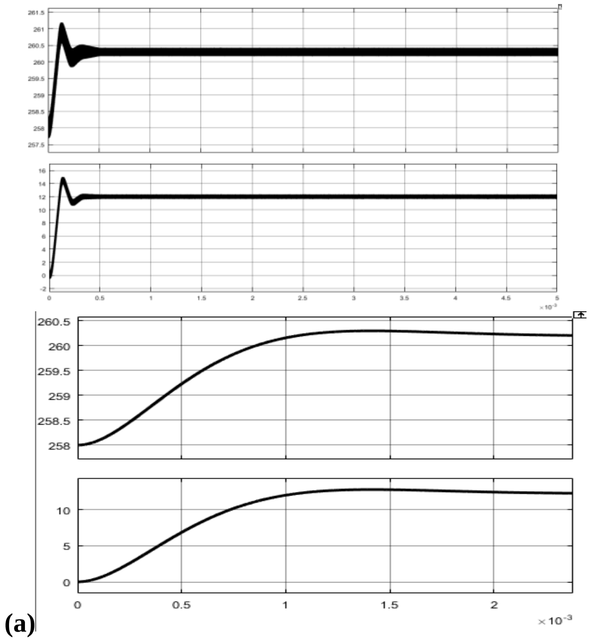

Fig 9 - Output characteristic for BC application a) without control b) with designed circuit

VII. CONCLUSION

Electrification is the most viable way to achieve clean and efficient transportation that is crucial to the sustainable development of the whole world. With respect to EVs, batteries are a critical factor, as these will determine the vehicle's autonomy. Comparative study has been done on Ni-MH and Li-ion batteries which constitutes major share. The EV could also benefit from this type of technology, reaching higher ranges, something that could help its adoption by drivers and users. Also, a basic discussion on charging infrastructure discussed with options like parked charging and charging on the go. With references to the Inductive power transfer (IPT) system utilize either zero voltage switching (ZVS) or zero current switching (ZCS) based power electronic converters while maintaining a near sinusoidal current for limited power transfer range. However, achieving ZVS or ZCS for all power switches simultaneously is still a challenging task in IPT systems. The voltage fed series compensation based ZVZCS topology and their tuning methods for wireless electrical vehicle battery charger

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