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Super Capacitor Based Battery Life Improvement In Electric Vehicles

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ABSTRACT
The production of battery technology, as well as electric vehicles (EVs), has recently gained a lot of attention. Despite major advancements in battery technology, current batteries do not fully satisfy the energy demands of EV electricity usage. Non-monotonic energy consumption followed by repeated adjustments during the battery discharging period is one of the major concerns. This is extremely dangerous to the battery's electrochemical operation. Combining the battery with a supercapacitor, which is essentially an electrochemical cell with a similar design but higher rate capability and greater cyclability, is a feasible alternative. The supercapacitor will provide the extra energy needed in this configuration when the battery fails. In addition to the battery and supercapacitor as separate components, the construction of the accompanying hybrid device must be designed from an electrical engineering standpoint. So, the outcome of this system (combination of battery and supercapacitor) will be insuring the battery life cycle and better performance of electrical vehicles.
Keywords: Electrical Vehicles, Super capacitor, Battery, Power storage system, Regenerative braking

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I. INTRODUCTION

Today we are witnessing that two-wheeler vehicles made it easier to travel between the cities and inside the cities. However, they are a great ease to our lives, they came with a lot of advantages and some problems with them. In initial innovations all the vehicles were running using conventional power source which is basically gasoline that empowers engines and motors to move. Fortunately, after all the research and studies scientists were gradually able to bring electricity to play the role of gasoline which let the motors run using electrical batteries.

A considerable part of the power or the energy consumed by variation of speed which is required because of traffic situations generally in cities and urban areas. In this case to improve the driving range of driving is possible only using hybrid system in vehicles. High spike and steep deeps are contained in the electrical load profile that results generation and demand surge. They cause the head generation in battery, by increasing heat internally the internal resistance also increasing which will decrease the performance of battery and finally pre-mature battery failure will occur. Batteries will not accept any kind of regenerated energy while they are fully charged. Performance of supercapacitors are much better over batteries as they are coping with current surges in some points in acceleration and deceleration because of their higher strength density limits as well as potential to shorter charge-discharge.

Supercapacitor is a new invented energy storing technique. By applying supercapacitors there will be a better replacement for current power sources and application of supercapacitors can provide a vast work opportunity for professionals and others. Connection of supercapacitor with battery helps when a high voltage power is needed and its short dynamic reaction. It is helping to take the stress off of battery by catching the maximum regenerative braking energy. As long as there are no chemical reactions involved in energy storage technique while using supercapacitors the size of battery will be decreased considerably. So, there are unlimited number of charge and discharge circles.

As they are not using any toxic materials so, the maintenance is not needed on these devices. However, the supercapacitors help to decrease the current surge, but it is beneficial to use supercapacitors power storage is to control their energy in them through power electronic converter. This kind of converter controls the power contained in supercapacitors as per state of battery charge. The analysis of battery performance is done by connecting the battery directly to supercapacitor as well as through a suitable power electronic converter by using simulation of real system.

India has explained the issues of protection national energy in National Electric Mobility Mission Plan (NEMMP) 2020 in 2013. The main goal of National Mission for Electric Mobility (NMEM) is to protect the nation energy, degrade the unwanted effect of machineries such as vehicles to the environment and establish local automobile sector productions. So, NEMMP 2020 visioned to achieve automobile sectors for electrical and hybrid vehicles.

Different authors explained about the EV and battery storage technologies in the literature. In ref [1] Different authors explained about the EV and battery storage technologies in the literature. In ref they have modeled and proposed batteries which are not able to give such output and fast reaction for vehicles.

[2] For an electrical vehicle the oscillatory power load or wave is needed is needed which the traditional batteries were not appropriate.

[3] Manufacturers are researching for producing batteries with higher rate of dynamic response for live applications. Pay et.al have proposed new technologies which tends to improve the driving range of an electrical vehicle battery.

[4] The internal resistance of batteries will increase due to regenerative braking which will cause pre-mature failure and inefficiency.

[5] For this there are applications in upcoming years such as; mass market and manufacturing opportunities for supercapacitor as there are some advantages of it over traditional batteries. Now the electrical automobile industries have hope on this technology.

[6] There are many researches have been done on it, they have studied on some applications of supercapacitors.

[7] They have found that in some applications a short and periodic power shout is required, so some kind of device is in need to deliver such energy when needed. For example, to transmit electromagnetic waves or micro waves devices need a high voltage to generate the high-power pulses.

[8] Authors have explained the power circulation and scenario of electrical vehicles as well as the power demand increment for security and comfort. DC to DC converter network or topology and Solectra's DC 400 are explained.

[9] After the survey the problem can be formulated to research on efficiency, battery life and effectiveness of combing two technologies such as; supercapacitor and battery in electrical vehicles.

[10] The intention was to improve the acceleration and deceleration performance and reduce the cost or complexity by combining supercapacitor in the circuit.

II. PROBLEM STATEMENT

In literature review some problems such as manufacturing and design of good storage electrical devices to improve the efficacy, performance and driving range of electrical vehicle have been studied.

Therefore, the problem statement can be stated as "Super capacitor-based battery life improvement in electric two-wheeler", considering development the system by using of MATLAB model and analyzing the results.

Scope of Work

- Theoretical Background: According to the knowledge and prior studies theoretical background of work, advantages and limitations of electrical vehicles will be developed. Hence, it will be used for designing the new proposed model.

Modeling: to develop the model of an effective power storage system for live applications in automation sectors we have to think about the driving load cycle of a two-wheeler vehicle first.

III. DESCRIPTION OF SYSTEM

3.1 COMPONENTS OF SYSTEM

3.1.1 BATTERY

A battery for an electric bike is one that is used to produce traction force. Charges are stored in a battery by a chemical reaction. Resistance, temperature, charging and discharging rates all have an impact on the battery's efficiency. Thevenin's equivalent circuit, which puts the open circuit voltage in series with an analogous resistance, is a widely used indefinite model for batteries. The SOC of the batteries are defined by the combination of resistance and voltage (State of Charge). After removing any Amp-Hr, the SOC is the volume of energy left in the battery. The voltage of the battery is seen as a function of the state of charge (SOC).

$Voc(t)= a1+a2*SOC(t)$, in specific temperature.

In comparison to SLI batteries, deep-cycle batteries are often found in vehicle industries. Deep-cycle battery is designed with a large charge unit size in mind. The strength to weight ratio of batteries for electric vehicles must be high. Electric and hybrid electric cars are becoming more common in today's markets, so it's important to look at how they can be used in public transit networks. Lead Acid batteries have been the most popular energy buffers being used in automobile applications due to their low cost. Until now, the chemical properties of lead acids have prevented fast charging or discharging without causing a temperature increase, lowering its efficiency and contributing to its long-term deterioration. Professionals suggest pairing the lead acid battery with the super capacitor to solve this problem.

3.1.2 CHARGING AND DISCHARGING

On discharge, lithium ions (Li+) transport current from the negative to positive electrodes of the battery, via a non-aqueous electrolyte and a separator diaphragm. An external electrical power source applies higher voltage while charging, causing the charging current to flow from positive to negative electrodes, in the opposite direction of discharge current. Under intercalation, the lithium-ion travels from the positive to negative electrode, where it is embedded in the absorbent electrode content. Electrical interaction resistance at the interfaces of electrode layers causes energy losses. Under standard operating conditions, energy losses from current-collectors can be as much as 20% of the total energy of the batteries.

The charging mechanism for a single Li-ion cell and a full Li-ion battery differs slightly.

There are two stages for charging a single Li-ion cell:

1. Constant Current
2. Constant Voltage

There are three stages for charging a series of Li-ion cells:

1. Constant Current
2. Balance
3. Constant Voltage

In Figure 1, the charger provides a constant current to a battery while gradually increasing the voltage until the voltage limit per cell is reached. During the balance point, the charger reduces the charging current when balancing the circuit to bring the state of charge of each individual cell to the same amount, until the battery is balanced. This stage of charging is skipped by some fast chargers. Some chargers finish the balance stage by charging each cell individually. During the constant voltage stage, the charger provides a voltage equal to the cell's maximum voltage, which gradually decreases to zero until the current falls below a fixed threshold of about 3% of the primary constant charge current. Once every 500 hours, a topping fee is applied. When the voltage falls below 4.05V/cell, top charging should be started.

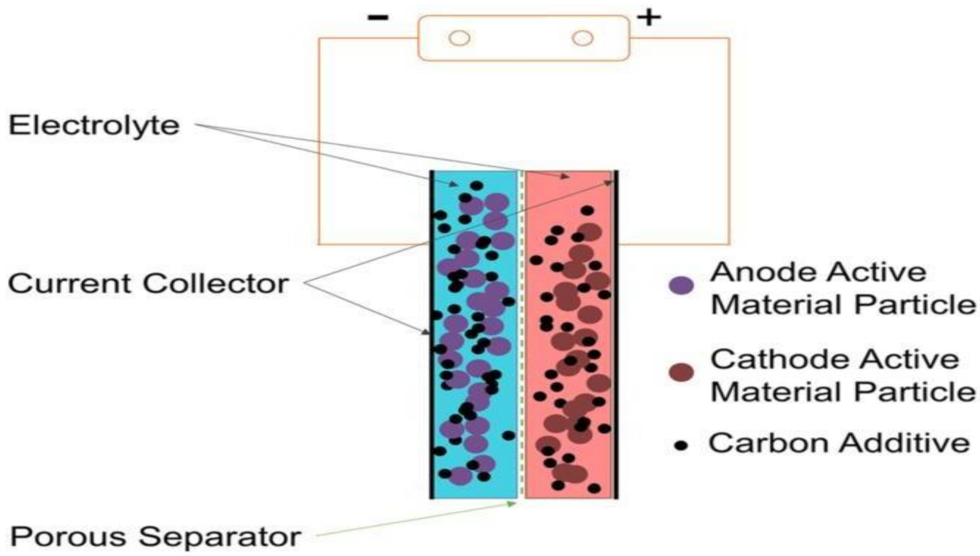

Fig.1: Lithium-ion battery

3.1.3 Charging

Electric two-wheeler batteries must be recharged. The most popular way to charge electric vehicles is from the distribution grid at home or at a recharging station. When using appropriate power supplies, a good battery lifetime can be achieved. It takes two to three hours to completely charge a battery, but faster charging is also possible without affecting battery life. Figure 2 shows how we use a household charger for this reason.

A battery charger must have a sophisticated control system for current and voltage regulation. Without such advanced control, the battery's life can be shortened. A battery for an electric vehicle is made up of a series of cells linked in a row. Due to charge unbalancing, the battery cells can be exposed to various charges when charging and discharging. Temperature is also a factor in such cases. To avoid battery failure and a shorter lifespan, the battery cells must be charged at full SOC on a regular basis. The main requirement for a battery charger is that it be fast. Owing to a lack of grid capabilities, no one can charge their bikes at home. As a result, an outside charging station should be available;

otherwise, electric bike use would be restricted to a certain extent. The issue with quick charging is that we can only charge it in fast mode up to 80% SOC, and the remainder of the charge must be performed in slow mode.

Fig.2 -Household Charger

So, considering the load required for the vehicle, components have to be prepared/chosen that can satisfy the requirements.
Simulating: To develop simulation MATLAB is used after selection of appropriate components for model.
Result analysis: after the simulation is done, it has to be compared and analyzed to confirm the computations and work done.

IV. MODELLING OF SYSTEM

4.1 SYSTEM SIZING ALGORITHM

A suitable part size is needed to satisfy the desired load, as well as to make the device most acceptable in terms of size and expense. The system's efficiency is determined by component selection, as its cost and capability determine the whole vehicle's dynamics and economics.

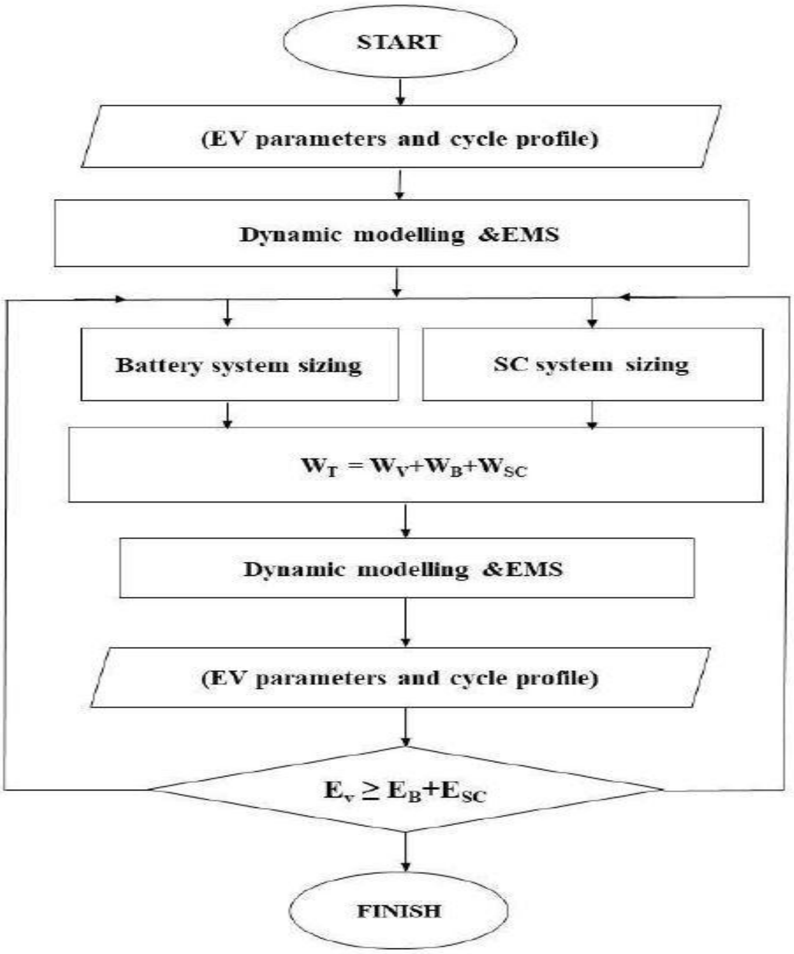

Fig.3- System Sizing Algorithm

4.2 SYSTEM SPECIFICATION

The battery system creates two parallel banks. Each battery bank is made up of 24 deep-cycle valve-regulated-leadacid (VRLA) battery cells that are connected in a cascade.

Table No.1 – Battery Specifications

Rated voltage	24 V
Capacity	14 Ah
Recharge rate current	14.5 A
Static recharge internal resistance	(SOC ≤ 50%)

SUPER CAPACITOR

The subsystem of a super capacitor is made up of a series of 12 cells connected in series. To increase the energy, capacitors are connected in series. Super capacitors have a low energy density and a high power density.

Table No. 2 – Super capacitor Cell Specifications

Rate voltage	2.7 Volt
Capacitance	350 F
Peak voltage	2.9 V
Series Resistance	1 mΩ

Table No. 3 – Super capacitor Subsystem Specifications

Rated voltage	32 V
Capacitance	29 F
Peak Voltage	34 V
Energy stored capacity	1.17 MJ

DC-DC CONVERTER

Table. 4 – Converter Specifications

Switching Frequency	1 KHz
Inductance	100 mH
Resistance	10 mΩ
Capacitance	100 mF

The overall power demand Pmax from the buck-boost converter and the system's thermal capabilities determine the size of the switches and diodes used for freewheeling.

4.3 SYSTEM MODELLING

4.3.1 DIRECT SUPER CAPACITOR CONNECTION

Combining a super capacitor with a battery-powered load circuit is complicated in order to simplify as well as make the super capacitor sub-system more convenient. The simplest way to incorporate a super capacitor is to connect it in parallel with the battery bank; it is charged to a voltage equal to the battery terminals first. The load current is provided by il flowing downward, which means it will be negative during regenerative breaking and positive during acceleration, as seen in figure 7. The super capacitor current ic and the battery current ib, which are measured using simple circuit rules such as Kirchoff's current and voltage laws, are given to a particular load that reflects any drive cycle of a vehicle. The optimal part will have a higher energy density and a higher power density than current batteries and capacitors. This part does not exist at the moment, but super capacitors are on their way. A super capacitor is a gadget that increases the power density of a battery or the energy density of a conventional capacitor.

Super capacitors now have around half the power density and one hundred times the energy density of the best tantalum capacitors. Sources and loads are always imperfect, and the amount of output that can be tolerated depends on the application. A super capacitor connects the source and the load. When used in parallel with the battery it flat out the load on the battery whereas improving the source impedance seen by the load. This shows that the battery supplies the energy and the super capacitor supplies the short-term power.

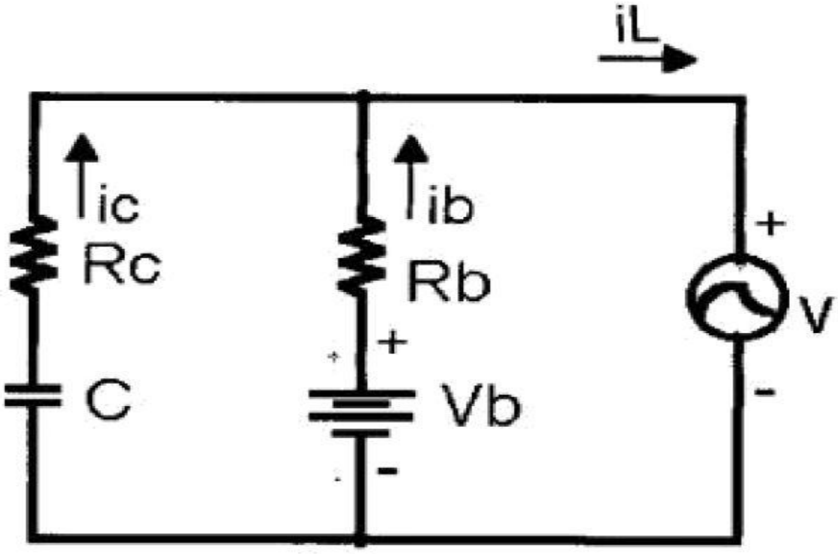

Fig.4 System Circuit

4.3.2 SUPER CAPACITOR CONNECTION THROUGH POWER CONTROLLER

For full use of the super capacitor bank, direct integration with a power flow controller in between storage blocks subsystems is needed (see Fig.6). The aim of a power converter like this is to get the battery's steady state current so that it doesn't overheat. During peak energy consumption, the super capacitor charged rapidly from the generative direction while breaking and discharging nearly all of its recycled power.

4.4 SIMULATION

The simulation is carried out using the MATLAB/SIMULINK software. For technical work, MATLAB is a higher-performance verbal. For power measurements, simulation models are prepared. The output of the combined device with buck and buck/boost power converter is also demonstrated using a vehicle model with power converter. For each load cycle, MATLAB simulations are run in discrete mode and the results are plotted. The power curve of an electric two-wheeler, as well as voltage / current characteristics, are shown in the fig. 9, which was obtained from a MATLAB model in which the super capacitors and batteries are connected in parallel as well as via a DC-DC power converter. According to the results of simulations on sudden load increases to DC systems at traditional substations and simulations on sudden load increases, a hybrid energy storage device for super capacitors and batteries will achieve buffered fast discharge of the super capacitor and buffered slow discharge of the battery, enabling them to both benefit from their respective advantages.

We created various scenarios for both pure electric and group hybrid vehicles to investigate the effect of super capacitors with lead-acid batteries on battery variables and fuel usage, adjusting parameters such as capacitance value and battery charge for optimum operating points.

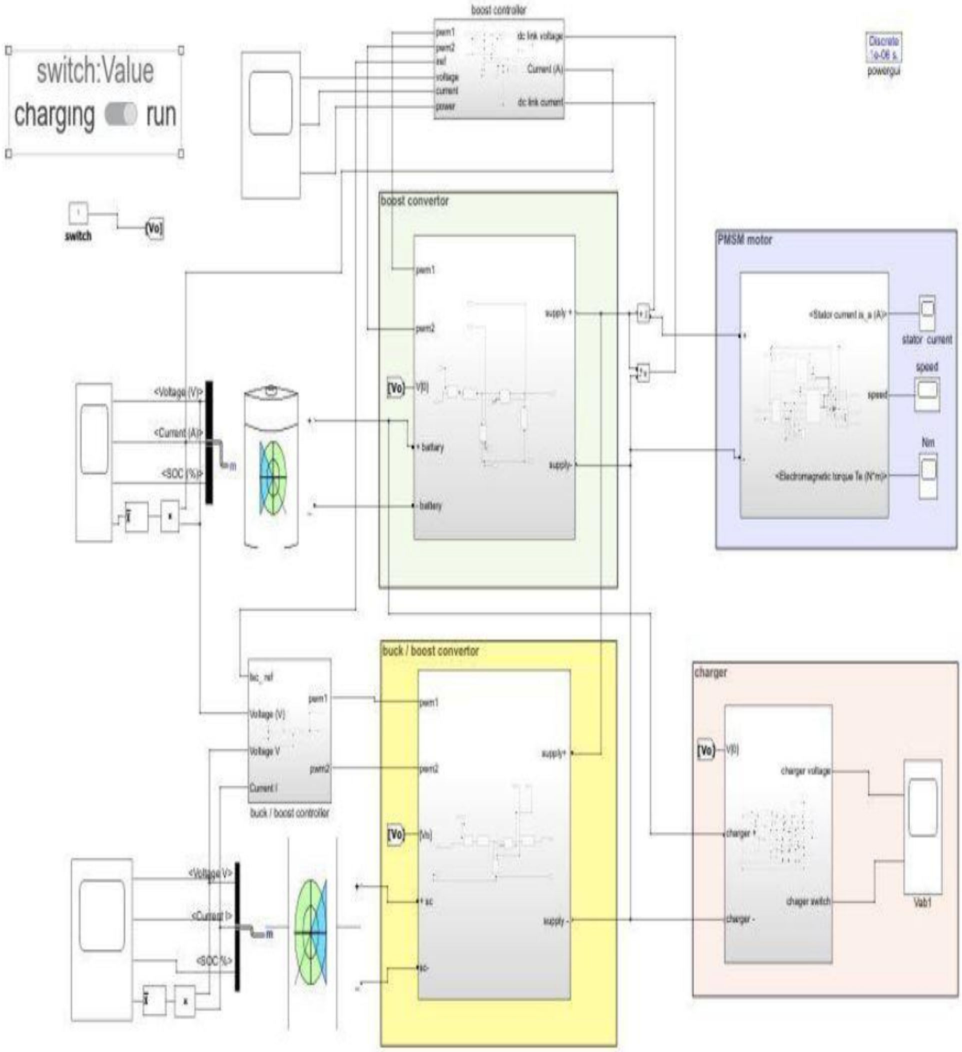

Fig.5- System Simulation

V. ANALYSIS AND RESULT

5.1 MATLAB MODELLING AND RESULT

Figure 8 displays an electric vehicle's power curve as well as current and voltage parameters obtained from a MATLAB model in which the super capacitor and battery are paired in parallel as well as via a DC-DC power converter.

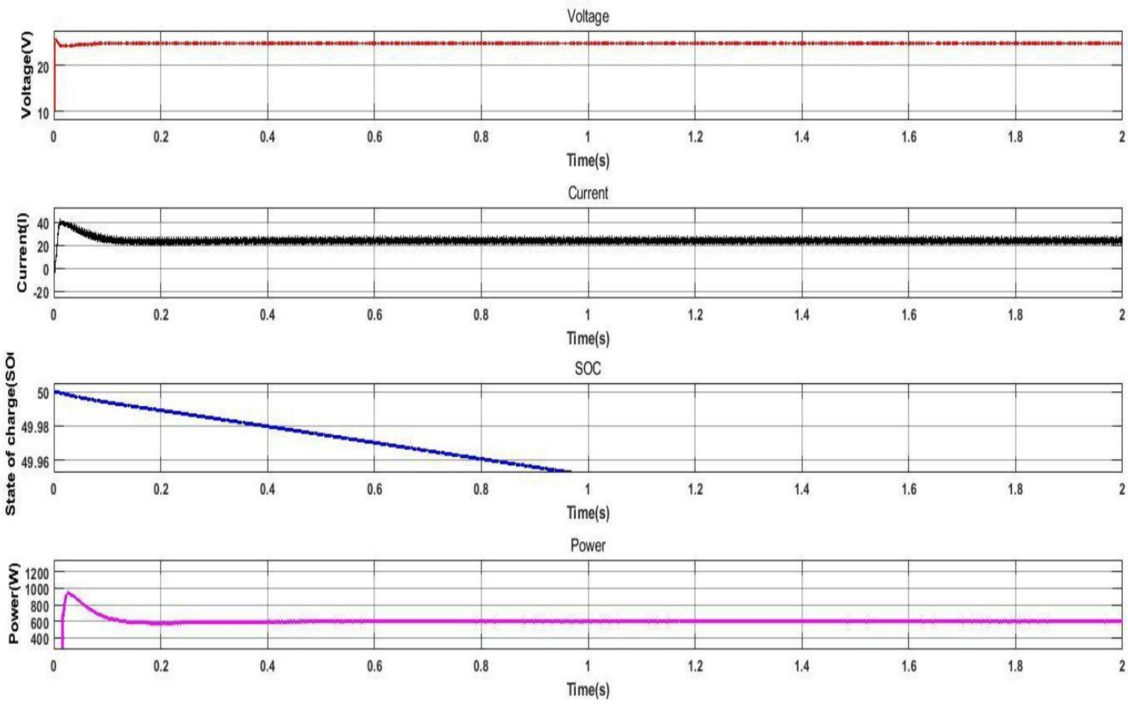

Fig.6 -Battery characteristics of electrical vehicle

The voltage of the battery is 24V. Since the battery is in run mode, the SOC (state of charge) of the battery will decrease, as seen in Figure 8. Without the use of a super capacitor in an EV drive with a battery. Without the peak output from the super capacitor bank, the battery wants to have peak power of 800W, as seen in Figure 10.

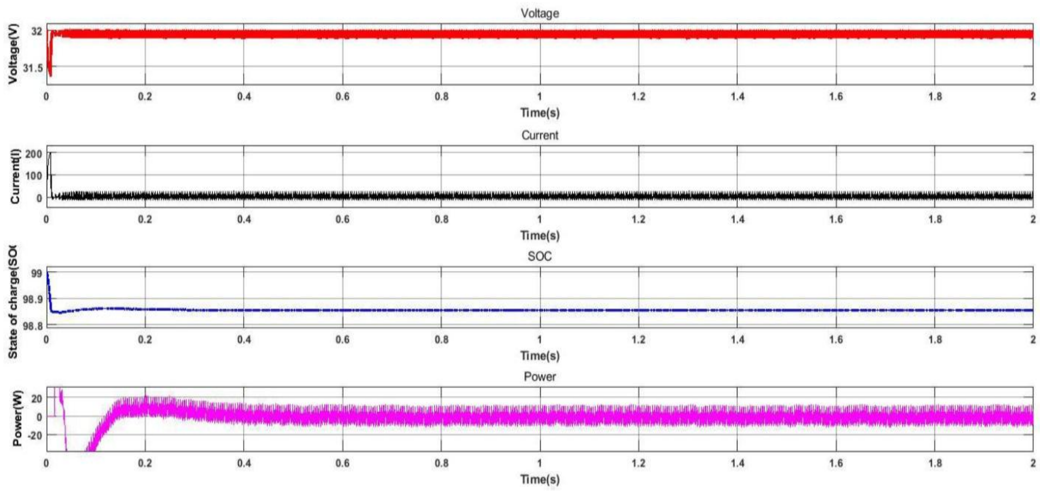

Fig.7 Super capacitor characteristics with Parallel Connection

When a super capacitor and a battery are coupled in parallel and a simulation is performed with a particular load demand, the current and voltage characteristics shown in Figure 9 are shown. As can be shown, the super capacitor produces peak voltage when the vehicle starts, as well as protecting the battery from high peak voltage and current, extending its existence.

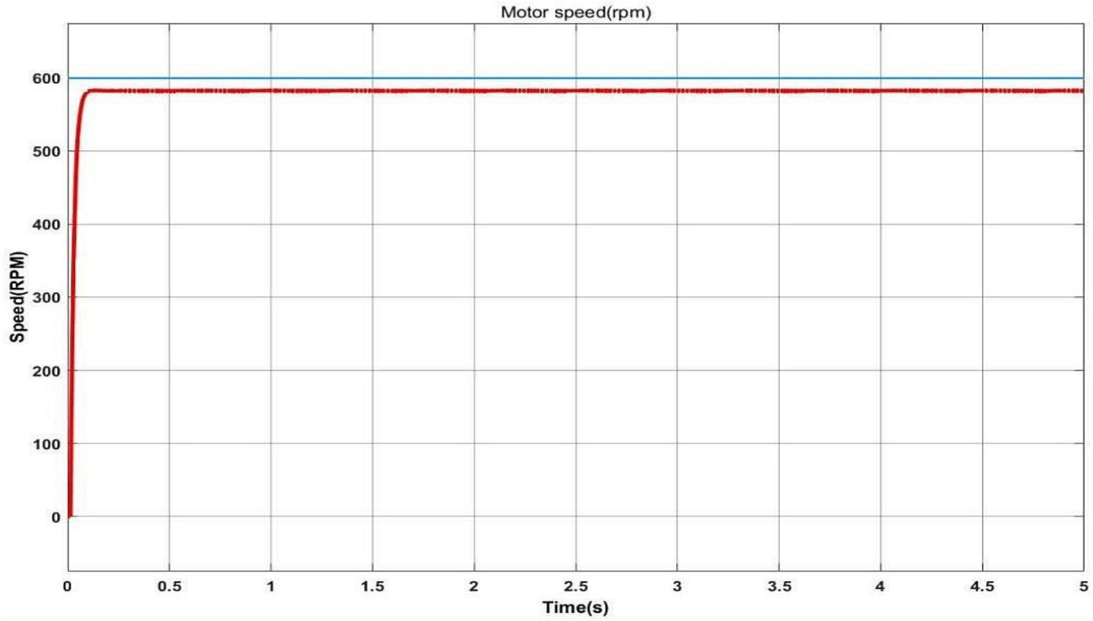

Fig.8 Speed Characteristics from Super capacitor Integrated with DC-DC Converter

Figure 10 depicts the vehicle's speed after the addition of a power controller for super capacitor charge regulation. The needed speed is 600rpm, as seen in the blue line, while the provided speed is about 580rpm. As a result, we can see that the curve has smoothed out, indicating that the super capacitor is being used to its full potential.

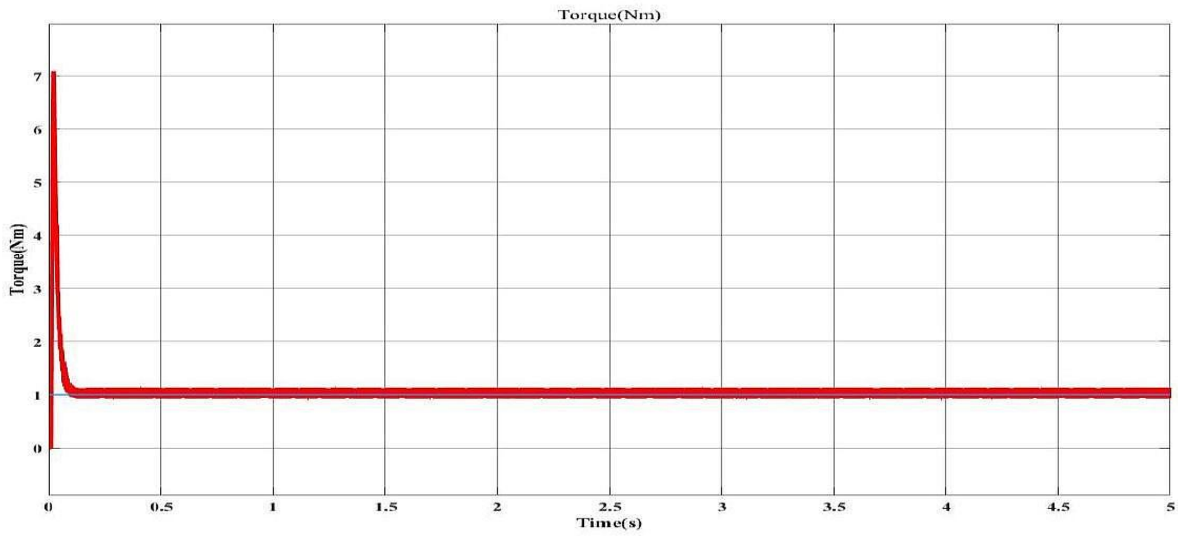

Fig.9: Torque Characteristics of motor

Load torque and electromagnetic torque are represented in Figure 11. The motor load is 1Nm, which is the necessary torque, and our system provides close to 1Nm. Since the torque properties are high in the starting period when the engine is started with a super capacitor, the battery load is reduced and the battery cycle is increased.

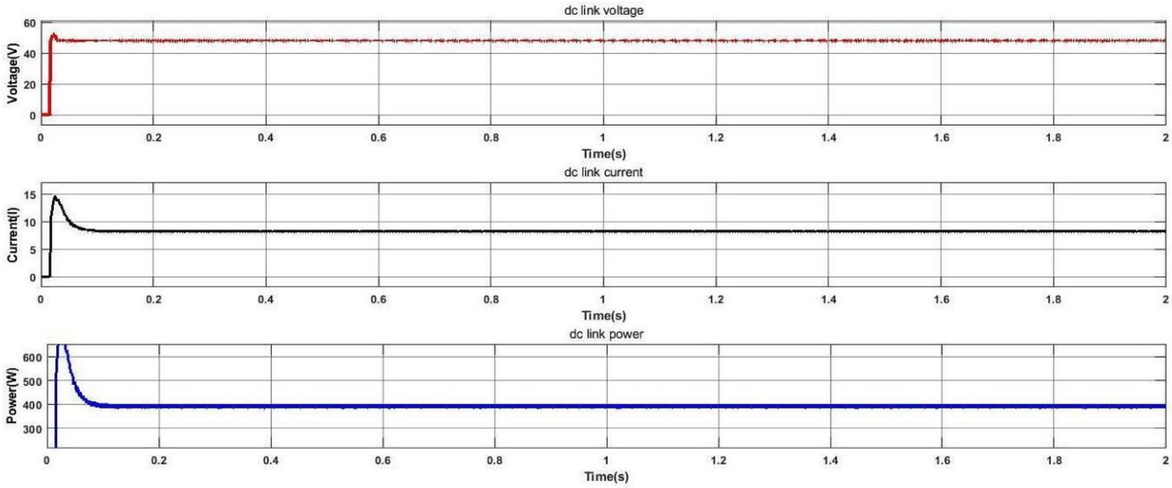

***Fig.10** -Motor characteristics of electrical vehicle*

Figure 12 depicts the vehicle's motor characteristics. Our battery provides 24V to the system, and the required electricity is supplied by a super capacitor. The extracted voltage in this figure is 48V, which is needed for the PMSM motor; this voltage is provided by the super capacitor; otherwise, our battery would not have any electricity, so the peak current of the battery would be decreased.

VI. CONCLUSION

For the power flow control of a hybrid energy storage device consisting of batteries and supercapacitors for electric vehicles, a model predictive controller has been developed. The controller's goals are to maintain a defined vehicle speed profile by proper power distribution within the battery and supercapacitors, as well as to prevent sudden changes in the battery's power flow to protect it.

Future efforts will be focused on the construction of a storage device that will operate in all driving modes. Advanced monitoring mechanisms, such as fuzzy control, will enhance our energy management control. Improvements to the vehicle-to-grid arrangement may be a potential project.

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