Improving Braking Energy Recovery Efficiency of Electric Vehicle Equipped with a Super capacitor

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Abstract - *major problems of the current era are pollution and energy deficiency. The considerable part of pollution was caused by passenger vehicles and heavy-duty trucks. That's why the demand of electrical vehicle is increasing day by day. The increasing petrol prices are also a fact behind the increasing popularity of electric vehicle. The electric vehicles are having advanced idiosyncrasies like braking energy recovery and no pollution. But due to the limitations associated with the battery (the lithium-ion battery take 1-3hour to charge fully, lifespan is less if it undergoes large braking current) and regenerative braking technique. The braking energy efficiency is decreasing and it, in turn, decreasing the energy efficiency of the electric vehicle. In this paper, we are improving the braking energy efficiency of the electric vehicle with the help of parallel regenerative braking technique and by utilizing the properties of the super capacitor.*

1. INTRODUCTION

We are accustomed to classical petroleum and diesel automobiles. The heart of conventional vehicles is the IC engine. It uses fuels for working, hence the vehicle producing pollution. In the braking mode of the conventional automobile, the kinetic energy of the vehicle is converted to heat energy. The braking energy was wasted in the form of heat. For this reason, classical vehicles are considered as an energy deficient product

A few years back the customers found options like color, performance, fuel (diesel or petrol) while choosing an automobile. Due to zoom in technology nowadays they are having the privilege to choose in between electric vehicle or conventional vehicle. The classical vehicles are not an only option while buying an automobile, electricity is also in the game than ever before.

An electric vehicle uses the electric motor as their major part, hence they free from pollution. Thanks to regenerative braking technique, electric vehicle demand is increasing in the automobile market. Regenerative braking is an additional and phenomenal characteristic of the electric vehicle thus the braking energy can be recovered and stored in the battery. As a result wastage of energy during braking is decreased. In that account electric vehicle treated as energy efficient product.

In the electric vehicle, the lithium-ion battery is used as an energy storage device. The battery is not capable of undergoing a large braking current and power fluctuations; in this situation, the conventional regenerative braking system goes for traditional friction braking instead of going regenerative braking. Hence the braking energy recovery is not done for protecting the battery pack. Hence the braking energy efficiency is decreased. The improvement of braking energy efficiency is possible only by doing braking energy recovery in each braking operation without bothering the braking current .it can be realized by using efficient storage devices and proper braking technique, hence a super capacitor introduced in the regenerative braking system as a storage device along with the battery and also in cooperating the parallel regenerative braking technique. The parallel regenerative braking technique will assist to rectify the constraints related to the regenerative braking.

2. LITHIUM- ION BATTERY

In an electric vehicle lithium-ion battery is used as an energy source as well as the storage device. A lithium-ion battery is a well-known rechargeable battery for its application in the various fields. In this type of battery during discharge lithium ion will move from negative electrode to positive electrode and during charging a reverse flow of lithium ions occur ie it flows from positive electrode to negative electrode .the lithium-ion battery consists of positive, negative electrodes and electrolyte as like any other battery. Generally, Lithium-ion with carbon and any metal oxide will be the negative and positive electrode of the lithium-ion battery respectively. The most prominent negative electrode of the lithium-ion battery is graphite. The lithium-ion battery is having the advantages of high power density, low maintenance and less self-discharging characteristics. The lithium-ion battery is available in a variety of types. The power rating and other properties of lithium-ion battery will be determined by the material used in the battery.

2.1 Limitations of lithium ion battery

The main disadvantages of the rechargeable battery are less utilization ratio of braking energy. The factors affecting the reduction of utilization ratio is given below

Braking current: The rechargeable battery is not capable of withstanding with the large braking current and braking energy. The large braking current may result from irreparable damages to the battery. So in conventional regenerative braking technique, regenerative braking is not possible with large braking current

Soc range of battery: Soc means the state of charge. It is a quantity represented in per cent. It indicates the state of charge of the battery. For example, if the soc is 100% then the battery is fully charged, if soc is 0% then the battery is empty. If the soc of battery is almost near to full charge (90%) and again charging the battery during braking operation may lead to overcharging of battery it may cause degradation in battery performance or damages the battery pack. As a result lifespan of the battery gets reduced.

Power fluctuation: battery cannot withstand with large power fluctuations, power fluctuations' may damage the

3. REGENERATIVE BRAKING

Regenerative braking is one of the peculiarities linked with the electric vehicle since they are using the electric motor instead of the IC engine. Regenerative braking is concerned as an energy recovery mechanism .during braking the kinetic energy of the vehicle is converted to electrical energy ie in braking operation the electrical motor will act as a generator. This whole process is called regenerative braking. The recovered energy is stored in the battery. Regenerative braking is based on the principle of the law of conservation of energy.

3. 1 traditional regenerative braking technique

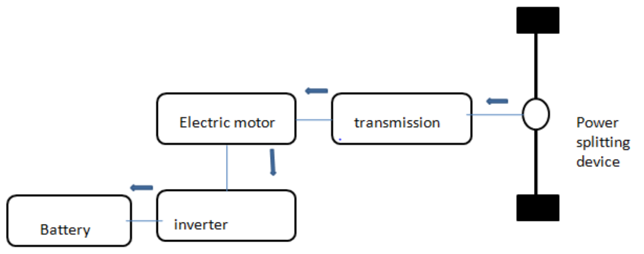

Fig -1: Traditional regenerative braking technique

In this system, the battery will supply power required for the motor to run through an inverter. The motor will convert electric energy fed from the battery to mechanical energy and vehicle starts moving .in braking mode when the brake has applied the direction of torque associated with the motor will change, it will change the direction of the motor current. Due to this, the motor starts to rotate in the opposite direction. Now motor working as a generator and convert the mechanical input (kinetic energy of a vehicle) into electrical energy and stored in the battery through a rectifier.

3.2 Constraints of regenerative braking

Inadequacy in generator

For smooth regenerative braking the braking force required for the braking always less than the maximum torque provided by the motor .if the braking force is too high and violates the above condition then the motor fails to meet the braking energy recovery requirements .hence the efficiency of regenerative braking reduces

Effects of cycle

If the vehicle is moving in the stop-go condition more energy can be recovered .so the efficiency increased. But in other condition recovery efficiency will be less

Soc range of storage device

If the soc limit of a battery is almost equal to 100%, then braking energy recovery is not possible

C. Types of regenerative braking technique

There 3 types of regenerative braking techniques are their series .idle and parallel regenerative braking technique. In this idle technique can apply only when the motor is working in ideal condition so it not a suitable method. In series regenerative technique a smaller engine is required in series regenerative braking technique because it has only to meet fewer power demands, So that the battery should be more powerful to supply the remaining power demands. The battery requirements will increase the cost. Such that series regenerative braking is more expensive than parallel. Also power train model of a vehicle have to change in series technique, so it is not a suitable one. Parallel regenerative braking is more suitable because it considering the influence of power distribution in braking direction and it is less expensive, no need to change the power train model of the vehicle.

4. SUPER CAPACITOR

Every electrochemical capacitor has two electrodes, mechanically separated by a separator, which are ionicily connected to each other via the electrolyte. The electrolyte is a mixture of positive and negative ions dissolved in a solvent such as water. At each of the two electrode surfaces originates an area in which the liquid electrolyte contacts the conductive metallic surface of the electrode. This interface forms a common boundary among two different phases of matter, such as an insoluble solid electrode surface and an adjacent liquid electrolyte. In this interface occurs a very special phenomenon of the effect. Applying a voltage to an electrochemical capacitor causes both electrodes in the capacitor to generate electrical double-layers. These double-layers consist of two layers of charges: one electronic layer is in the surface lattice structure of the electrode, and the other, with opposite polarity, emerges from dissolved and solvated ions in the electrolyte. The two layers are separated by a monolayer of solvent molecules, e. g. for water as solvent by water molecules, called inner Helmholtz plane (IHP). Solvent molecules adhere by physical adsorption on the surface of the electrode and separate the oppositely polarized ions from each other, and can be idealised as a molecular dielectric. In the process, there is no transfer of charge between electrode and electrolyte, so the forces that cause the adhesion are not chemical bonds but physical forces (e.g. electrostatic forces). The adsorbed molecules are polarized but, due to the lack of transfer of charge between electrolyte and electrode, suffered no chemical changes. The amount of charge in the electrode is matched by the magnitude of counter-charges in outer Helmholtz plane (OHP). These double-layer phenomena stores electrical charges as in a conventional capacitor. The double-layer charge forms a static electric field in the molecular layer of the solvent molecules in the IHP that corresponds to the strength of the applied voltage.

$$c = \varepsilon A / d \qquad \text{Eq. (1)}$$

Accordingly, capacitance *C* is greatest in capacitors made from materials with a high permittivity *ε*, large electrode plate surface areas *A* and small distance between plates *d*. As a result, double-layer capacitors have much higher capacitance values than conventional capacitors, arising from the extremely large surface area of activated carbon electrodes and the extremely thin double-layer distance on the order of a few angstroms (0.3-0.8 nm), of order of the Debye length.[13][21]The main drawback of carbon electrodes of double-layer SCs is small values of quantum capacitance[24] which act in series[25] with capacitance of ionic space charge. Therefore, further increase of density of capacitance in SCs can be connected with increasing of quantum capacitance of carbon electrode nanostructures. The amount of charge stored per unit voltage in an electrochemical capacitor is primarily a function of the electrode size. The electrostatic storage of energy in the double-layers is linear with respect to the stored charge, and corresponds to the concentration of the adsorbed ions. Also, while charge in conventional capacitors is transferred via electrons, capacitance in double-layer capacitors is related to the limited moving speed of ions in the electrolyte and the resistive porous structure of the electrodes. Since no chemical changes take place within the electrode or electrolyte, charging and discharging electric double-layers in principle is unlimited. Real super capacitors lifetimes are only limited by electrolyte evaporation effects.

5. PARALLEL REGENERATIVE BRAKING

5.1 Algorithm of control strategy

Step1: start

Step2: determine the current soc value and total braking Force

Step3: if total braking force is too large (non recyclable) Then go to step7, otherwise go to next step.

Step4: judging the braking strength if braking Energy = big then go to next step, otherwise go to Step8.

Step 5: if (maximum regenerative power rating of motor >max regenerative braking, then go to next step, otherwise go to step 7

Step 6: compound braking, both friction braking and regenerative braking, go to step 9

Step 7: 100% frictional braking, go to step 9

Step 8: 100% of regenerative braking

Step 9: stop

6. CONTROL STATEGY FOR CHARGING

Step1: start

Step2: collecting data's ie acceleration a, braking current Ib.Super capacitor soc cap-soc. battery soc bat-soc.

Step3: if a<0 go to next step, otherwise go to step 9.

Step4: braking condition.

Step5: if Ib <A1, then go to next step, otherwise go to step8

Step6: if bat-soc <A2 then go to next step otherwise go to Step 8

Step 7: braking energy is stored in the battery pack.

Step 8: braking energy is stored in the capacitor.

Step 9: non braking condition.

Step 10: if cap-soc >A3 go to next step, otherwise go to step13.

Step 11: if bat –soc<A2 go to next step otherwise go to step 13

Step 12: braking energy is transferred from super capacitor to battery pack .go to step 14

Step 13: remains unchanged.

Step 14: stop

7. BRAKING ENERGY RECOVERY EFFICIENCY

$$fd = fw + fr + fg + fa \qquad (1)$$

fd is the driving force needed to move a .*vehicle* fw is the friction offered by the air opposite to the motion of vehicle. fr is the rolling friction . fg is grading friction , grading friction is actually gravitational force offered by the ground. fa Acceleration force

$$PL = fd \times v \tag{2}$$

S is the speed of vehicle

During braking operation load power will be

$$PL = -fa \times v \tag{3}$$

Initial kinetic energy

$$KE1 = \frac{1}{2} Mv1 \wedge 2 \tag{4}$$

Final kinetic energy

$$KE2 = \frac{1}{2} Mv2 \wedge 2 \tag{5}$$

Change in kinetic energy

$$\Delta KE = \frac{1}{2} M(v1 \wedge 2 - v2 \wedge 2) \tag{6}$$

$$P2 = \eta 1 \times PL \tag{7}$$

$\eta 1$ is the efficiency of generator

Input power of energy storage system P3

$$P3 = \eta 2 \times P2 = \eta 1 \times \eta 2 \times PL \tag{8}$$

$\eta 2$ Efficiency of generator power

Recovery power P4

$$P4 = \eta 3 \times P3 = \eta 1 \times \eta 2 \times \eta 3 \times PL \tag{9}$$

$\eta 3$ is the efficiency of energy storage system

Total energy recovered during braking is

$$E = \int P4.dt = \int \eta 1 \times \eta 2 \times \eta 3 \times PL = \eta 1 \times \eta 2 \times \eta 3 \int fa \times v \tag{10}$$

From this equation it is clear that braking recovery energy is depends upon the efficiency of energy storage device and the efficiency of braking system. Using super capacitor we can improve the efficiency of storage system by absorbing braking energy irrespective of magnitude of the braking current. Hence the braking energy recovery efficiency is improved

8. CONCLUSION

In this paper we are discussed about the braking energy recovery efficiency of electric vehicle equipped with a super capacitor. When battery is used in electric vehicle, it will undergo power fluctuations (rapid charge or discharge) this may damage the battery. Also the battery is not capable to withstand by the large braking current. Another limitation is soc limit. (soc means state of charge, if the battery is fully charged then it soc is 100%, if the battery having no charge then the soc of battery is 0% . soc is expressed in %). If the battery having 85% soc and it is further charging while regenerative braking will may cause irreparable damages to the battery. So this irreparable damages to the battery can be avoided by using the super capacitor, because the super capacitor can withstand with large power fluctuations and it having higher soc limit than a battery .in turn it improved the braking energy recovery efficiency ie the braking energy is depends up on the generator efficiency as well as the energy storage device efficiency. By using super capacitor the storage device efficiency is improved and by using parallel regenerative braking technique the generator efficiency is improved, hence the overall total braking energy recovery efficiency is improved.

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