Implementation of a New Charging Feature with SOC Estimation in Electric Vehicles

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Abstract*:* This paper presents a new charging feature in Electric Vehicles using PIC. Algorithm works utilizing the back electro motive force(BEMF) produced by the motor. The structure is a buck-boost converter chip, which transfers the energy stored in battery for driving motor, and can recycle the energy resulted from the back electromotive force (BEMF) to charge battery by changing the operation mode. A relay is employed for switching the buck-boost converter. An algorithm for State-of- Charge(SOC)estimation is also proposed.

Keywords*:* Electric vehicle, BEMF, buck-boost converter, relay.

I.   INTRODUCTION

Today, electric vehicles (EVs) have received much attention as an alternative to traditional vehicles powered by internal combustion engines with the advancement in battery technology and motor efficiency. The secondary batteries are the main energy sources of the EV. Thus, energy management is the most important key factor in EV or HEV design [1]-[2]. Moreover, the electric capacity of the battery will influence the endurance of electric vehicles. Generally, an energy management mechanism is very important for improving system efficiency and extending endurance. Therefore, well design charging strategies are key features in energy management of EV or HEV.

Electric vehicles are charged at charging stations by directly connecting to the AC mains which is the conventional method of charging. Nowadays EVs are charged through regenerative braking in which the vehicle's momentum is captured and turned into electricity[3]. Recently various schemes are employed for converting the kinetic energy of the vehicle such as independent switching scheme, charging through ultra-capacitors, electronic throttle control system [4]-[5].

Many advanced techniques, research results or control strategy related to the bi-directional converter are explored in succession. In reference [6], the power management and circuit topologies of single-phase and multi-phase bidirectional converters including non-isolated type and isolated type are all detailed. The non-isolated converters can be categorized into: buck, boost, and buck-boost types, which are low cost, compact size, without transformer, and easy to control due to having common ground. However, a transformer is still essential based on safety considerations, e.g. the voltage ratio between the primary side and secondary side is high enough or these two sides cannot be grounded together. Moreover, flyback type bi-directional converter is commonly used in many related applications [7]. The buck-boost type bidirectional converters not only possess step down and step up functions, but also can control the energy flow to achieve energy recovery, which is also suitable for many EV design [8]-[11].

This paper presents a new charging method making use of the BEMF produced by the main motor of the vehicle. PIC is used as a control core. BEMF is sensed and the buck-boost converter is switched accordingly using a relay.Generally, an energy management mechanism is very important for improving system efficiency and extending endurance. Therefore, the new charging strategy is proposed which ensures charging of the EVs while it is running by making use of the BEMF produced by the motor.

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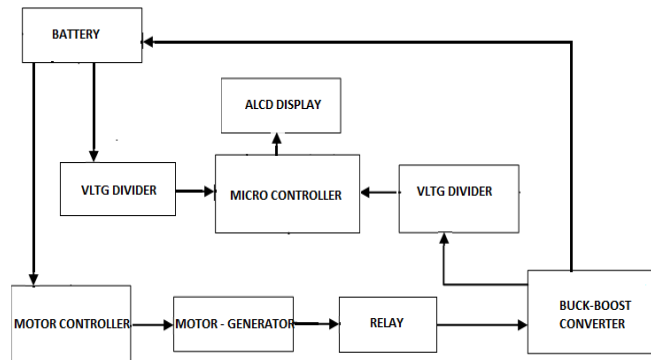## II. SYSTEM TOPOLOGY AND OPERATING MODES

Fig. 1. Block schematic of the new system topology

Fig. 1 shows the system block diagram of the proposed charging feature. With this system, the battery can provide energy to motor through a motor driver. Variable speed is achieved by the motor controller circuitry. BEMF generated from motor is measured by the generator coupled with the motor and can be transferred to store in the battery. Besides, the bidirectional converter is switched into boost or buck mode depending on the charge of the battery. The battery voltage, back emf produced by the motor and boost voltage are displayed in the ALCD panel. A voltage divider is used to divide the voltage when fed to the microcontroller PIC16f877a.

Motor is driven by the battery array which is the source of power in any Electric Vehicle. Thus the battery charge must be retained as long as possible inorder to increase the legal limit of the vehicle. In the proposed system battery is charged by the BEMF produced by the motor of the vehicle during its
run.

When the back electromotive force (BEMF) generated by motor is higher than the battery voltage V_{bat}, then the buck-boost converter is switched through a relay. Relay is turned on switching the bidirectional converter into the boost mode. Thus battery is charged in this mode which increases the legal limit of the vehicle. When the battery voltage is sufficient ie.between the required range to charge the battery then the relay is turned off. If the back emf is greater than that required to charge the battery then the buck-boost converter switched into buck mode inorder to limit the voltage.

III. CONTROL ALGORITHM

Control algorithm for entire system topology is as follows.
Step1:Ports are configured as input and output ports.
Step2: Initialize ALCD.
Step3:Initialize PWM by setting the CCPx pin of the   microcontroller.
Step4: ADC is initialized.
Step6: Display the battery voltage .
Step7: Check if BEMF occurs or not
If BEMF occurs then goto step 8 else goto step7.
Step8: If the battery voltage V_{bat} is less than that required for charging then the relay is turned on.
Step8:Buck-boost converter is switched into boost mode providing sufficient voltage to charge the battery.
Step9:Else if the battery voltage is sufficient as per requirement then the relay is turned off.
Step10: Buck-boost converter is switched into the buck mode if the back emf is much greater than that required for charging.
 Thus the back emf provides a battery backup and the battery charge is maintained which ensures increased legal limit for the vehicle sudden variation in the speed of vehicle is also avoided.

Mode 1: Motor driving mode:

   In this mode, motor is driven by a battery array through a motor driver which inturn regulates the motor speed. The bi-directional converter will enter Mode I when the handle signal is detected, i.e., the battery offers energy for driving motor. Conversely, the system will detect whether BEMF occurs or not. If not, it represents system idle, and the program will return to initial state. On the other hand, the electric bike may be decelerated or in descent state as the BEMF occurs. And then, the system will automatically select Mode II to recycle energy to battery according to whether the BEMF higher than battery voltage or not.

Mode 2: Battery charging mode:

   Initial battery voltage is displayed and if the battery voltage falls below a particular value that is the critical value required to drive the motor then the relay is turned on thereby switching the buck-boost converter into boost mode. The BEMF voltage is thus boosted and used for charging the battery. If the BEMF voltage is much greater than that required for charging the battery then the bidirectional converter is switched into buck mode maintaining the voltage within a range.
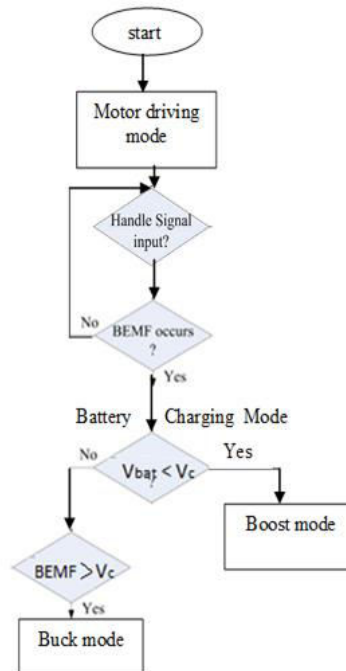

Fig.2. Flow chart of system topology

IV. SOC ESTIMATION

   When the battery electrical parameters are obtained from the battery parameter estimation algorithm[12], in particular, the OCV, a voltage-based SOC_V can be inferred. In the presence of battery hysteresis, the relationship between OCV and SOC is not a one-to-one mapping. Such a nonlinear relationship can be generalized as follows:

$$SOC_V = h(Voc , V_h). \qquad\qquad (1)$$

   As discussed in Section II, a switch type of hysteresis modelcan be used to model the battery hysteresis for iron phosphateLi-ion batteries. The model defines an additional hysteresis voltage V_h in OCV. By taking out the hysteresis

voltage from OCV, the remaining voltage Vo can be monotonically mappedto SOC. The remaining Vo, called the thermodynamic voltage,is defined as the difference between Voc and V_h :

$$Vo\ (k) = Voc\ (k) - V_h\ (k). \tag{2}$$

For the switch type of hysteresis model, V_h is governed by

$$V_h\ (k) = (\ -1) + \theta_7 I\ (k-1)\ [V_{hmax} - \text{sign}\ I\ (k-1)\ V_h\ (k-1)\ ]. \tag{3}$$

whereθ_7 is a parameter to determine convergence rate, and V_{hmax} defines the boundaries of battery hysteresis. The values of θ_7 and V_{hmax} can be obtained through experiments and vary with OCV (i.e. SOC). The hysteresis model in (3) describes a type of hysteresis with fast convergence to hysteresis boundaries from any point inside the boundary loop. With such a switch type of hysteresis model, the voltage -based SOCV is robust to the initial hysteresis voltage, that is, it is not necessary to require accurate knowledge of the initial hysteresis voltage because the hysteresis voltage governed by the model quickly converges to boundaries wherever it starts. The SOC estimation algorithm combines the voltage-based SOC_V and a current-based SOC_I through Coulomb counting. The final SOC estimate is a weighted combination of SOC_V and SOC_I as

$$SOC\ (k) = wSOC_I\ (k) + (1-w)\ SOC_V\ (k) \tag{4}$$

where 0<w<1 is the weighting factor. The combined SOC (k) will be used as a new starting point for the next update at the time instant k +1. The benefit is to reduce the dependency on the initial SOC and increase algorithm robustness.

The weighting factor w is tuned based on the signal excitation level. For instance, the value of w decreases by 5%when the excitation level is lower than a threshold at the present time instant k. On the other hand, the value of (1- w) decreases by 5%, when the excitation level is higher than another threshold at the present time instant k. The signal excitation level can be evaluated through monitoring the six elements in the diagonal matrix D or the determinant of D. It should be noted that real Li-ion batteries are not an ideal linear time invariant system. The model given by (4) is a simplified one for the estimation purpose, matching the Li-ion battery dynamics under a specific operation condition. Model uncertainties as well as the shifting of operation conditions, in combination with the use of the forgetting factor λ, will cause the increase of the values in one or several of the six elements in D, which should be decreasing in an ideal case of linear time invariant systems.

Following the battery parameter estimation algorithm in Section II, the SOC estimation algorithm is as follows:

Step 1: Starting with initialization, the algorithm sets the initial value of SOC(0) by reading the estimation result of previous operation from ROM.

Step 2: Obtain Voc from the battery parameter estimation   algorithm and determine the validity of the estimated Voc. If Voc is not valid, set the weighting factor w=0 and go to Step 7.

Step 3: Update V_h using (2).

Step 4: Calculate Vo using (1).

Step 5: Infer $SOC_V(k)$ from Vo at the present time step.

Step 6: Tune the weighting factor w for SOC_V and SOC_I based   on the signal excitation level.

Step 7: Read data (k) and calculate the $SOC_I(k)$ via

$SOC_I\ (k) = SOC_I\ (k-1) + (k)\Delta t$

where $SOC_I (k-1)$ is from the previous time step, and $I(k)\Delta t$ is the contribution from the Coulomb counting.

Step 8: Calculate the combined SOC(k) using (4)

Step 9: Determine whether it is the end of operation. If yes, save SOC(k) to NVM for next operation and end the algorithm.

Otherwise, go back to Step 2 and continue the estimation.

V. EXPERIMENTAL PROTOTYPE

PIC16f877a   microcontroller is used as the control core. A 12V, 100 RPM NR-DC-ECO permanent magnet dc motor is used which is coupled to a generator to measure the BEMF of the motor. Speed of the motor can be varied by means of a motor driver. Motor driver used is L239D which is a dual driver and the rating is limited to 600mA. IL34063A is a bidirectional dc-dc converter used to operate in boost and buck mode according to the battery voltage and BEMF produced.
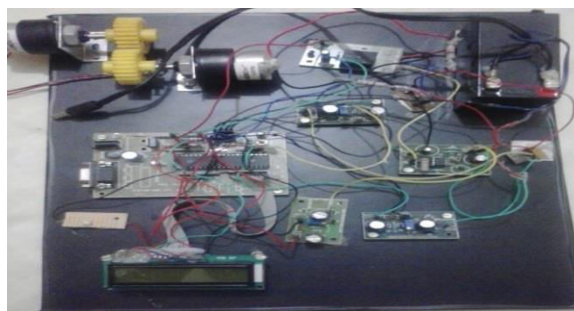

Fig.3. hardware prototype of the system

VI. CONCLUSION

The paper thus presents a new charging feature making use of the back emf produced by the motor which increases the legal limit of the vehicle and ensures its smooth run. Motor is driven by the battery array and simultaneously charged by the BEMF produced by the motor. Thus the disadvantages of conventional method of charging and charging during regenerative braking can be mitigated by employing the new charging feature.

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BIOGRAPHY

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