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Optimization and control of the brushless DC motor speed for a Battery Electric Vehicle (BEV) using Fuzzy-grasshopper optimization regenerative braking system

Sochima Vincent Egoigwe * and James Eke

Department of Electrical and Electronic Engineering, Enugu State University of Science and Technology, Enugu State, Nigeria.

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Abstract

Transportation electrification is at the core of the possible solutions to many challenges the world is currently facing. Efficient vehicle electrification has the potential to simultaneously reduce greenhouse gasses emissions and to tackle range anxiety issues. Among different strategies for advancements in Battery Electric Vehicle (BEV) efficiency, enhancing Regenerative Braking (RB) capabilities is an area with opportunities. As RB faces different impediments, upgrades in safety, efficiency, and/or battery quality of life are usually accompanied with further strain in energy management schemes, limiting RB performance. Power Electronics (PE) improvements are among the options that have the potential to benefit RB and overall efficiency. This work proposes a method to improves RB through brushless DC Motor.

As the EV speed drops, the fuzzy-grasshopper optimization regulates the regenerative braking torque to maintain the braking system's dependability. The fuzzy-grasshopper optimization controller also provides real-time fulfillment of the brake distribution force between the front wheel, rear wheel, and subsection of the regenerative forces and mechanical. At the conclusion of the run, the estimated SOC for smooth roads was 23.72%, compared to the measured SOC for smooth roads of 20.71%, and the simulated FL-RB SOC is 21.25%. At the rough road's conclusion, the measured SOC was 14.8%, the SOC simulated with the FL-RB was 15.98%, whereas without the FL-RB, the predicted SOC was 20.72%.

Keywords: Regenerative Braking System (RBS); Battery Energy storage system (BESS); Electric Vehicle (EV); Brushless DC Motor; Fuzzy-grasshopper optimization

1. Introduction

Due to its unique attributes such as minimal emissions, high efficiency, and silent operation, electric and hybrid electric vehicles (HEVs) are garnering increasing interest. Traditional automobiles powered by internal combustion engines (ICEs) can be replaced with electric vehicles and hybrid electric vehicles (HEVs) in the era of green technology. As a result, they're helping to improve vehicle efficiency once again. On the other side, the prohibitive cost of EVs/HEVs has kept them off the road in large numbers. By simplifying EV settings, the goal of this project is to make it less cumbersome for users. One of the primary goals of research is to find a way to increase the amount of power that can be recovered through braking. Hybrid and electric vehicle development is becoming increasingly popular. As a result, there has been an increase in the public's awareness of global warming and an increase in the cost of gasoline. Due to rising oil prices and an increase in air pollution, electric vehicles (EVs) have become the primary and final mode of transportation. In a battery-operated EV, the primary source of power is the battery, which is experiencing issues such as a lack of charging and recharging cycles as well as inadequate responsiveness in terms of driving range [2-5]. Ultra capacitors, flywheels, electrochemical batteries, and other energy sources can all be used to solve the challenges listed above [5-7].

* Corresponding author: Sochima Vincent Egoigwe

Regenerative braking is one of several procedures that have been implemented to address this issue. Some of the vehicle's kinetic energy is stored during deceleration in the form of kinetic energy, which is translated and stored in the battery and ultracapacitor [7- 10]. The regenerative braking does not work all the time on a smooth road surface. It can be seen in places where vehicles have to apply the brake, such as speed bumps, pits in the road, and slopes. Only when the battery is fully charged can regenerative braking be noticed; otherwise, mechanical brakes is required in EVs. Electric vehicles employ mechanical brakes to enhance the roughness of the wheel in order to decelerate. Since the EV's kinetic energy is converted back into electric energy when the mechanical brake is applied, this wastes a significant amount of energy. Regeneration is possible with the simple-to-control motors. Mechanical brakes are typically utilised in two-wheel EVs to slow or stop the vehicle's speed; this results in the loss of all stored kinetic energy [11–15]. The kinetic energy lost during braking can be recovered and stored in batteries and ultra-capacitors as electrical energy. If the motor, drive, and battery are all properly handled and controlled, this energy can be stored in the battery. To date, demand for electric vehicles has been expanding in response to the market. According to a study published in the journal Energy Storage Systems for Automotive Applications et. All [2], the fuel efficiency and performance of innovative cars with electric propulsion capabilities are greatly constrained by their capacity to store energy efficiently and effectively. [2] (ESS). The current state of ESSs in automotive applications is examined in this research. Battery technology choices are examined in great detail, with a focus on battery monitoring, management, protection, and balancing approaches. Additionally, ultra-capacitors, flywheels, and fuel cells are mentioned as ESS options. Last but not least is the concept of merging two or more energy storage devices to generate a more powerful power source, known as hybrid power sources. According to the classification and review of control strategies for plug-in hybrid electric vehicles by S. G. Wirasingha and A. Emadi, [3] In plug-in hybrid electric vehicles (PHEVs), selecting the right drive train architecture and implementing an effective power flow control method are both critical to reducing fuel consumption and emissions. Control techniques for hybrid electric vehicles (HEVs) have been devised and presented, however they do not take full use of the PHEV's ability to operate in electric mode over substantial distances. The most up-to-date control strategies are examined and organised in this work. While both rule-based and optimization-based PHEV control algorithms have their merits, they are not mutually exclusive. The controllers are described in detail, and an evaluation of the best technique for maximizing PHEV performance under various driving circumstances is offered. Finally, a new classification of PHEV control strategies based on the vehicle's operation has been provided and proven by simulation results. According to M. Montazeri and M. Soleymani in their study, "Investigation of the energy regeneration of the active suspension system in hybrid electric vehicles et. all.,"[4] hybrid electric vehicles' active suspension (AS) system can be used to generate power (HEVs). Simultaneous simulation and control methods are used to produce a unified medium in which both HEV powertrain and AS systems are simulated simultaneously. The suggested hybrid energy storage system (ESS) consists of electrochemical batteries and ultracapacitors (UCs). The regeneration of the AS energy improves fuel efficiency, according to the results of the simulations. To further enhance battery life and efficiency by adopting a hybrid energy storage system (ESS), load fluctuations from the batteries can be passed over to the UCs. According to L. Wang, et. al, Optimal design and real-time control for electric vehicle energy management et. all.,[5] An active combination of an ultracapacitor (UC) and an energy-dense Li-ion battery has been proven to be a potential technique for electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) to extend lithium-ion (Li-ion) battery cycle life (PHEVs). Using an optimization problem to reduce fuel usage, this article approaches the issue of battery and UC sizing, as well as the degree of hybridization between battery and UC power, from a fresh perspective. A unique energy management technique based on battery power reference generation, UC state-of-charge regulation, and forecast control based on driver orders is suggested to execute this optimum power sharing in real time. Finally, to validate that the suggested method reduces battery current stress and improves fuel economy, simulations and experiments using the flywheel + generator + controlled load is described. Regenerative Braking Control for Light Electric Vehicles et. all.,[6] by Cheng-Hu Chen, Wen-Chun Chi, and Ming-Yang Cheng described a simple yet effective electric brake energy regeneration system for an electric vehicle's brushless DC motor (EV). To manage inverse torque during braking, a proposed solution merely alters inverter switching sequences. This means that the battery's braking energy is returned. By eliminating the need for a converter, ultracapacitor, or a complicated winding-changeover procedure, the proposed technology accomplishes both the electronic brake and energy regeneration aims simultaneously

2. Materials and Methods

Regenerative braking generates energy (electricity), which can be utilized right away or saved in a battery for later use. The controller is connected to depends on the need and accessibility of the switching ON or OFF the regeneration process. Additionally, there is a facility for frictional forces to stop the car, which ought to be employed in an unforeseen situation or when regenerators malfunction.

Regenerative braking systems might not be sufficient to meet all of the fundamental braking system conditions. This is due to a restriction on energy loss at extremely high power. Due to operational restrictions, energy storage and electrical systems might not be able to function at those levels. The durability of the system remains questionable due to the essential level of protection involved, necessitating the coexistence of a frictional forces brake mechanism and a battery-powered regenerative braking mechanism.

The idea behind how braking forces is distributed between the front and back wheels when traveling on a flat surface. Equation (1) may be used to calculate the vehicle acceleration and estimate the braking force F_{car}. The following relationship may be used to depict the interaction between the braking car's force F_{car}, the forces at the front and rear wheels, F_f and F_r:

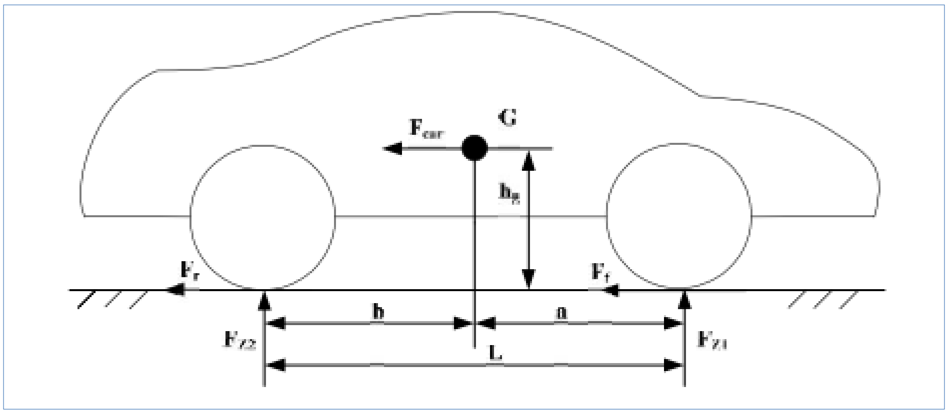

Figure 1 The brake operation of Load movements on flat roads

It is generally accepted that a boost DC/DC converter is typically utilized in HEVs through small pack battery.

$$F_{car} = M.\propto_{car} = F_f + F_r \qquad 1$$

When the brake pedal is pressed, the weight is transferred from the side of the wheel rear to the wheel front, which changes how the braking force is distributed between the front and back wheels. Z is the Brake strength which is expressed as follows to gauge the effect of braking load movement:

$$Z = \frac{\propto_{car}}{g} \qquad 2$$

As a result, equation (3)-(5) gives the peak braking forces Fr and Ff that can be produced for the real and front wheels, respectively.

$$F_f = \emptyset.F_{Z1} = \frac{\emptyset.G(b+Z.h_g)}{L} \qquad 3$$

$$F_r = \varphi.F_{Z2} = \frac{\varphi.G(a-Z.h_g)}{L} \qquad 4$$

$$F_f + F_r = \varphi.G \qquad 5$$

Where G is the overall weight of the vehicle, FZ1 and FZ1 are the actual forces in the real and front wheels, respectively; and indicates the coefficient of friction between the road surface and tire. For any friction coefficient, the optimal distribution curve provides the greatest braking force that can simultaneously lock the rear and front wheels. Safe braking is ensured when the operating curve of rear and front wheels get equal distribution of the braking force. It may be modeled as:

$$F_r = \frac{1}{2}\left[\frac{G}{h_g}\sqrt{b^2 + \frac{4h_gL}{G}F_f - \left(\frac{G_b}{h_g} + 2F_f\right)}\right] \qquad 6$$

2.1. Schematic Diagram of Brushless Dc Motor Using Regenerative Braking System

This circuit is based on SIMULINK's DC block. It simulates a 5 HP DC motor's single-phase two-quadrant rectifier drive. To emulate regenerative braking (operation mode for quadrant IV), a brake unit block has been installed. A steady 150

V DC field voltage source is used to individually excite the 5 HP DC motor. The single-phase rectifier that supplies the armature voltage is controlled by two PI regulators. A linear transformer is used to increase the voltage to a suitable level before feeding a 220 V AC 50 Hz power source into the rectifier. The rectifier thyristors' firing angle is regulated by the regulators. A speed regulator is put in place first, and then a current stability. The current controller uses the current reference armature (in p.u.) output by the speed regulator to generate the electromagnetic torque required to achieve the target speed. In order to prevent abrupt reference fluctuating the result in armature high current and lead the system to become unstable, the reference speed change rate follows acceleration and deceleration ramps. The correct thyristor firing angle is calculated by the current regulator in order to regulate the armature current. By doing so, the rectifier voltage output required to produce the actual armature current is generated. A finite machine state which includes two domains—normal operating state and operating braking mode—manages the braking unit block. Armature switches become active when the system is in braking mode and allow the flow of the armature to be reversed. For rapid speed deceleration, this produces a reverse electromagnetic braking torque. When the current armature passing through the switches that is 0A, the current flow is reversed. By doing this, damaging arcs in the switches are prevented during commutation.

2.2. Regenerative Braking in Brushless DC Motor

The stator, which is permanent, and the rotor, which is mobile, are the two primary components of the DC brushless motor, as with any electric motor. The excitation or armature winding and field winding are two commonly used in brush DC motors. The field winding, as its name suggests, creates a magnetic excitation field inside the motor, while the armature coils transport the generated motor current. The principle of speed control through dynamic change of armature voltage is faster than altering field voltage due to the time constant (L/R) of the armature circuit that is less than that of the field winding. As a result, the armature windings are fed by a variable DC source, while the excitation field is fed by a source of constant DC voltage. A phase-controlled thyristor converter creates the latter source. A three-phase AC supply is used to power the thyristor converter. Forward and backward brakes are controlled by operating in quadrants II and IV, respectively. This braking is regenerative for the Electric drives DC models which means that the motor-load kinetic energy system is converted to electric energy and sent back to the power supply. When the current drops to zero, the motor's connections are inverted to create this bidirectional power flow. This technique enables reversing the motor current to provide an electric torque that is perpendicular to the motion.

3. Result and Discussion

The comparison of actual and simulated data from two long-distance tests on rough and smooth roads was determined, measuring 120km and 110 km in length, respectively, as illustrated in Figures 2 and 3, the suggested fuzzy regenerative braking system was assessed.

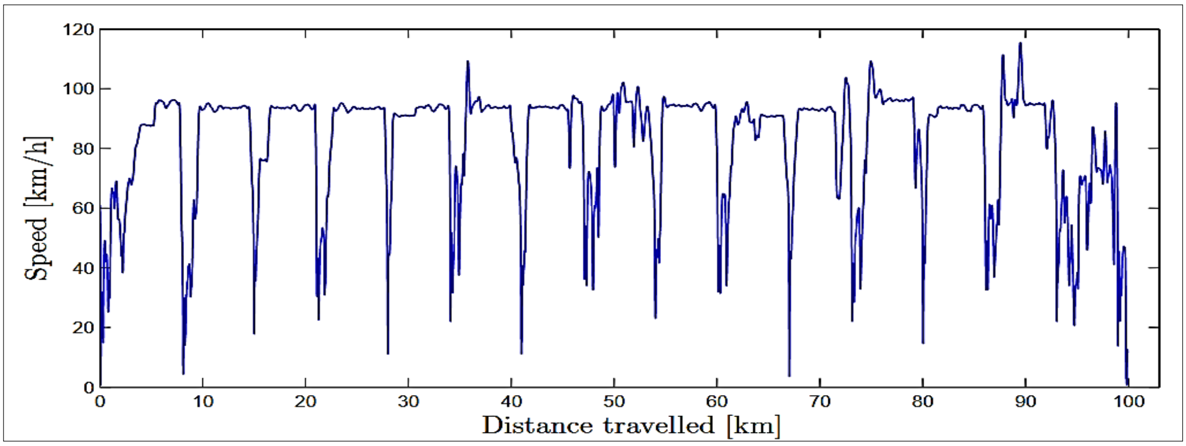

Figure 2 Smooth Road Speed Profile

Figure 2 shows the rate at which brake is applied at different distance on the smooth road. This sinuates that when the vehicle speed attains to the maximum of 90km/h, the brake is applied which cause the vehicle speed to drop to 5km/h at road distance of 9km. Also, at distance of 16km, 22km, 28km, 34km, 41km, 48km, 54km, 60km, 67km, 73km, 80km, 85km the brake was applied when the vehicle speed varies between 85km/h to 110km/h. It can be observed that the duration at which brake was applied is not often due to smooth road.

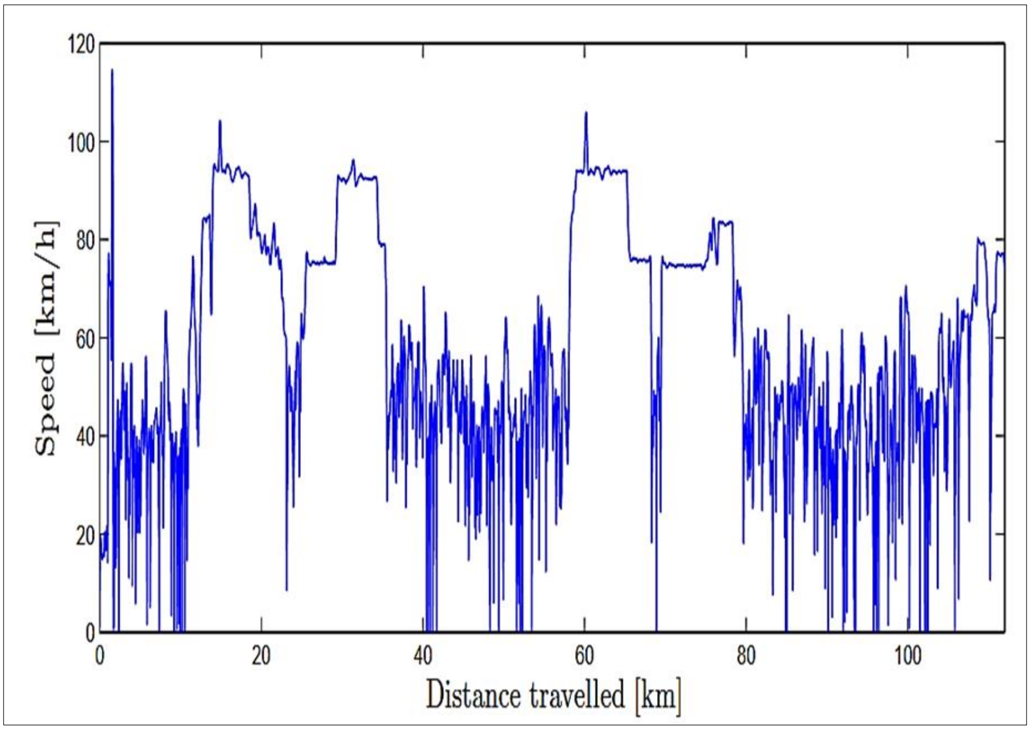

Figure 3 Rough Road Speed profile

Figure 3 shows that the vehicle accelerate to 125km/h at the distance of 10km and instantaneously return to 5km/h when brake was applied. The brake was constantly applied between distance 5km to 10km and at 11km the vehicle was accelerated gradually until it reaches 110km/h. Also, between the distance of 35km to 60km and 80km to 110km the brake was applied constantly due to bad or rough road. Therefore, the duration of applying brake in rough road is much compare to smooth road.

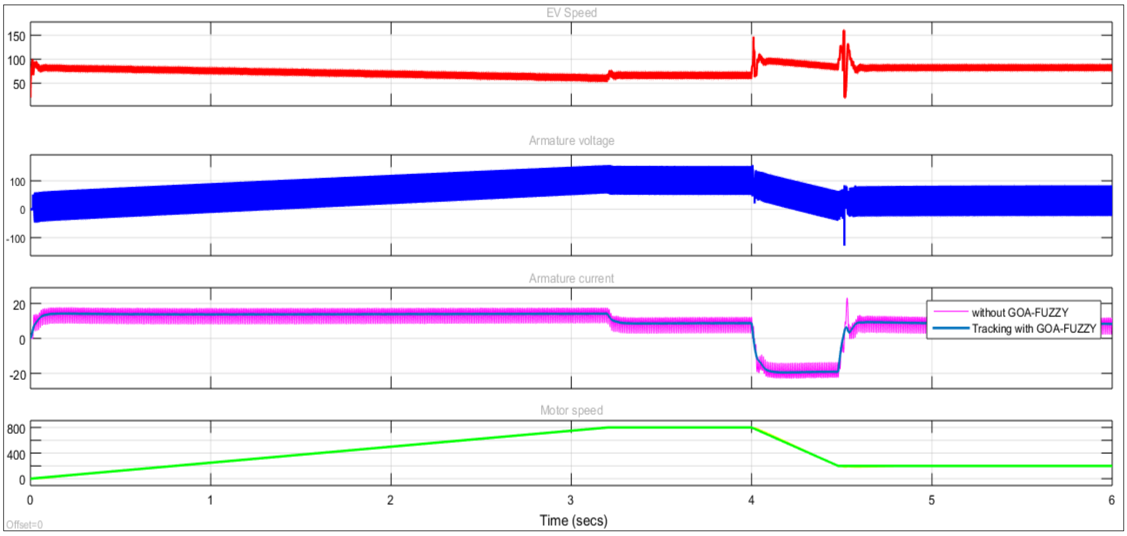

Figure 4 EV DC Motor with regenerative braking

Figure 4 shows EV DC Motor with regenerative braking using grasshopper fuzzy controller. At t = 4 s, the speed reference drops to 200 rpm and the system passes in braking mode. The armature switches are activated when the armature current reaches 0 A and reversal of the current flow through the motor takes place (the current flow direction through the bridge is of course unchanged). Observe again that the motor speed follows the deceleration ramp as wanted. The deceleration ramp has been set to a high value (-1250 rpm/s) to clearly show the effect of the braking electromagnetic torque. During this period of time, the bridge works in inverter mode (second quadrant operating mode).

At t = 4.5 s, motor speed is slightly lower than speed reference and the armature current flow through the motor is reversed back to normal. The bridge operates in rectifier mode and motor speed reaches 200 rpm around t = 5.5 s.

Notice the current overshoot during commutation. This is due to the sudden voltage reversal at the bridge output caused by armature switching. The bridge output voltage cannot follow instantaneously this voltage reversal. This sudden voltage difference between bridge and motor creates the current overshooting. However, the overshoot peak is of reasonable value and is not damageable.

4. Conclusion

The outcomes of the tests were utilized to compare the outcomes of two other simulations—one utilizing FL-RB and the other taking 100% regeneration into account—that also employed real-world input data. The results demonstrate that the predicted current battery is closely to true variable when FL-RB is applied than when simulating with 100% regeneration. It was further demonstrated that the suggested FL-RB also permits suitable SOC estimate.

The improvement achieved by the GOA-Fuzzy regenerative braking system was the most substantial at 32.9% when compared to the fuzzy logic controller under both smooth and bumpy driving conditions. The energy regulation for multi-objective braking regenerative system of the real vehicle, this work offers a more effective control technique. It was discovered that the Fuzzy-GOSAF controller has an effective capacity tracking model, but the proportional integral (PI) controller's operation is unable to endure transient characteristics because of its linear model assumptions.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

Reference

[1] Y. Kim, and N. Chang, ‘‘Design and management of energy-efficient hybrid electric energy storage systems,’’ springer, pp.19- 25, 2014

[2] S. M. Lukic, J. Cao, R. C. Bansal, F. Rodriguez, and A. Emadi, “Energy storage systems for automotive applications,” IEEE Transactions on Industrial Electronics, vol. 55, no. 6, pp. 2258–2267, June 2008.

[3] S. G. Wirasingha, and A. Emadi, ‘‘Classification and review of control strategies for plug-in hybrid electric vehicles,’’ IEEE Trans. Veh. Technol., vol. 60, no. 1, pp. 111-122, Oct. 2010.

[4] M. Montazeri, and M. Soleymani, ‘‘Investigation of the energy regeneration of active suspension system in hybrid electric vehicles,’’ IEEE Trans. Ind. Electron., vol. 57, no. 3, pp. 918-925, Oct. 2009.

[5] L. Wang, E. G. Collins, and H. Li, ‘‘Optimal design and real-time control for energy management in electric vehicles,’’ IEEE Trans. Veh. Technol., vol. 60, no. 4, pp. 1419-1429, Mar. 2011.

[6] Cheng-Hu Chen, Wen-Chun Chi, Ming-Yang Cheng, “ Regenerative Braking Control for Light Electric Vehicles “ IEEE PEDS 2011, December 5-8, 2011.

[7] B. Enache et al., “Comparative study for generic battery models used for electric vehicles,” 8th International Symposium on Advanced Topics in Electrical Engineering (ATEE), pp. 1-6, 23-25 May 2013.

[8] H. L. Chan, “A new battery model for use with battery energy storage systems and electric vehicles power systems,” in Proc. 2000 IEEE Power Engineering Society Winter Meeting, vol. 1, pp. 470-475, 2000.

[9] H. L. Chan, “A new battery model for use with battery energy storage systems and electric vehicles power systems,” in Proc. 2000 IEEE Power Engineering Society Winter Meeting, vol. 1, pp. 470-475, 2000.

[10] Lijun Gao et al., “Dynamic lithium-ion battery model for system simulation,” IEEE Trans. Compon. Packag. Technol., vol. 25, no. 3, pp. 495-505, Sep 2002.

[11] H. A. Hairik et al., “Proposed scheme for plugging three-phase induction motor,” 15th IEEE Mediterranean Electro technical Conf., MELECON, pp. 1-5, 26-28 April 2010. [

[12] H. A. Hairik et al., "Proposed scheme for plugging three-phase induction motor," 15th IEEE Mediterranean Electro technical Conf., MELECON, pp. 1-5, 26-28 April 2010.

[13] Okan TUR,Ozgur USTUN, Member IEEE, and R.Nejat TUNCAY, "An Introduction to Regenerative Braking of Electric Vehicles as Anti- Lock Braking System",IEEE june 13-15 2007.

[14] Beck et al., "Plugging an Induction Motor," IEEE Trans. Industry and General Applications, vol. IGA-6, no. 1, pp. 10-18, Jan. 1970

[15] A. Fazeli, M. Zeinali, and A. Khajepour, ''Application of adaptive sliding mode control for regenerative braking torque control,'' IEEE/ASME Trans. Mechatronics, vol. 17, no. 4, pp. 745-755, April 2011.