ANALYSIS OF A BI-DIRECTIONAL POWER CONVERTER OF ELECTRIC VEHICLE

Vericherla N Malleswari [1] , Jyothilal Nayak Bharothu [2], Madhu Kiran .B [3], Srinivasarao .M [4], Kishor Babu Gunti [5*]

[1] Department of Electrical Engineering, NRI Institute of Technology and Sciences, Perecherla, Medikonduru Mandal, Guntur, Andhra Pradesh- 522438, India.

[2] Department of Electrical & Electronics Engineering, AP IIIT-N, Rajiv Gandhi University of Knowledge Technologies-Nuzvid, Andhra Pradesh.

[3] Department of Electrical and Electronics Engineering, Seshadri Rao Gudlavalleru Engineering College, Gudlavalleru, Andhra Pradesh- 521356, India.

[4] Department of Electrical and Electronics Engineering, BVC Engineering College, Odalarevu, Allavaram, Andhra Pradesh- 533210, India.

[5*] Department of Electrical and Electronics Engineering, Kallam Haranadhareddy Institute of Technology, Dasaripalem, Andhra Pradesh-522019, India

Abstract: - The level of exhaust gases is rising with increasing usage of internal combustion engine vehicles. In order to reduce carbon emission, researchers and industry head up for improving electric vehicle technologies in all over the word. This paper deals with simulation of a bi-directional power converter of electric vehicle. The power electronics block is comprised by batteries, bi-directional dc-dc converter and dc machine. The initial state of battery charge is set around 90% where the discharge current is 43A during motor mode. The nominal voltage of battery stack is 350 V and maximum capacity is 100 Ah. The rated power of dc machine is set to 250 HP with 500 V armature voltages and 300 V field voltages. The charge and discharge conditions of batteries have been controlled regarding to operating modes of de machine. And the DC-DC converter is controlled with PI controller & fuzzy logic controller in both modes individually. The proposed converter and controller are designed to meet charge control and motor drive requirements of an all-electric vehicle. The proposed converter and controller are designed to meet charge control and motor drive requirements of an all-electric vehicle.

Index Terms:- Electric vehicle, dc-dc converter, bi-directional power converter, PI controller, fuzzy logic controller

1. INTRODUCTION

Transportation sector occupies a fundamental place in the world. Fossil fuels used in conventional vehicles technology emit greenhouse gases such as carbon dioxide, carbon monoxide and methane. The excessive consumption of these gases causes air pollution, climate change and global warming. In order to reduce these effects, there is a tendency to electric vehicle (EV) technology. The EV has much lower fuel cost according to fossil fueled car since they are mainly composed of battery system, power electronic circuits and electric machine. The battery system in an EV is the most crucial component in charge control time and determining distance [1], [2]. The electric machines of an EV are operated in both motor and generator modes due to regenerative breaking feature that enables electric machine to be operated in generator mode which is impossible in conventional internal combustion engine (ICE) vehicles. Therefore, electric machine charges the battery by operating in generator mode during the regenerative braking and it ensures recharging the batteries [3,4]. EV is classified into two types as hybrid EVs (HEVs) and all-electric vehicles. The HEV technology is used in conjunction conventional vehicle technology. The main system in HEV technology includes fuel tank and ICE such as diesel or gasoline engine, and auxiliary system which is comprised by electric machine, power electronic circuits and battery. HEVs are classified as parallel and series hybrid vehicles [5] that the parallel HEV consists ICE and electrical machine together. As the parallel electric vehicles operate at electric mode during the acceleration of electric machine, the motor operation is supplied from battery. The designed EV motor driver is comprised by four sections such as battery, bi- directional dc-dc converter, Fuzzy Logic Controller (FLC) and dc machine as shown in Fig.1. In this study, the starting voltage of battery is set to 378 V while the operating voltage of dc machine used in traction system is 500 V dc.

The battery voltage is increased up to 500 V with bi-directional dc-dc converter in generator mode. The battery is discharged when dc machine is started acceleration. The motor mode simulation with various torque values are performed to observe battery parameters such as state of charge (SoC), current, voltage and voltage of the dc machine[6]. The voltage of the dc machine is decreased to 500 V with bidirectional dc-dc converter which is controlled with FLC. The battery is charged during the generator mode operation of dc machine. The FLC determines duty cycle of S1 and S2 to ensure charge and discharge of battery. The dc machine is comprised by brushes, armature core and windings, commentator, field core and windings. Armature circuit is comprised by series structure with inductor, resistance and counter-electromotive source. Similarly, battery parameters such as SoC, current, voltage and voltage of the dc machine are observed in the generator mode simulation regarding to various torque values applied to dc machine.

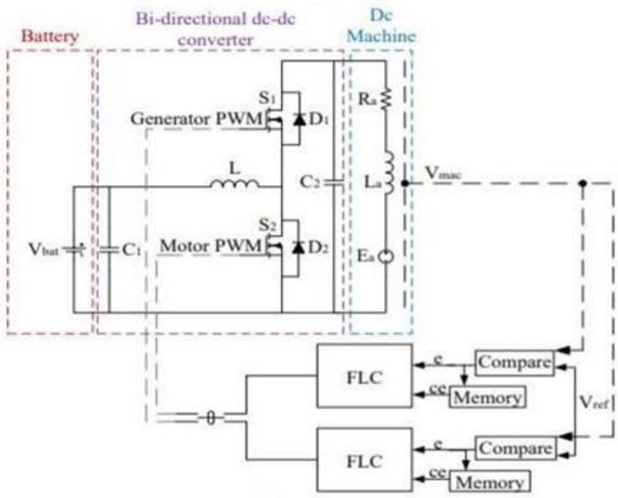

Fig. 1. Block diagram of circuit configuration

The electrical energy is converted to mechanical energy or vice versa by dc machine that operates regarding to electromechanical energy conversion theory [7]. If a conductor is moved within the magnetic field, the voltage is induced on it which is known as generator operating mode. If alternating current passes through the conductor, magnetic field is created around it which explains the motor mode operation. When the dc machine is started acceleration, the resultant positive torque is achieved. On the other hand, negative torque is generated at the dc machine when it is operated in generator mode FLC is comprised by fuzzification, rule base, interface mechanism, defuzzification. The charge and discharge conditions of batteries have been controlled regarding to operating modes of de machine. And the dc-dc converter is controlled with Professional Integral (PI) controller & fuzzy logic controller in both modes individually. The proposed converter and controller are designed to meet charge control and motor drive requirements of an all-electric vehicle. The proposed converter and controller are designed to meet charge control and motor drive requirements of an all-electric vehicle.

2. BATTERY STORAGE SYSTEM

A battery is a device consisting of one or more electrochemical cells with external connections for powering electrical devices such as flashlights, mobile phones, and electric cars. When a battery is supplying electric power, its positive terminal is the cathode and its negative terminal is the anode. The terminal marked negative is the source of electrons that will flow through an external electric circuit to the positive terminal. When a battery is connected to an external electric load, a redox reaction converts high-energy reactants to lower-energy products, and the free-energy difference is delivered to the external circuit as electrical energy. Historically the term "battery" specifically referred to a device composed of multiple cells, however the usage has evolved to include devices composed of a single cell. As of 2017, the world's largest battery was built in South Australia by Tesla. It can store 129 MWh. Energy density of the battery pack is estimated to roughly double, up to about 300 Wh per kg, between 2007 and 2030 [8]. As a result, batteries with higher energy and power densities are being developed, such as lithiumair (Li-air), lithium-metal or lithiumsulphur (Li-S), but these are far from commercialization [9]. Li-air batteries may reach energy densities of up to 11,680 Wh / kg [10], which approximates the energetic content of gasoline.

Also, they have a relatively long life cycle and low self discharging losses. A battery in Hebei Province, China which can store 36 MWh of electricity was built in 2013 at a cost of $500 million. Another large battery, composed of Ni–Cd cells, was in Fairbanks, Alaska. It covered 2,000 square metres (22,000 sq ft)—bigger than a football pitch—and weighed 1,300 tones. It was manufactured by ABB to provide backup power in the event of a blackout. The battery can provide 40 MW of power for up to seven minutes. Sodium–sulfur batteries have been used to store wind power. A 4.4 MWh battery system that can deliver 11 MW for 25 minutes stabilizes the output of the Auwahi wind farm in Hawaii. PHEVs and BEVs use similar batteries, with Li-ion being the most common chemistry.

3. DC TO DC CONVERTER

Buck–Boost converter is a type of dc-dc converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. It is equivalent to a fly back converter using a single inductor instead of a transformer. Two different topologies are called buck–boost converter. Both of them can produce a range of output voltages, ranging from much larger (in absolute magnitude) than the input voltage, down to almost zero.

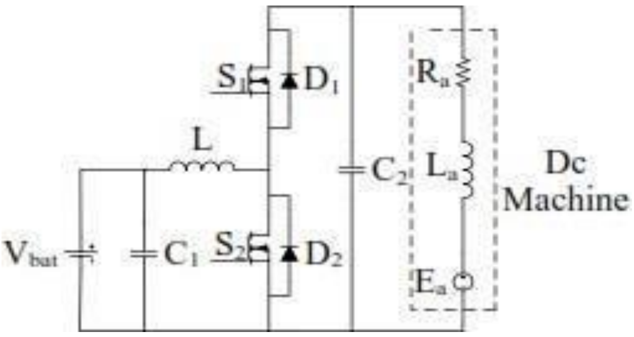

Fig. 2. Bi-directional converter

The output voltage is of the opposite polarity than the input. This is a switched-mode power supply with a similar circuit topology to the converter and the converter. The output voltage is adjustable based on the duty cycle of the switching transistor. One possible drawback of this converter is that the switch does not have a terminal at ground; this complicates the driving circuitry. However, this drawback is of no consequence if the power supply is isolated from the load circuit (if, for example, the supply is a battery) because the supply and diode polarity can simply be reversed. When they can be reversed, the switch can be on either the ground side or the supply side.

A converter is a switch mode dc-dc converter in which the output voltage can be transformed to a level less than or greater than the input voltage. The magnitude of output voltage depends on the duty cycle of the switch. It is also called as step up/step down converter. The name step up/step down converter comes from the fact that analogous to step up/step down transformer the input voltage can be stepped up/down to a level greater than/less than the input voltage. By law of conservation of energy the input power has to be equal to output power (assuming no losses in the circuit).

Input power (P_{in}) = output power (P_{out})

In step up mode $V_{in} < V_{out}$ in a converter, it follows then that the output current will be less than the input current. Therefore for a converter in step up mode $V_{in} < V_{out}$ and $I_{in} > I_{out}$

In step down mode $V_{in} > V_{out}$ in a converter, it follows then that the output current will be greater than the input current. Therefore for a converter in step down mode $V_{in} > V_{out}$ and $I_{in} < I_{out}$

The main working principle of converter is that the inductor in the input circuit resists sudden variations in input current. When switch is ON the inductor stores energy from the input in the form of magnetic energy and discharges it when switch is closed. The capacitor in the output circuit is assumed large enough that the time constant of RC circuit in the output stage is high. The large time constant compared to switching period ensures that in steady state a constant output voltage $V_o(t) = V_o$(constant) exists across load terminals.

Assume the switch is open for ton seconds which is given by $D*T_s$ where D is duty cycle and T_s is switching time period. The current through the inductor at the end of switch onstate is given as

$$I_{L,on} = (1/L)*V_{in}*D*T_s + I'_{L,on} \quad (1)$$

Hence $\Delta I_{L,on} = (1/L)*V_{in}*D*T_s$.

When switch in OFF the diode will be forward biased as it allows current from output to input (p to n terminal) and the Buck Boost converter circuit can be redrawn as follows shown Fig.2. Assume the switch is open for t_{off} seconds which is given by $(1-D)*T_s$ where D is dutycycle and T_s is switching time period. The current through the inductor at the end of switch off state is given as

$I'''_{L, off} = -(1/L) *V_{out}*(1-D)*T_s + I''_{L, off}$ (2)

In steady state condition as the current through the inductor does not change abruptly, the current at the end of switch on state and the current at the end of switch off state should be equal. Also the currents at the start of switch off state should be equal to current at the end of switch on state. Hence

$I'''_{L, off} = I_{L, on}$ also $I'_{L, off} = I''_{L, off}$

Using the equations 1 and 2 we get

$(1/L) *V_{in}*D*T_s =$

$(1/L) *V_{out}*(1-D)*T_s V_{in}*D = V_{out}*(1-D)$

$V_{out}/V_{in} = D/(1-D)$ (3)

Since $D < 1$, V_{out} can be greater than or less than V_{in}.For $D>0.5$ the Buck boost converter acts as boost converter with $V_{out} > V_{in}$.

For $D<0.5$ the Buck boost converter acts as buck converter with $V_{out} > V_{in}$.

Assuming no losses in the circuit and applying the law of conservation of energy

$V_{out}*I_{out} = V_{in}*I_{in}$ (4)

This implies $I_{out}/I_{in} = (1-D)/D$, Thus $I_{out} > I_{in}$ for $D<0.5$ and $I_{out} < I_{in}$ for $D<0.5$. As the duty cycle increases the output voltage increases and output current decreases.

4. PI CONTROLLER AND FUZZY LOGIC CONTROLLER

The PI controller will eliminate forced oscillations and steady state error resulting in operation of on-off controller and P controller respectively as shown in Fig.3. However, introducing integral mode has a negative effect on speed of the response and overall stability of the system. Thus, PI controller will not increase the speed of response. It can be expected since PI controller does not have means to predict what will happen with the error in near future. This problem can be solved by introducing derivative mode which has ability to predict what will happen with the error in near future and thus to decrease a reaction time of the controller.

PI controllers are very often used in industry, especially when speed of the response is not an issue. A control without D mode is used when:

a) fast response of the system is not required

b) large disturbances and noise are present during operation of the process

c) there is onlyone energy storage in process (capacitive or inductive)

d) there are large transport delays in the system

In general it can be said that P controller cannot stabilize higher order processes. For the 1st order processes, meaning the processes with one energy storage, a large increase in gain can be tolerated. Proportional controller can stabilize only 1st order unstable process. Changing controller gain K can change closed loop dynamics.

A large controller gain will result in control system with:

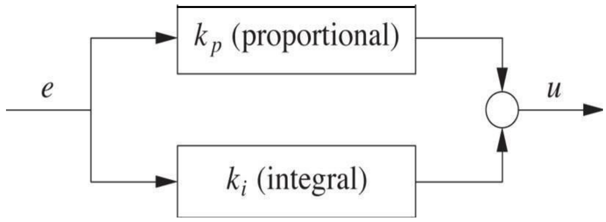

Fig. 3 Diagram of PI Controllers

a) smaller steady state error, i.e. better reference following

b) faster dynamics, i.e. broader signal frequency band of the closed loop system and larger sensitivity with respect to measuring noise

c) When P controller is used, large gain is needed to improve steady state error. Stable systems do not have problems when large gain is used.

Adaptive control is the control method used by a controller which must adapt to a controlled system with parameters which vary, or are initially uncertain. For example, as an aircraft flies, its mass will slowly decrease as a result of fuel consumption; a control law is needed that adapts itself to such changing conditions. Adaptive control is different from robust control in that it does not need a priori information about the bounds on these uncertain or time-varying parameters; robust control guarantees that if the changes are within given bounds the control law need not be changed, while adaptive control is concerned with controllaw changing them. In recent years, the number and variety of applications of fuzzy logic have increased significantly.

Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalve logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with un-sharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of fl. Even in its more narrow definition, fuzzy logic differs both in concept and substance from traditional multivalve logical systems.

The knowledge-base module contains knowledge about all the input and output fuzzy partitions. It will include the term set and the corresponding membership functions defining the input variables to the fuzzy rule-base system and the output variables, or control actions, to the plant under control as shown in Fig. 4..

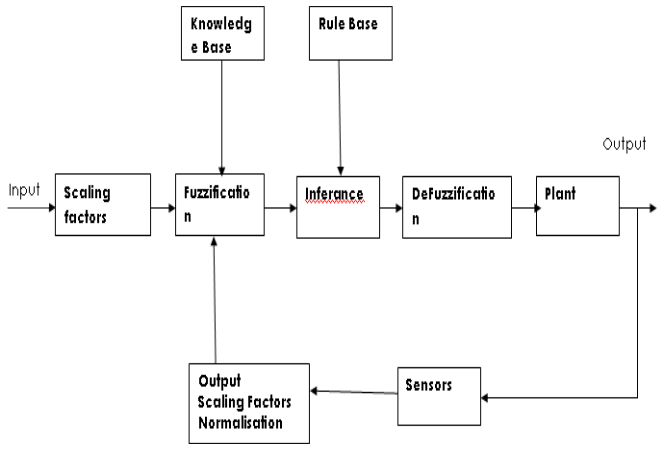

Fig. 4 A Simple Fuzzy Logic Control System

5. BATTERY MANAGEMENT SYSTEM

The battery is connected to converter where the mechanical energy is produced and this energy is given to the converter which generates electrical energy and gives back to the battery. The process of charging and discharging of the battery is controlled by using PIcontroller. And the rest of components are assembled as per requirements.

SoC Characteristics:

Initially the SoC is having the charge of 87.4%.At the half distance the charge discharges to 82%.The battery is not charged and soc remains constant. In scale on X-axis 1 unit=5seconds and Y-axis 1 unit=0.05%

Current Characteristics:

During discharge the positive peak is maintained. Negative current is not produced, so battery charge will not change in scale on X-axis 1 unit=5seconds and Y-axis 1 unit=20A

Voltage Characteristics:

The voltage is maintained slightly constant in scale on X-axis 1 unit=5seconds and Y-axis 1 unit=500V. The battery is connected to converter where the mechanical energy is produced and this energy is given to the converter which generates electrical energy and gives back to the battery as shown in Fig.5 and Fig. 6 .

The process of charging and discharging of the battery is controlled by using Fuzzy logic controller as shown in Fig.7 and Fig.8. And the rest of components are assembled as per requirements and the fuzzy.

SOC Characteristics:

Initially the soc is having the charge of 87.4%.

At the half distance the charge discharges to 82%.During reverse mode SOC will improves to 91% in scale on X-axis 1 unit=5seconds and Y-axis 1 unit=0.05%

Current Characteristics:

During discharge the positive peak is maintained. During reverse mode Negative Current will produced, so battery will change scale on X-axis 1 unit=5seconds and Y-axis 1 unit=20A.

Voltage Characteristics:

The voltage should be improved. Scale on X-axis 1 unit=5seconds and Y-axis 1 unit=500V.

Comparison Table-1

Parameters	PI Controller	Fuzzy Logic Controller
SOC	SOC at discharge 83%	It will charge upto 92%.
Voltage	320V	350V
Current	It does not maintain negative current	Negativecurrent is upto -5A.

- Savings of around 30% in energy consumption.
- Increased battery autonomy.
- Besides minimizing energy loss and extending electric range.
- Maximum efficiency
- At freezing temperature the battery charges slower.

In an electric vehicle, this is used to change the kinetic energy of the vehicle into chemical energy which is stored within the battery. Later, it can be used to drive the electric vehicle. An electric vehicle with regenerative braking includes motors to rotate the wheels improved SoC as observed comparison table-1.

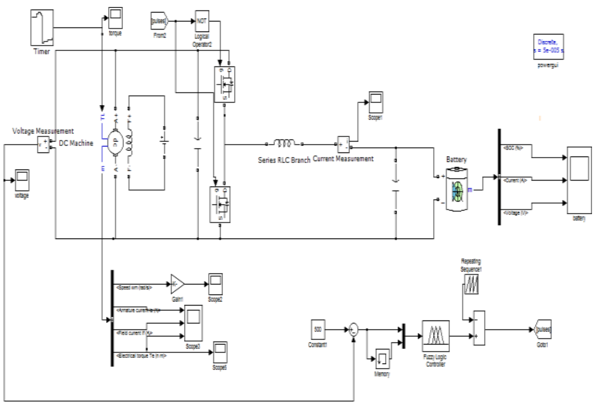

Fig. 5. Configuration of PI Controller

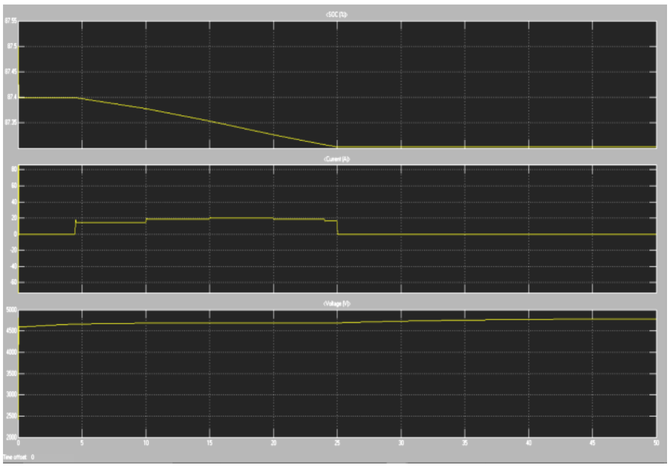

Fig. 6. Observed battery SoC, current and voltage in PI system

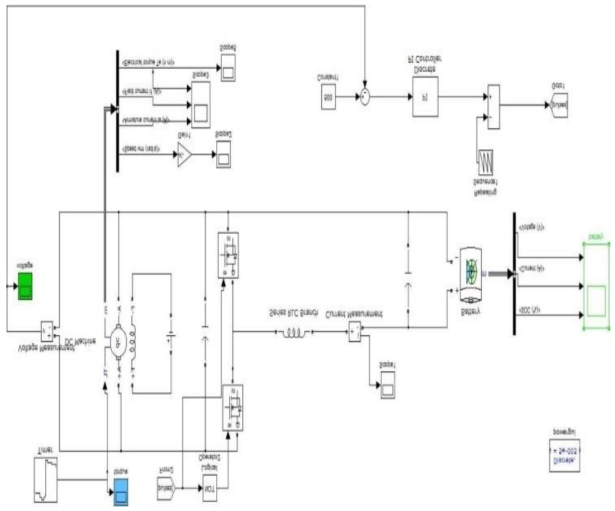

Fig. 7. Configuration of Fuzzy Logic Controller

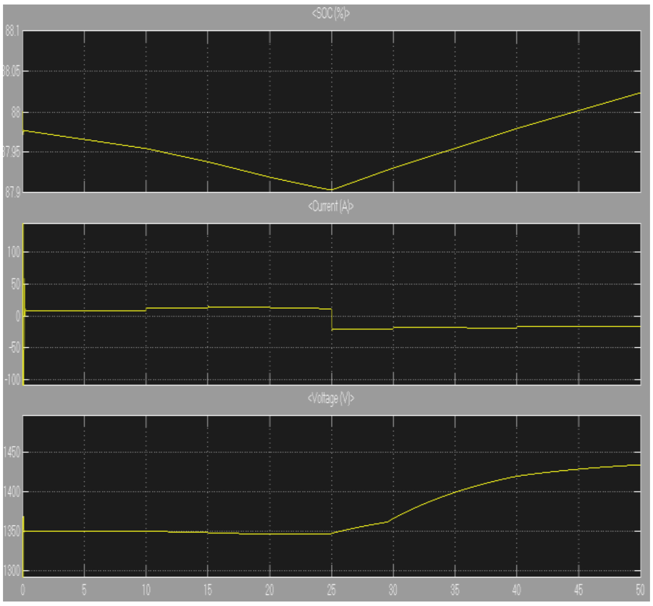

Fig. 8. Observed battery SoC, current and voltage in FLC system

Conclusion

This paper presents design and control bi-directional dc-dc converter for all-electricvehicle. The bi-directional dc-dc converter is controlled with PI Controller and FLC according to rules. When the battery is discharged, the dc machine is operated in motor mode and bi-directional dc-dc converter is operated in boost mode. Variable positive torque values are applied to the dc machine and condition of the battery is observed. According to simulation result, the battery SoC is reduced from 88% to 85% and voltage of the dc machine is constant at 500 V. Whenthe battery is charged, the dc machine is operated generator mode and bi-directional dc-dc converter is operated in buck mode. Variable negative torque values are applied to the dc machine and effect on the battery is observed. According to simulation result, the battery SoC is increased from 85% to 90%. In all-electric vehicle, regenerative breaking is occurred in this state in the FLC. Where as in PI controller there is no much better output than the FLC Charge and discharge states of the battery are the most essential for distance to determining.

REFERENCES

[1] F. Zhang, X. Zhang, M. Zhang and A. S. E. Edmonds, “Literature review of electric vehicletechnology and its applications,” 2016 5th International Conference on Computer Science andNetwork Technology (ICCSNT), Changchun, 2016, pp.832-837.

[2] A. Tiwari and O. P. Jaga, “Component selection for an electric vehicle: A review,” International Conference on Computation of Power, Energy

Information and Commuincation(ICCPEIC), Melmaruvathur, 2017, pp. 492-499.

[3] Jia Ying Yong, Vigna K. Ramachandaramurthy, Kang Miao Tan, N. Mithulananthan, "A review on the state-of-the-art technologies of electric vehicle,its impacts and prospects,"Renewable and Sustainable Energy Reviews, vol: 49, 2015,pp: 365-385

[4] X. Nian, F. Peng and H. Zhang, "Regenerative Braking System of Electric Vehicle Driven by Brushless DC Motor," in IEEE Transactions on Industrial Electronics, vol. 61, no. 10, pp. 5798-5808, Oct. 2014.

[5] Yanzhi Wang, Xue Lin, M. Pedram and N. Chang, "Joint automatic control of the powertrain and auxiliary systems to enhance the electro mobility in hybrid electric vehicles," 2015 52nd ACM/EDAC/IEEE Design Automation Conference (DAC), San Francisco, CA, 2015

[6] J. Zhang, T. Shen, Receding Horizon "Optimal Control of PHEV with Demanded Torque Estimation Model," IFAC-PapersOnLine, Volume 51, vol: 31, 2018, pp: 183-187

[7] Z. Haishui, W. Dahu, Z. Tong and H. Keming, "Design on a DC Motor Speed Control," 2010 International Conference on Intelligent Computation Technology and Automation, Changsha, 2010, pp. 59- 63.

[8] Kromer, M. A., & Heywood, J. B. (2007). Electric Power trains: Opportunities and Challenges in the U.S. Light-Duty Vehicle Fleet (Publication No. LFEE 2007-03 RP).

[9] Edwards, R., Hass, H., Larivé, J.-F., Lonza, L., Maas, H., & Rickeard, D. (2014, April). Well-to-Wheels Analysis of Future Automotive Fuels and Power trains in the European Context (Version 4a). Retrieved from the European Commission Joint Research Centre, Institute for Energy and Transport (IET)

[10] Nelson, P. A., Ahmed, S., Gallagher, K. G., & Dees, D. W. (2015). Cost savings for manufacturing lithium batteries in a flexible plant. Journal of Power Sources, 283, 506–516.