NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT]
ISSN: 2394-3696
VOLUME 2, ISSUE 2 FEB.-2015

Simulation Development of Ultra Capacitor Bank in Energy Management Strategies through Regenerative Braking in Diesel Locomotive

Adarsh Jitendra Mehta
Department of Electrical Engineering,Solapur University / Nagesh Karajagi Orchid College of Engineering & Technology, Solapur, India

Amruta Ankush Gaikwad-Patil
Department ofElectrical Engineering,Solapur University / Brahmdevdada Mane Institute of Technology, Solapur, India

Abstract
The aim of this paper to build a ultra-capacitor (UC) bank, dc to dc converter topology, and testing rig to perform efficiency testing for various configurations for dc drive with dc motor with the super-capacitor bank against various hybrid electric vehicle regenerative braking profiles. A bank of 5F cells was constructed along with a bidirectional DC to DC converter or a chopper allowing practical testing in two of the four possible bank configurations. It was obtained by that capacitor bank with a higher maximum voltage i.e. one or more cells in series were more effective as there were lower input and output currents and most of losses were restricted to the converter or chopper. At the time of regenerative braking we store the electrical energy it is help to save the energy. In this paper, we selected ultra-capacitor bank for the energy storage device of the equipment.

Index Terms:-Bidirectional dc–dc converter, energy storage, regenerative braking, ultra-capacitors(UC),diesel locomotive.

INTRODUCTION

The increase of the specific power demand by present day railway traction vehicles implies to find reliable technical solution in order to reduce the energy consumption. The typical journey i.e. of subway trains, light rail vehicles (tram) is made of accelerations, coasting and braking periods. In particular, the largest part of the energy or power drawn by the train is ascribed to the acceleration and braking because of the reduced distance between two subsequent stations. Modern electrical drives for traction motors benefit from the possibility of regenerative braking and the advantages related to the saving of energy attempting to inject the energy into the supplying line.
DC series motors have been used traditionally in traction equipment areas, regenerative braking hasn’t often been used in conventional traction equipment in the past. The main reason for this is that a series excited generator is unstable when working into a fixed voltage supply. Thus, for run on the traction supply, a other

excitation is required. these arrangement, however, is very sensitive to supply voltage fluctuate, and a fast dynamic output is required to provide an adequate brake control. However, the applications of a DC chopper allow the regenerative braking of DC series motors due to its fast dynamic response. In practice, the chopper must cope with the transient conditions and should be fitted with a fast acting closed loop controller. This is necessary to felicitate the required performance characteristics in the steady-state and transient conditions. Before study, analysis and simulation of chopper circuit with the facility of regenerative braking, the motoring as well as braking characteristics of a DC motor needs to be evaluated to determine the limits of braking speed and the control so as to follow within the constraints of the maximum braking power and current.
Once the initial stage is completed, a model of the drive performance in MATLAB is envisaged to be made in order to study and to determine the regenerative characteristics under pulsed power conditions.

TWO QUADRANT CHOPPER

A chopper is a static power electronic device that converts fixed dc i/p voltage to a variable dc o/p voltage. A Chopper may be consider as dc equivalent of an ac transformer since they behave in an identical manner. A two quadrant chopper involves one stage conversion, these type of conversion more efficient [2].
Choppers are now being used all over the world for rapid transient systems. These are use in trolley car, marine hoist, forklift truck and mine haulers, etc. Electric automobiles are likely to use choppers in future for their speed control and braking. Chopper systems to working smooth controlling, Extra-large efficiency, very fast response and re-generation facility [2]. The power semiconductor devices used for a chopper circuit can be force commutated thyristor, power BJT (Bipolar Junction Transistor), MOSFET (Metal Oxide Field Effect Transistor) and IGBT (Insulated Gate Bipolar Transistor).GTO based chopper are also used. These devices are also known as switch. When the switch is off, no current flow. Through the load can flow the current when switch is “on”. The power semiconductor devices have on-state voltage down of +0.5V to +2.5V across Semi-conductor. For the sake of easy, this voltage down to across these devices is generally neglected. As mentioned above, a chopper is dc equivalent to an ac x-mer, have continuous variable turn’s ratio. Like a x-mer, a chopper use to step down or step up the fixed dc input voltage.

$$\text{Average Voltage, } V_o = (T_{on} / (T_{on}+T_{off})).Vs$$

$$= (T_{on}/T).Vs$$

$$= \alpha.Vs$$

$$T_{on} = \text{on-time.}$$

$$T_{off} = \text{off-time.}$$

$$T = T_{on} + T_{off} = \text{Chopping period.}$$

$$\alpha = T_{on}/T_{off}.$$

Chopper is commonly divided into four types: step-down chopper, step-up chopper, two-quadrant chopper and four-quadrant chopper. Two-quadrant chopper would be used in the project. Two-quadrant chopper is combination of step up and step down chopper. Two-quadrant chopper is operated in two mode of operation.

When current is flowing to the load (positive), it acts as a step down chopper. When current is flowing back to the supply (negative), it acts as a step up chopper.

In the research, two-quadrant DC to DC converter is used. The configuration of basic dc to dc converter is shown below

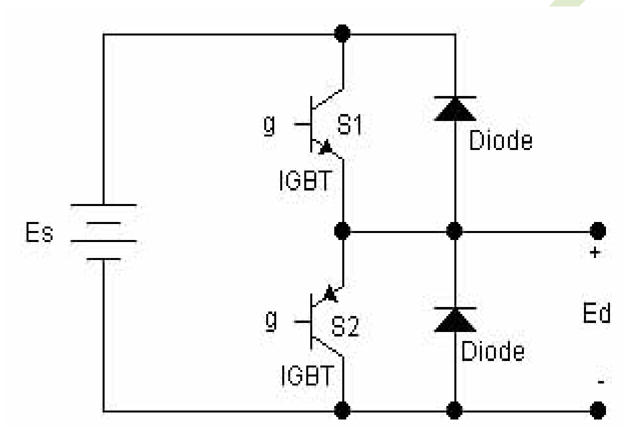

Fig1: Circuit diagram of two-quadrant chopper

There are two switches S1 and S2 connected across a dc voltage source Es. The switch S1 and S2 open and close alternately in such a way that when S1 is closed, S2 is open and vice versa. S1 and S2 turn on time contribute to one period of switching. Diode connected parallel with the switch would block the current to flow downward but provided flowing upward. IGBT and diode connected in parallel can be simplified and represented as a single bidirectional ideal switch. IGBT provides the current to flow downward while diode provides the current to flow upward. Turn on voltage for diode is small enough to be neglected. Hence, a bidirectional ideal switch was chosen to model IGBT and diode in parallel. The two switch used in two-quadrant chopper were controlled by a gating signal supply to the switch. This gating signal is either on or off in a periodical type. To serve this purpose, pulse generator block was used. Since the two switches were turned on alternatively. gating signal is more accurate to use only one gating circuit, that meanonly one pulse generator. Inverter was designed to invert the gating signal supplied for second switch.

MODELLING OF ULTRACAPACITOR

There are several propositions of ultra-capacitor model representation. The easiest of all the classical equivalent circuit with the lump capacitance, equivalent parallel resistance(EPR) and equivalent series resistance(ESR). Figure 2 shows the classical equivalent circuit with the three parameters, Determination of these parameters provides a first approximation of an ultra-capacitor cell. The equivalent parallel resistance(EPR) represents the current leakage and influences the long-term energy storage. In multiple series connections of ultra-capacitors, the EPR influences the cell voltage distribution due to the resistor divider effect. Showed that the EPR is related to the voltage decay ratio by,

$$EPR = \frac{-t}{\ln\left(\frac{V_1}{V_2}\right) C}$$

Where V_1 is the initial voltage, V_2 is the final voltage and C is taken as the rated capacitance.

Through experimental measurements of voltage decays of several ultra-capacitors having various capacitance values, these shown that the equivalent parallel resistance effects could be neglected for transient discharge calculations. However, the equivalent parallel resistance(EPR) value is important when cell balancing of series connected super-capacitors is considered. This parameter is not significantly dependent on the terminal voltage nor the charge rates. Hence the equivalent series resistance (ESR) can be considered as a non time dependent parameter. A three resistors and capacitor (RC) branch network with one branch having a voltage dependent capacitance.

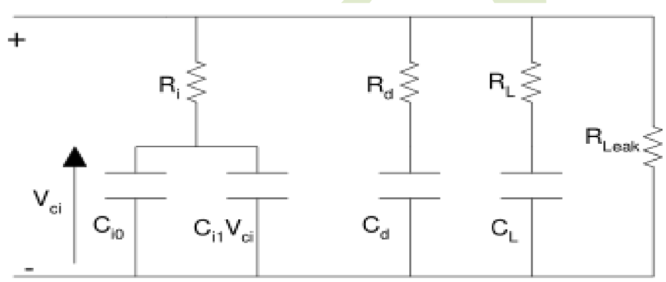

Fig 2: Brach representation ultra-capacitor model

Each branch of the circuit shown in Fig.2 is a different associated time constant. Containing R_i as the "immediate and urgent branch". This branch dominions the ultra-capacitor behaviour in the order of a few seconds. The "delayed effect branch", with R_d has influential behaviour in the range of minutes and seconds. The third branch is the "long-term" branch. This branch governs the long-term response of the circuit after periods exceeding ten minutes. Finally, the branch with resistance R_{Leak} represents the ultra-capacitor leakage current. The "immediate and urgent branchR_i" contains a voltage dependent capacitor C_{i1} that reflects the voltage dependency of the cells double-layers capacitance.

REGENERATIVE BRAKING

Forward and Reverse braking in DC6 chopper for Operation in quadrants II and IV, respectively. For the DC models of the Electric Drives library, this type of braking is regenerative, that means the kinetic energy of the motor-load system is converted to electric energy and returned to the energy or power source. This bidirectional power flow are obtain by inverting the motor's connections when the current becomes null (DC1 and DC3) or by the use of a second converter (DC2 and DC4). (DC1 and DC3) and (DC2 and DC4) methods allow inverting the motor current in order to create an electric torque opposite to the direction of motion. The chopper-fed DC drive models (DC5, DC6, and DC7) produce regenerative braking in similar fashions.

NOVATEUR PUBLICATIONS
INTERNATIONAL JOURNAL OF INNOVATIONS IN ENGINEERING RESEARCH AND TECHNOLOGY [IJIERT]
ISSN: 2394-3696
VOLUME 2, ISSUE 2 FEB.-2015

The basic principle of regenerative braking in DC chopper drives is explanation in figure 3, which depicts chopper and the motor equivalent circuit. Figure 4 displays the simplified equivalent circuit of regenerative braking for the sake of analysis. On closing the chopper switch the current rises due to a virtual short-circuit that is created across the machine terminals. The energy thus stored in the motor armature due to inertia is allowed to develop the current as shown in figure 4(a). This current makes energy stored in the inductance. As and when the chopper switch is opened as depicted in figure 4(b), this energy is next transferred to the DC mains supply. This happens provided the supply is receptive.

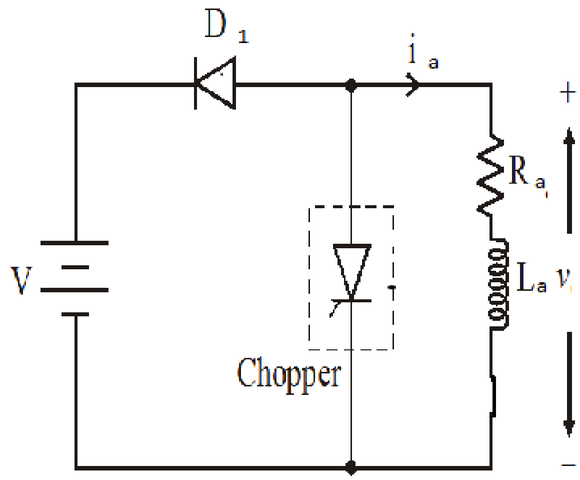

Fig 3: Operation of Regenerative Braking

The equivalent circuits of DC motor now working as a generator, in the regenerative mode of operation is shown in figures 4(a) and (b) for duty and freewheeling intervals of operation. Further, figure 4(c) gives the waveform of current and voltage during this mode of machine operation. Since average voltage is zero, therefore, we have the following steady-state equation:

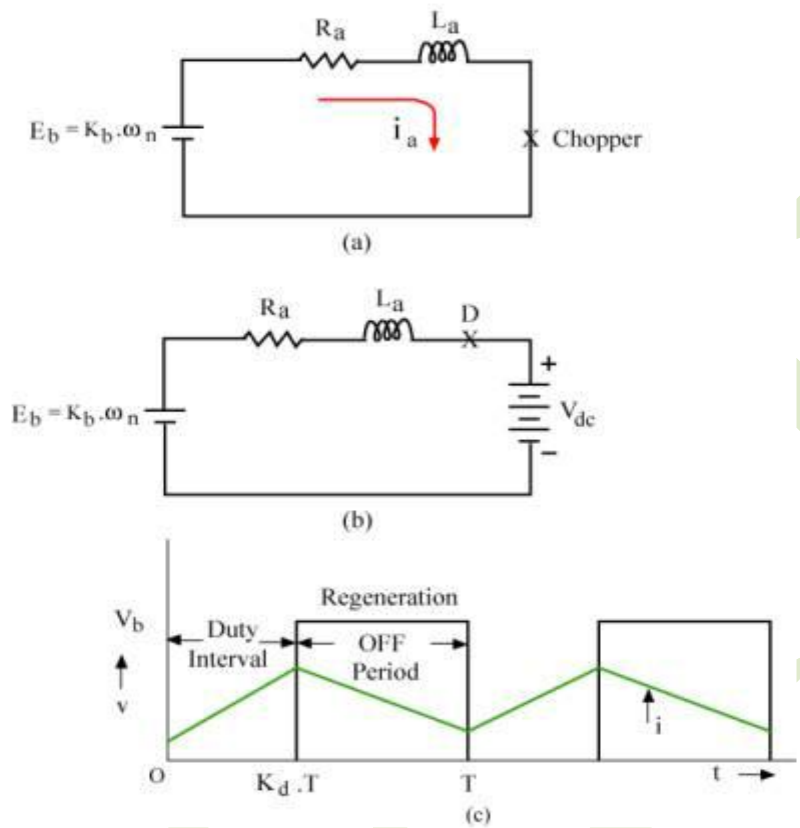

Fig 4:- Waveform of current and voltage and Equivalent Circuit

$$\boldsymbol{V_d(1 - K_d) \;=\; K_b.\,\omega n - I_{av}R_a} \text{ (1)Therefore,}$$

$$\boldsymbol{\omega_n} = \frac{\mathbf{V_d(1 - K_d) + I_{av}R_a}}{\mathbf{K_b}} \quad (2)$$

For duty-interval, the initial conditions for steady-state values of currents are expressed as:

$$\boldsymbol{i_d\,(t = \;0) \;=\; I_f}$$

$$\&\boldsymbol{i_d\,(t = \;K_d.T) \;=\; I_d}$$

$$\boldsymbol{K_b\omega_n = i_d\,R_a + \;L_a\frac{di_d}{dt}} \text{ (3)}$$

The value of i_d as;

$$\boldsymbol{K_b\omega_n = V_{dc} + i_f\,R_a + \;L_a\frac{di_d}{dt}}\text{(4)}\mathbf{i_d \;=\; I_f\,.\,e^{-\frac{t}{\tau a}}\left(1 - e^{-\frac{t}{\tau a}}\right)\frac{K_b\omega_n}{R_a}}\text{(5)}$$

For the off interval with i_d (at $t = k_d.T$) = I_d, & i_d ($t = 0$) = I_f

We obtain after solving equation (5):

$$\mathbf{I_f} = \mathbf{I_d}.\mathbf{e}^{-\frac{tk_dT}{k_d\tau a}} + \left(\mathbf{1} -.\mathbf{e}^{-\frac{tk_dT}{\tau a}}\right)\left(\frac{K_b\omega_n - V_{dc}}{R_a}\right) \quad (6)$$

Proceeding in the similar manner as before, for the solutions I_d and I_f are obtained as under;

$$I_d = \frac{E_b - V_{dc}}{R_a}\left\{\left(1 -.e^{-\frac{(1-k_d)T}{\tau a}}\right)\left(1 -.e^{-\frac{(1-k_f)T}{\tau a}}\right)\right\}(7) I_f = \frac{E_b - V_{dc}}{R_a}\left\{e^{-\frac{k_dT}{\tau a}} -.e^{-\frac{T}{\tau a}}\right\} 1 -.e^{-\frac{T}{\tau a}}(8)$$

Substituting the contents of (4) into equation (5) & simplifying we get the ripple factor γas;

Now the ripple factor $\gamma = \frac{I_d - I_f}{2I_{av}}$(9)

$$\gamma = \frac{V_d}{2I_{av}R_a}\left\{\frac{1 - e^{-\frac{(1-kd)T}{\tau a}} - e^{-\frac{k_dT}{\tau a}} + e^{-\frac{T}{\tau a}}}{1 - e^{-\frac{k_dT}{\tau a}}}\right\}(10)$$

Where, $E_b = K_b.\omega_n$

Equation (10) is derived to give the ripple contents in the armature current of excited DC motor in the monitoring & regenerating modes of the drive. It is important to note that the mathematical expressions derived and developed in this section are valid for continuous conduction of current through the armature. The pulsating nature of current waveform during these modes of the DC drives operation. However, if the motor is fully loaded the inductance of the armature winding and that of the field winding are generally enough to do the inherent smoothing of armature and field current waveforms

SIMULINK EXPERIMENT MODEL

Matlab/Simulink version 7 R2007b is being used as a tool for simulation [15].For simulation purposes in place of OHP cable a 25KV power supply is used. Popular two quadrant chopper model DC6 is used to study normal and braking modes. The battery bank is considered as 72V 100Ah. To change over between battery bank and main power supply current direction is taken as feedback. At the reverse direction of current a contactor is operated automatically that redirects the braking generated EMF to the battery bank. Further a charging control system can be used to regulate the current being supplied to the battery bank. And that will also take care of overcharging and deep discharge. On normal run i.e. on first quadrant operation system operates normally in motoring mode. Speed and torque values are taken as variables that represent engine speed and torque. Depending on theses values chopper switching pulses are generated.

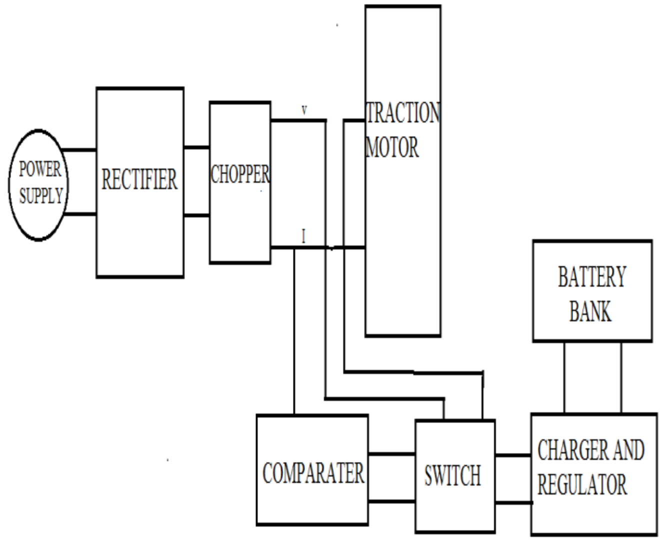

Fig 5: Block diagram of experiment setup of system.

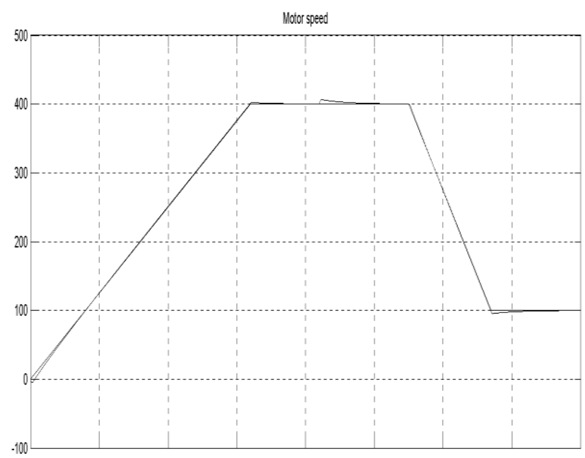

Fig 6: motor speed curve for system

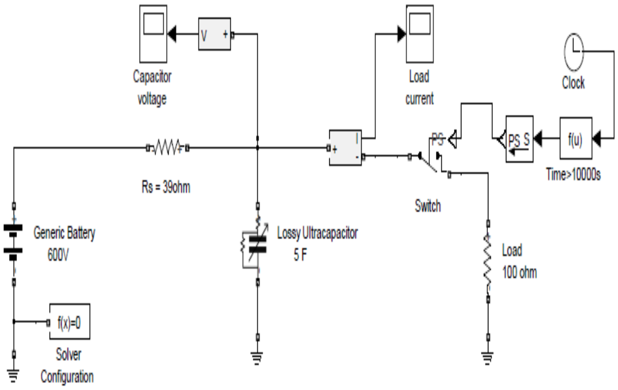

Fig 7: Ultra Capacitor Charging and Discharging Experimental Setup

RESULT

Study of WDM2 diesel locomotive engine is done for the basis of our project. it is obtain that heat loss occurring in the resistance used in regenerative braking can be utilized for other electrical device and also for charging battery banks and ultra-capacitor in this way a huge amount of power can be saved . In these model ultra-capacitor are being used as storage. A PI based charger charges theultra-capacitor bank up to 400 V. Further this stored energy in battery banks can be transferred to other attached boogies.

Fig.8: Charging Voltage for Ultra-Capacitor

CONCLUSION

A DC to DC converter was built, a test rig was constructed and efficiency was tested for a bank configuration under two different braking profiles. While improvements in the operation of the converter would have been ideal to allow for more testing of the capacitor bank in different configuration. By the use of these techniques we save a large amount of energy which is wasted on the time of regenerative braking. Same study with some specification changes can be used for hybrid electric vehicle and other locomotive as well. In place of battery bank,fuel cells, ultra-capacitor can be used.

References

1) Patel, K. R., & Desai, R. R. *Calculation of Internal Parameters of Super Capacitor to Replace Battery by Using Charging and Discharging Characteristics. International Journal of Engineering and Innovative Technology (IJEIT), vol.2 (1), pp.142-146, 2012.*
2) P. W. Franklin, *"Theory of the D.C. Motor Controlled byPower Pulses-Part II-Braking Methods, Commutation and AdditionalLosses", pp. ,256-262, this issue.*
3) *Parameter Prediction and Modelling Methods for Traction Motor of Hybrid Electric Vehicle. World Electric Vehicle Journal, vol.3, pp.1-6, 2009.*
4) N. Schofield, H. T. Yap, and C. M. Bingham, "*Hybrid energy sources for electric and fuelcell vehicle propulsion," presented at IEEE Vehicle Power and PropulsionConference,VPPC, 2005.*
5) J. Moreno, M. E. Ortuzar, and J. W. Dixon, *"Energy-management system for a hybridelectric vehicle, using ultracapacitors and neural networks," IEEE Transactions on IndustrialElectronics, vol. 53, pp. 614-623, 2006.*
6) P. Pisu and G. Rizzoni, *"A supervisory control strategy for series hybrid electric vehicleswith two energy storage systems," presented at IEEE Vehicle Power and PropulsionConference,VPPC, 2005.*
7) Tao Sun, Soon-O Kwon, Geun-Ho Lee, Jung-Pyo Hong *Parameter Prediction and Modelling Methods for Traction Motor of Hybrid Electric Vehicle World Electric Vehicle Journal Vol. 3 - ISSN 2032*-6653
8) Chan-Heung Park, Su-Jin Jang, Byoung-Kuk Lee, Chung-Yuen Won, Han-Min Lee, "*Design and control algorithmresearch of active regenerative bidirectional DC/DCconverter used in electric railway", ICPE'07 7th International Conference on Power Electronics,pp. 790-794, 22-26 Oct. 2007.*
9) G. Morita, T. Konisihi, S. Hase, Y. Nakamichi, H. Nara,T. Uemura, "*Verification tests of electric double layercapacitors for static energy storage system in DCelectrified Railway", Proc. of IEEE International Conf. ofPower Electronics SPEEDAM 2008, Ischia, Italy,pp. 1017-1022, June 2008.*
10) R. Rizzo and P. Tricoli, "*Power flow control Strategy forElectric Vehicles with renewable energy sources", Proc.of the 1st international power and energy conferencePECON 2006, Putrajaya, Malaisa, pp. 34-39, 2006.*
11) R. Barrero, X. Tackoen, J. Van Mierlo, *"ImprovingEnergy efficiency in Public Transport: Stationarysupercapacitor based energy storage systems for a metronetwork",Proc. of Vehicle Power and PropulsionConference VPPC'08, pp. 1-8, 2008.*
12) M. Steiner, M. Klohr, and S. Pagiela, "*Energy StorageSystem with UltraCaps on Board of Railway Vehicles",Proc. European Conference on Power Electronics andApplications, 2007.*

13) A. D. Napoli, F. Crescimbini, L. Solero, F. Caricchi, and G. F. Capponi,"*Multiple-input DC–DC power converter for power-flow management inhybrid vehicles," in Conf. Rec. 37th IEEE IAS Annu. Meeting, 2002,pp. 1578–1585.*
14) F. Salmasi, *"Control strategies for hybrid electric vehicles: Evolution,classification, comparison, and future trends," IEEE Trans. Veh. Technol.,vol. 56, no. 5, pp. 2393–2404, Sep. 2007.*
15) *http:// www.mathworks.com*
16) P. Caratozzolo,M. Serra, and J. Riera, "*Energy management strategies forhybrid electric vehicles," in Proc. IEEE Int. Elect. Mach. Drives Conf.,J. Riera, Ed., 2003, pp. 241–248.*
17) Bose B.K., *Power electronics and motor drives recent technology advances, Proceedings of the IEEE International Symposium on Industrial Electronics, IEEE, 2002, pp 22-25.*
18) Chinnaiyan V. Kumar, Jerome Joritha, Karpagam, J. S.Sheikh Mohammed, *Design and Implementation of High Power DC-DC converter and speed control of dc motor using TMS 320F240DSP, Proceedings of India International Conference on Power Electronics, 2006.*
19) *http. www.indianrailway.gov.*
20) Rashid, M.H., Power *Electronics, Prentice Hall of India, New Delhi, 1993.*
21) Yu, L. He, J. H., Yip, H. T. Du, F., Bo, Z. Q., & Hu, j. *Simulation of Regenerative Braking in DC Railway System Based on MATLAB/Simulink. UPEC, 2010 .*
22) Danila, E., LUCACHE, D. D., & Livint, G. *Models And Modelling The Supercapacitors For A Defined Application. Annals of University of Craiova, vol.35, pp.200-205, 2011.*
23) Bae, C.-h., Jang, D.-u., Kim, Y.-g., Chang, S.-k., & Mok, J.-k. *Calculation of regenerative energy in DC 1500V electric railway substations. IEEE 7th International conference on power electronics , pp.801-805, 2008.*
24) Lu, S., Hillmansen, S., & Roberts, *C. A Power-Management Strategy for Multiple-Unit Railroad Vehicles. IEEE Transactions On Vehicular Technology, vol.60 (2), pp.406-420, 2011.*

IJIERT