Energy Efficient DC Traction System through Regenerative Braking

Mitha Thampi, Thomas K. P

***Abstract*— Journey of a train is made up of acceleration, coasting and deceleration. Largest part of energy drawn by train is consumed by acceleration and braking of the train. Distance between two subsequent stations is becoming very small in these days, hence trains will have to accelerate and decelerate frequently. During deceleration motion of train motor is made to run as a generator and the output is dissipated in some form or the other and the speed of machine goes on reducing. In regenerative braking the energy generated during braking is used wisely. The energy produced is stored for supplying the auxiliary requirements in the train such as lighting and cooling.**

***Index Terms*—Diode bridge rectifier, regenerative braking, and three state switching cell.**

I. Introduction

Out of the total energy supplied to train, 90% is consumed for traction and the remaining 10% is utilized for auxiliary energy requirements in the train. Braking energy is approximately 40% of total energy consumption. There are electric trains with regenerative braking, which are capable of returning energy regenerated during braking to the supply mains. The energy thus injected can be used to feed other trains which are accelerating at the same time. Energy generated during braking of train will simply be converted into waste heat by braking resistors, if no other train is accelerating at exactly the same time. Such a synchronization between braking and acceleration of two different trains cannot be coordinated all the time, therefore we need an energy storage system that stores the energy generated during braking and discharges for other electrical uses. The energy storage system creates optimum conditions for energy regeneration. The energy storage system is able to store and discharge energy extremely quickly. The energy storage system reduces primary energy consumption without affecting transport capacity and punctuality.

II. Proposed Regenerating Braking Traction System

Block diagram of the Energy Efficient DC Traction System through Regenerative Braking is shown in figure 1. The system consist of a rectifier unit, DC to DC converter, switch, DC motor and a battery.

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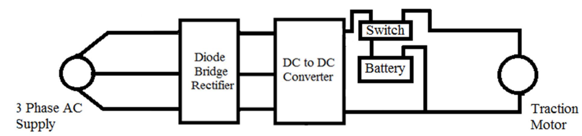


Figure 1: Block Diagram of Energy Efficient DC Traction System through Regenerative Braking.

The rectifier employed in the system is a diode bridge rectifier, which converts the incoming AC supply to DC. Then there is a DC to DC converter to step down the DC voltage level. Three state switching cell (3SSC) based DC to DC converter is employed. In 3SCC based converter current level on the devices is low compared to other converters, which enables the use of inexpensive semiconductor devices and simple control circuitry. Output of the DC to DC converter is fed to the motor through a switch. An energy storage battery is also connected to the motor terminals through the same switch. During the acceleration period and normal run period of the train, motor is fed by output of the converter. But during deceleration period of the train motor act as a generator, the energy thus produced is stored in the battery. Operation of switch depends on the mode of operation of train.

III. Diode Bridge Rectifier

A rectifier is a circuit that converts AC input voltage to DC output voltage. Semiconductor diodes are used extensively in power electronic circuits for the conversion of power from AC to DC. A rectifier employing diodes is called an uncontrolled rectifier, because its average output voltage is a fixed DC voltage.

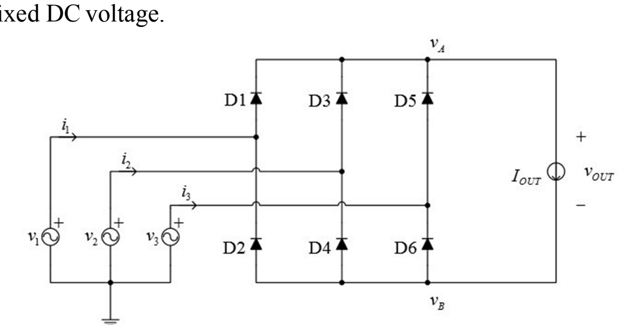


Figure 2: Three Phase Diode Bridge Rectifier.

The rectifier consists of a three phase diode bridge, comprising diodes D1 to D6. First, let us assume that the rectifier is supplied by a balanced undistorted three phase voltage system, specified by the phase voltages.

$$v_m = V_m(\cos\omega t)$$
$$v_m = V_m(\cos\omega t - \frac{2\Pi}{3}) \quad (1)$$
$$v_m = V_m(\cos\omega t - \frac{4\Pi}{3})$$

.

Assuming that load current is strictly greater than zero during the whole period, in each time point two diodes of the diode bridge conduct. The first conducting diode is from the group of odd indexed diodes (D1, D3, D5) and it is connected by its anode to the highest of the phase voltages at the time point considered. The second conducting diode is from the group of even indexed diodes (D2, D4, D6) and it is connected by its cathode to the lowest of the phase voltages. Since one phase voltage cannot be the highest and the lowest at the same time for the given set of phase voltages specified by equation (1), two of the phases are connected to the load while one phase is unconnected in each point in time. This results in an input current equal to zero in the time interval when the phase voltage is neither maximal nor minimal.

The described operation of the diodes in the diode bridge results in a positive output terminal voltage equal to the maximum of the phase voltages, i.e.,

$$v_A = \max(v_1, v_2, v_3) \quad (2)$$

While, the voltage of the negative output terminal equals the minimum of the phase voltages,

$$v_B = \max(v_1, v_2, v_3) \quad (3)$$

The diode bridge output voltage is given by

$$v_{out} = v_A - v_B \quad (4)$$

The DC component of output voltage equals

$$v_{out} = \frac{3\sqrt{3}}{\Pi} v_m \quad (5)$$

IV. Dc To Dc Converter

3SSC based DC to DC converter shown in figure 3 is employed. 3SSC comprises of two controlled switches, S1 and S2, two diodes, D1 and D2, one autotransformer, and one inductor L. Operation of converter is based on the complementary operation of two switches.

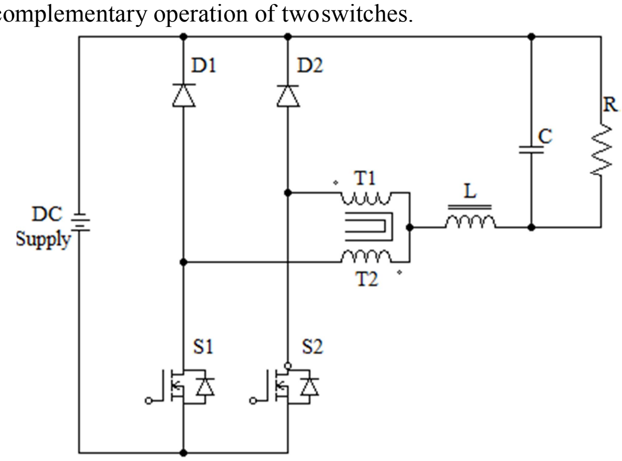
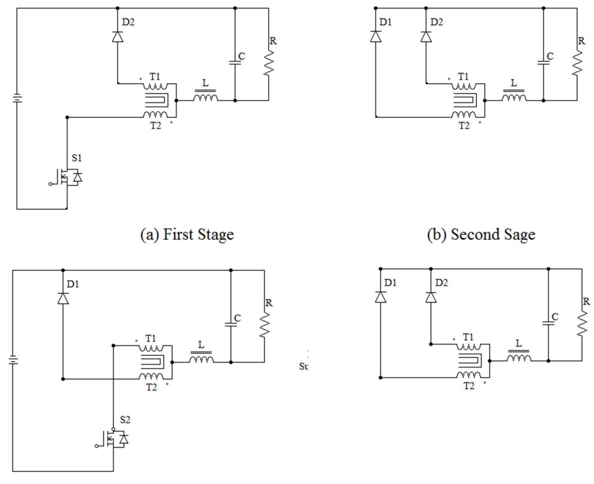


Figure 2: Three State Switching Cell DC DC Converter

Operation of the 3SSC based converter consist of four different stages, out of which two are the same. The four stages of operation are depicted in figure 3.



(a) First Stage (b) Second Sage

(c) Thrird Stage (d) Fourth Stage

Figure 3: Four Stages of Operation of the 3SSC DC to DC Converter

During the first stage of operation switch S1 is turned ON and S2 remains turned OFF. Current through the inductor L is divided into two parts, one part will flow through T1 and D2 delivering energy to the load. The other part of current through L will flow through T2 and S1. Number of turns of T1 and T2 is the same so as to maintain current sharing. Current through the inductor increases linearly. Windings T1 and T2 have same impedance, thus voltage across them are equal and will be half of the input voltage.

During the second stage of operation both the switches S1 and S2 are in OFF state. Voltage across inductor, L is inverted. Diode, D1 is forward biased and diode D2 is conducting. Energy stored in L during first stage is then transferred to the load.

Third stage begins when switch, S2 is turned ON. Due to the symmetry of the circuit operation of this stage is similar to that of first stage. Diode D1 keeps conducting and diode D2 is reverse biased. Inductor current is divided into two, one part will flow through T2 and D1 delivering energy to the load and the other part will flow through T1 and S2.

Fourth stage of operation begins when S2 is turned OFF. This stage of operation is same as the second stage, both switches, S1 and S2 are OFF.

In 3SSC current is distributed among the semiconductors, only a part of the energy from input source flows through active switches and the remaining part is directly transferred to the load without being processed by the switches. Energy transfer to the load takes place not through the active components like semiconductor switches but through passive components, such as the diodes and the transformer windings of the converter. Hence the voltage stress and power loss across the switch is low. Despite of the increase in number of semiconductor compared to other converters, the current level on these devices are less in 3SSC. Thus inexpensive switches and simplified control circuit can be employed in 3SSC. PWM is employed to drive the switches.

V. Regenerative Braking

Braking is the process of reducing speed of any rotating machine. There are three different types of braking namely dynamic braking, plugging and regenerative braking. Dynamic braking is the method of braking in which the motor in running condition is disconnected from the supply and connected across a resistor. When the motor is disconnected from the source, the rotor keeps rotating due to inertia and act as a self excited generator. When motor works as generator flow of current and torque reverses. The energy thus generated is dissipated in the resistance connected across the motor terminals. In plugging type of braking the terminals of the supply are reversed, as a result the generator torque also reverses which resists the normal rotation of the motor and as a result the speed decreases.

In regenerative braking motor is made to run as a generator but the generated energy instead of being fed to a resistance is used wisely. Rotating machine will behave like a generator when it is driven in the motoring direction by some external mechanical means. Energy can be transferred from the rotating machine to the electrical circuit connected to its terminals.

The proposed DC traction system employs regenerative braking. During the braking operation of train the motor acts as a generator and the generated energy is then stored in a battery. The energy stored in battery can be employed in supplying auxiliary requirements such as cooling and lighting in trains.

VI. Simulation Model and Results

The simulation model of the proposed system is shown in figure 4. This paper builds the simulation model of single motor instead of the whole train. Simulation is carried out in MATLAB/SIMULINK environment. The input AC supply is rectified into DC, then it is stepped down to 300V DC using 3SSC based converter. 300V DC drives the motor. Motoring and regeneration operation of motor is chosen using two breakers controlled by two control signals.

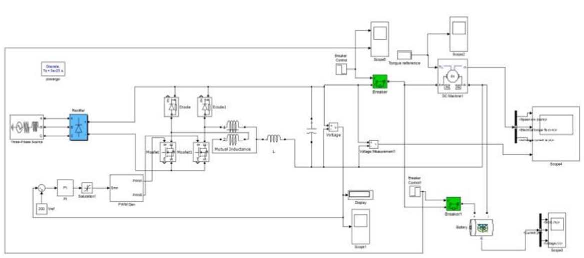
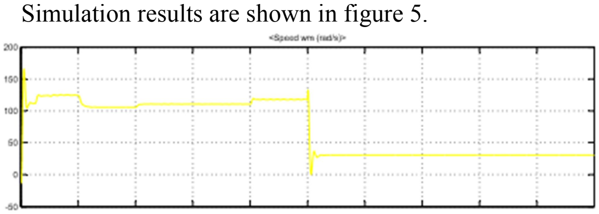
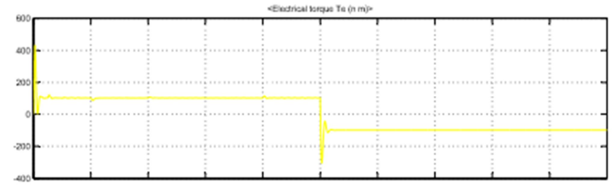


Figure 4: Simulation Diagram

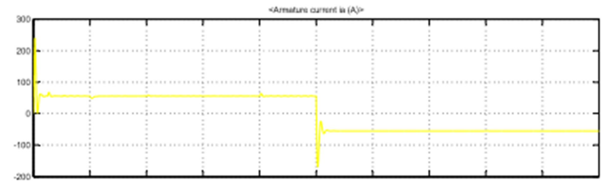
Simulation results are shown in figure 5.



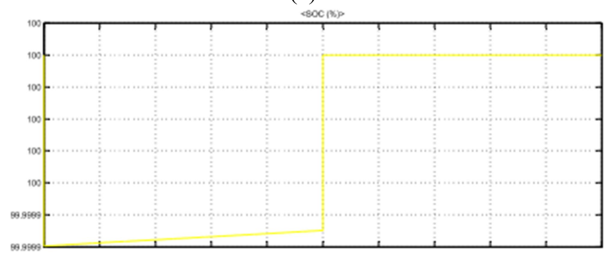
(a)



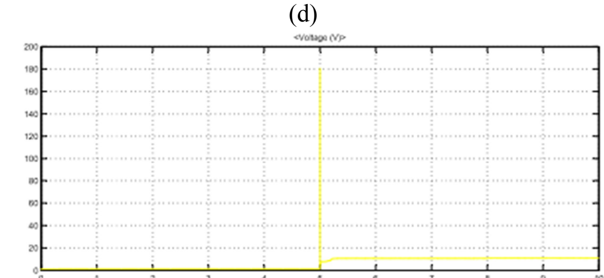
(b)



(c)



(d)



(e)

Figure 5; Simulation Results, (a) speed wave form of the motor, (b) torque waveform of the motor, (c) armature current waveform of the motor, (d) state of charge in percentage of

VII. Conclusion

The paper presents a MATLAB/Simulink simulation model of Energy Efficient DC Traction System through Regenerative Braking. Energy otherwise would be wasted is used wisely using a storage battery and utilized for auxiliary applications in train. Three state switching cell helps in the reduction of switching losses. In addition simple and inexpensive control is employed.

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