CASCADED H BRIDGE INVERTER MOTOR DRIVE FOR ELECTRIC VEHICLE APPLICATIONS

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Abstract

An Electric Vehicle (EV) is a combination of advanced electric drive systems, new battery technologies, fuel cells, which is an emerging technology in the modern world. It reduces environmental pollutions and at the same time increases fuel efficiency of the vehicles. Multilevel inverter is used to control the electric drive of EV and enhances its performance. The use of multilevel inverter is desirable as it can generate sinusoidal voltages with only fundamental switching frequency and have almost no electromagnetic interference. This project validates for the feasibility of using the Extended H Bridge (EHB) multilevel inverter for the enhanced operation of an electric vehicle as this inverter is generate all the three phases simultaneously in a single unit with only twelve switches. The motor drive is the core of the EV propulsion system which here is an induction motor. Contribution of multilevel inverter has led to achieve high performance motor drive. The performance of an electric vehicle under its various modes of operating conditions is demonstrated and the simulations are carried out by Matlab/Simulink software.

Index Terms: Electric Vehicle (EV), Extended H Bridge (EHB) inverter, Induction motor, Multilevel inverter.

I. INTRODUCTION

Presently, most of today's automobiles run on petroleum based products, which are estimated to be depleted in coming years [1]. Environmental and economical advantages can be gained by applying the alternative transportation technologies. The electric vehicles (EV) enabled by high efficiency electric motor and controller, and powered by alternative energy sources, provide the means for a clean, efficient, and environmental friendly urban transportation system. Consequently, electric vehicles are the only zero emission vehicles (ZEVs) possible [1].

The performance of an Electric Vehicle must cater different needs by addressing the factors like energy efficiency, cost and the driving performance. Uninterrupted starting, steady running conditions, effortless braking to make a halt on time are the general requirements in an EV. In Figure 1 it is shown that the electric propulsion system of the vehicle requires a motor, which here is an Induction Motor (IM). The Induction Motor is chosen due to its own significant advantages. Prior to the 1950s variable speed and traction drives used DC machines since AC machines were not capable of smoothly varying the speed of the system [2]. Technological developments presently have lead to the increase use of Induction Machines in traction applications [3]. The induction motor shows a good efficiency over a wide speed range of operation [4]. Therefore, the induction motor would be a decent choice for EV propulsion system.

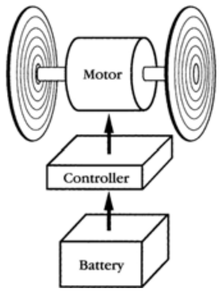

Figure 1. General block diagram of an EV

On the other hand, power converter technology is continuously developing, and multilevel inverters have become a very attractive solution for EV applications, due to its modular structure, voltage capability, reduced common mode voltages, near sinusoidal outputs, and smaller or even no output filter [7]. The diode clamped inverter had issues regarding excessive clamping diodes (m-1)(m-2) per phase which increases its complexity [9]. The flying capacitor MLI has issues relating to the use of expensive and bulky capacitors and complex control is required to maintain the capacitor voltage balance [9]. The Cascaded MLI did not have the ability to generate all the three phases simultaneously and as the voltage level increases, the number of semiconductor switches increases so is the required DC sources [12,13].

Bringing forth a concurrent three phase supply, size of the motor is reduced, the power transferred is uniform throughout and hence vibrations are diminished. Affording three phase voltage to the motor makes it more convenient to integrate the EV with the distribution grid for charging. So, a new inverter topology called the Extended H Bridge (EHB) for three phase generation is proposed. This can generate all the three phases simultaneously in a single unit with only twelve switches. This inverter is then employed for the conversion of dc power from the batteries into ac and given to induction motor drive which is responsible for the propulsion of Electric Vehicle system.

This paper consists of a five level EHB inverter that satisfies the basic requirements of EV replacing the conventional pulse width modulated inverter. Apart from that it also exhibits enhanced performance in terms of motor characteristics, ease of grid utilization.

II. MODELING

This section deals with the modeling of various segments including EHB inverter, Electric Vehicle and the induction motor for EV put together forming the entire EV system.

A. Modeling of Extended H Bridge (EHB) inverter

It consists of twelve switches connected in a fashion as shown to produce a minimum five level output. This topology can be extended to produce a 7, 9 level output by adding three more switches per level increase. This is discussed below. Table 1 is derived by considering phase A as reference.

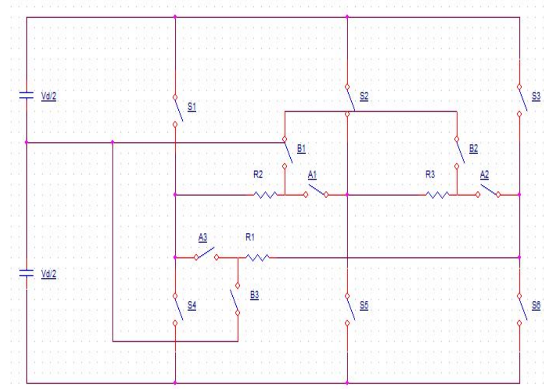

Figure 2. Schematic of the inverter

Table I. Triggering states for five level output

Volt	S1	S2	S3	S4	S5	S6	A1	A2	A3	B1	B2	B3
0V	0	0	1	1	1	0	1	0	1	0	1	0
0.5V	1	0	1	0	1	0	0	1	0	1	0	1
1V	1	0	1	0	1	0	1	0	1	0	1	0
0.5V	1	0	0	0	1	1	0	1	0	1	0	1
0V	1	1	0	0	0	1	1	0	1	0	1	0
-0.5V	0	1	0	1	0	1	0	1	0	1	0	1
-1V	0	1	0	1	0	1	1	0	1	0	1	0
-0.5V	0	1	1	1	0	0	0	1	0	1	0	1

Modes of operation

Mode1: S1, S3, S5, A1, A3 and B2 ON
$V_0=V_{d/2}+V_{d/2}=V_d$

Mode2 : S1, S5, S6, A2, B1 and B3 ON
$V_0=V_{d/2}$

Mode3 : S1, S2, S6, A1, A3 and B2 ON
$V_0= 0$

Mode4 : S2, S4, S6, A2, B1 and B3 ON
$V_0=-V_{d/2}$

Mode5 : S2, S4, S6, A1, A3 and B2 ON
$V_0=-V_d$

B. *Modeling of Electric Vehicle*

Automobiles are an indispensable part of our day to day life. Unfortunately, most automobiles use fossil fuels such as petrol and diesel. Consequently, internal combustion (IC) engines release toxic effluents to the environment. The chemicals cause building up of greenhouse gases in the atmosphere. Electric vehicles (EV) powered by alternative energy provide the means for clean and environment friendly transportation. In EVs, an electric motor is the only propulsion unit, and power is supplied from a battery pack. Batteries are the source of energy that is essential for electric propulsion. The capacity of a battery is given by $C = \int I_d \, dt$ where I_d is the discharge current and t is the time of discharge.

C. *Induction Motor modeling*

The electric propulsion system of the vehicle requires a motor, which here is an Induction Motor (IM). Direct-Quadrature (d-q) transformation is a mathematical transformation used to simplify the analysis of three phase circuit. In the case of balanced three phase circuits, application of d-q transformation reduces the three AC quantities to two quantities.

Flux linkage equations: stator

$$\lambda_{sd} = L_s * i_{sd} + L_m * i_{rd} \quad (1)$$

$$\lambda_{sq} = L_s * i_{sq} + L_m * i_{rq} \quad (2)$$

Flux linkage equations: rotor

$$\lambda_{rd} = L_s * i_{rd} + L_m * i_{sd} \quad (3)$$

$$\lambda_{rq} = L_s * i_{rq} + L_m * i_{sq} \quad (4)$$

Current equation: stator

$$i_{ds} = \frac{1}{X_{ls}} (\lambda_{ds} - \lambda_{md}) \quad (5)$$

$$i_{qs} = \frac{1}{X_{ls}} (\lambda_{qs} - \lambda_{mq}) \quad (6)$$

Current equation: rotor

$$i_{dr} = \frac{1}{X_{ls}} (\lambda_{dr} - \lambda_{md}) \quad (7)$$

$$i_{qr} = \frac{1}{X_{ls}} (\lambda_{qr} - \lambda_{mq}) \quad (8)$$

Electromagnetic torque:

$$T_{em} = \frac{p}{2} * L_m (i_{sq} * i_{rd}) - (i_{sd} * i_{rq}) \quad (9)$$

where, d- Direct axis, q- Quadrature axis, s- Stator variable, r- Rotor variable, λ- flux linkage, R_s = Stator resistance, R_r = Rotor resistance. Simplified calculations can be carried out on these imaginary quantities before performing the inverse transformation to recover the actual three phase ac results.

III. SIMULATION RESULTS

In this section, the simulation results are presented for the following

a) Extended H bridge (EHB) inverter

b) EHB inverter induction motor drive for EV application

A. *Extended H Bridge (EHB) inverter*

The Extended H bridge inverter controls the performance of the induction motor which in turn drives the Electric Vehicle in various modes. MATLAB/Simulink model of EHB inverter is shown below in Figure 8 and the gate pulse for the inverter switches is as shown in Figure 9.

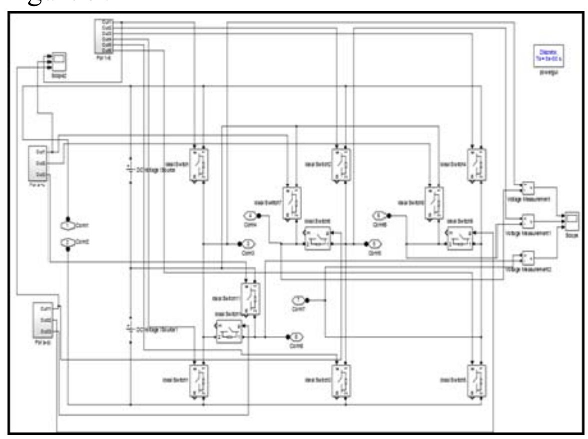

Figure 8. MATLAB/Simulink diagram of Extended H bridge inverter

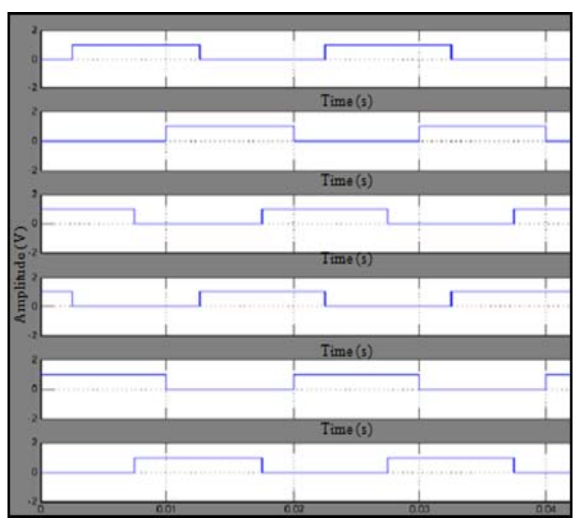

Figure 9(a)

From Figure 10 it can be inferred that the MLI generated three phase output voltages with a phase displacement of 120^{o} from each other. It can also be seen that the voltage waveform is stiff without any distortions.

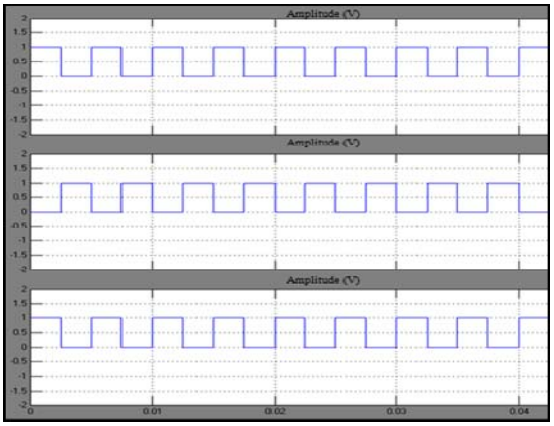

Figure 9(b)

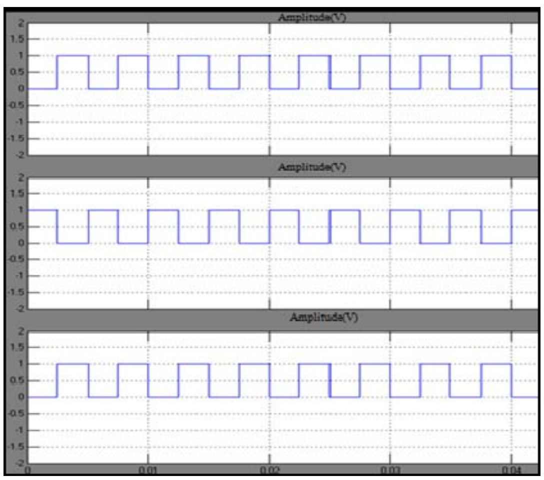

Figure 9(c)

Figure 9. Gate pulses for five level inverter, (a) For switches S1-S6, (b) For switches A1-A3, (c) For switches B1-B3

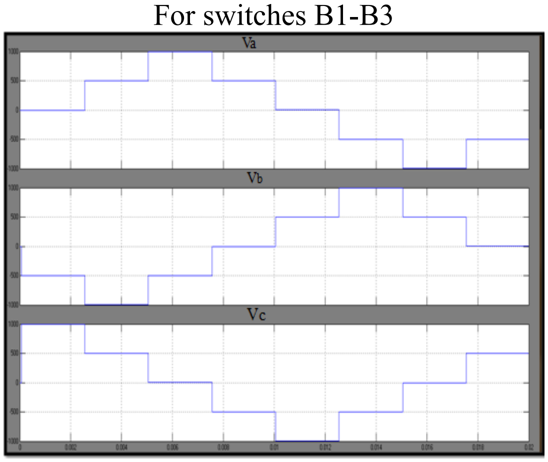

Figure 10. Analysis of five level inverter - Load voltage

A. Extended H Bridge (EHB) inverter

The induction motor is driven by the five level Extended H bridge inverter through a three phase transformer in order to provide a means of connecting an AC motor with the MLI output ports. EHB based Electric Vehicle is simulated where there is no particular control mechanism imposed on the induction motor driving the EV.

Figure 11 shows the MATLAB/Simulink model of EHB based Electric Vehicle system, which results in various operating conditions. The output voltages form with 5 level stepped multilevel waveform as seen in figure 12.

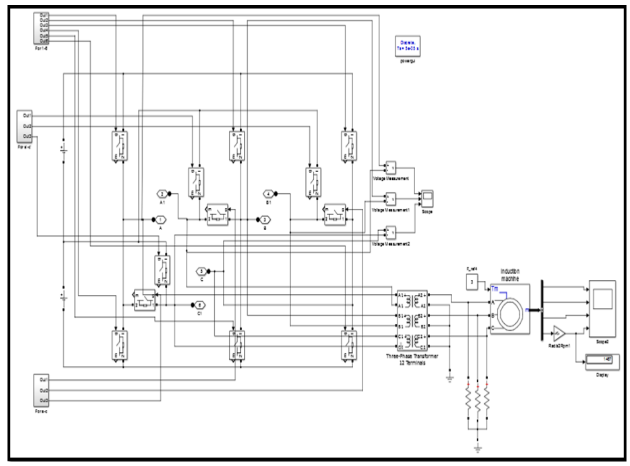

Figure 11. MATLAB Simulink diagram of EHB based EV

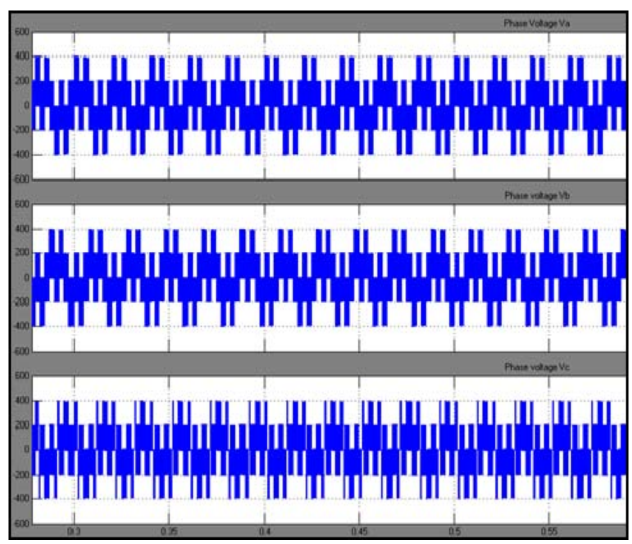

Figure 12. Load voltage of EHB

The Electric Vehicle is made to run by the EHB Multi-level inverter and the motor exhibits the starting characteristics followed by running and braking modes of operation as shown in figures 13, 14 and 15 respectively. The braking operation is achieved by cutting the AC supply bringing the motor to halt swiftly.

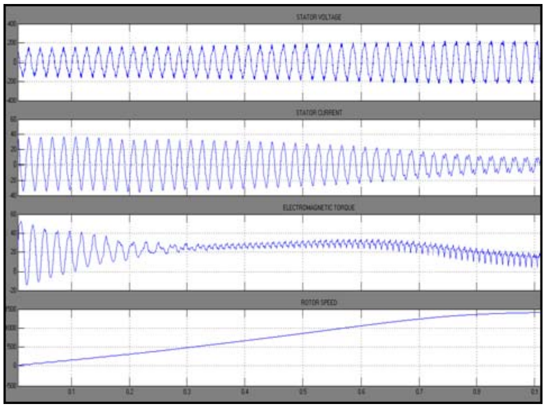

Figure 13. Stator Voltage, Stator current, Electromagnetic Torque, Rotor speed - Starting characteristics

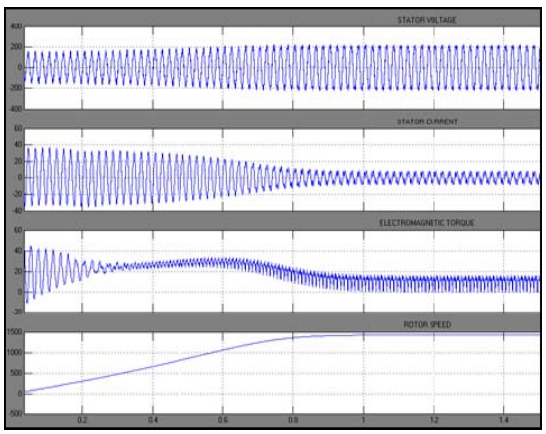

Figure 14. Stator Voltage, Stator current, Electromagnetic Torque, Rotor speed - running condition

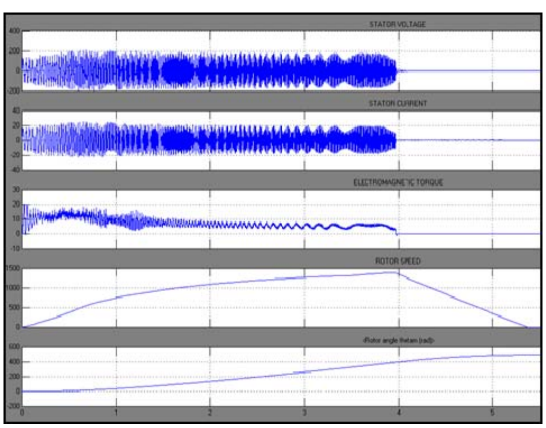

Figure 15. Stator Voltage, Stator current, Electromagnetic Torque, Rotor speed - barking condition

IV. CONCLUSION

Thus the Electric Vehicle system was simulated with Extended H Bridge inverter and the outcome of this paper indicated that the Electric Vehicle driven by the MLI could attain different operating regions. Contribution of multilevel inverter in motor drive application has led to uninterrupted starting, steady running conditions, effortless braking to make a halt on time as shown by the MATLAB simulations.

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