AN IMPEDANCE NETWORKS BOOST CONVERTER FOR AC TRACTION APPLICATION

[1]Alka Raj, [2] Jeena Joy, [3]Geethu James
[1]PG Scholar, [2]Professor, [3]Professor
Department of Electrical & Electronics
Mar Athanasius college of engineering, Kothamangalam, Eranakulam, India

Abstract: High-step-up and high-efficiency DC-DC converters are necessary to handle large input currents and to reach high output voltages. Here the low voltage source is boosted to high voltages for feeding into inverter drive three phase induction motor. The conventional boost converter realize high voltage gains at rather large duty cycles (normally exceeding 50%) resulting in saturation of inductors but the impedance networks boost converter can reach a higher voltage gain with fewer diodes and small duty cycle and avoid instability caused by saturation of its inductors. Further, it can well fulfill the stringent industrial requirements, particularly of renewable power systems. Theoretically conventional boost converters may realize infinite voltage gains for switching duty-cycles very close to 100\% which however degrade the converter's overall efficiency. The induction motor became the workhorse in the industries. Low cost, high efficiency, high robustness, reliability and low maintenance are some the advantages of the induction motors over DC motors. When mechanical loads are changed the speed characteristics for induction motor also changes. The induction motors do not have the constant speed characteristics. A three phase induction motor is basically a constant speed motor so it’s somewhat difficult to control its speed. There are many control methods the induction motor to provide it with the constant speed characteristics. Some of the prominent methods are scalar control, vector control etc. The popular V/F method of induction motor operation has been done here. In the present work, low voltage is boosted by the impedance networks boost converter and then it drives the induction motor for traction application. Simulation of the system was done in MATLAB/SIMULINK and verified. The hardware of the system was also done and verified the result.

***IndexTerms* - Boost converter, high voltage gain, few diodes, inductor saturation, induction motor.**

I. INTRODUCTION

High-step-up and high-efficiency DC-DC converters are necessary to handle large input currents and to reach high output voltages, e.g. where the low voltages of renewable energy sources need to be boosted to high voltages for feeding into grid-connected inverters. Theoretically, conventional boost converters may realize infinite voltage gains for switching duty-cycles very close to 100% which, however, degrade the converter's overall efficiency. This drawback is overcome by the proposed high-step-up boost converter. Compared to the traditional boost converters, the proposed one reaches a higher voltage gain with fewer diodes, and with a small duty-cycle to avoid inductor saturation. Its design combines three active cross-shaped networks, viz. a boost part at the input consisting of two inductors and three diodes, a switching part consisting of a switch, two capacitors and a diode, and a boost part at the output consisting of two inductors and three diodes. By suitably adjusting the duty-cycle, desired voltage gain in renewable energy systems can be achieved.

Conventional boost converters are limited by parasitic effects of their devices and by serious losses, so the voltage gain is limited even with a very large duty cycle. In practical applications, the voltage gain of a conventional boost converter for a given duty-cycle D of the switching signal is limited to about the factor 5 to 6, which is far away from industrial needs [12]. This converter possesses a higher voltage gain than the one of conventional boost converter, but at the expense of large corresponding leakage inductance and a complex structure.

In very simple words induction motors can be described as a three phase, self starting constant speed AC motors. The reason of describing induction motors as constant speed is because normally these motors have a constant speed depending on the frequency of the supply and the no of windings. In the past it was not possible to control the speed of the induction motors according to the need. That’s why their use was limited and despite having many a motors they advantages over DC motors they could not be used because of this disadvantage. But at the field of drivers have improved due to the availability of thyristors or SCRs, power transistors, IGBTs and GTOs the variable speed induction motor drives have been invented.

Induction motor is one of the most commonly used motor. About 90% of motor produced in market is induction motor and cost is moderate. The synchronous speed of the motor can be control by using controlling the frequency of the stator voltage. Induction motor can be drive by connecting induction motor with converter and inverter. The output voltage from the DC-DC converter is dc voltage. This voltage should be converted to ac voltage for converting it to ac voltage a three phase inverter is connected to converter. A 20V source is connected to the input of the converter and the converter boost the voltage to 200V. The 200V DC voltage is converted to three phase ac voltage by using a three phase inverter.have been specified for three reasons: (1) ease of use when formatting individual papers, (2) automatic compliance to electronic requirements that facilitate the concurrent or later production of electronic products, and (3) conformity of style throughout a conference proceedings. Margins, column widths, line spacing, and type styles are built-in; examples of the type styles are provided throughout this document and are identified in italic type, within parentheses, following the example. Some components, such as multi-leveled equations, graphics, and tables are not prescribed, although the various table text styles are provided. The formatter will need to create these components, incorporating the applicable criteria that follow.

II. SYSTEM DESCRIPTION

2.1 Impedance Networks Boost Converter with High Voltage Gain

As shown in Fig. 1, the design's distinct features are not only to use just a single switch, but also the minimum number of diodes. Moreover, the proposed converter can realize a higher voltage gain with a smaller duty cycle.

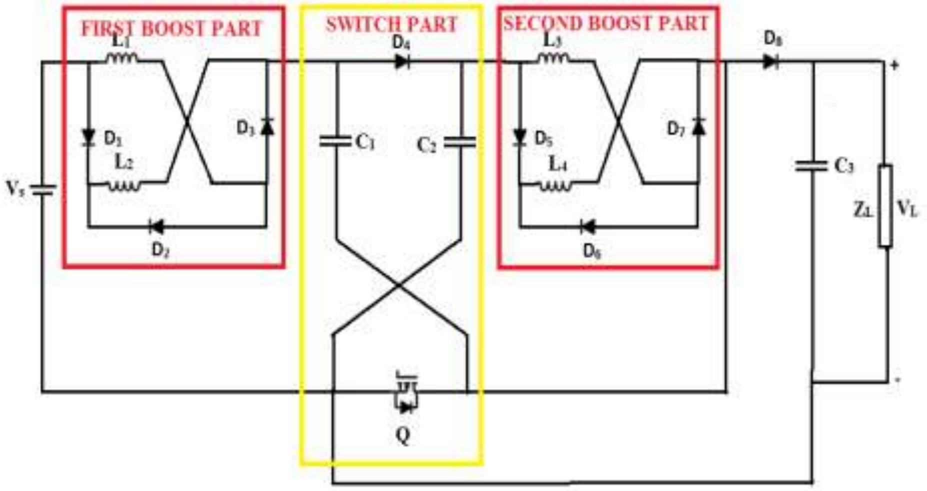

fig 1. Impedance Networks Boost Converter.

This boost converter can operate both in Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM). There are cases of DCM in terms of the discontinuous currents of inductors L1, L2, L3 and L4. As CCM is normally employed in industrial applications, the operation of the proposed converter is analysed in the sequel for this mode, only. For simplicity, it is assumed that all components are ideal, the free-wheeling diode of the switch is ignored, the capacitances of the capacitors C1, C2, C3 are large enough to consider the voltages C1, C2, C3 to be constant as well as L1 = L2 and L3 = L4.

There are two sub modes of the converter in CCM, namely Mode 1 and 2. Therein, vL1 are the voltages at L1,...,L4, respectively. Assume the clockwise direction as the reference current direction and the voltages marked regarded as the reference voltages of inductors. Denote with D the duty cycle of the switching signal applied at switch Q, with t0 the beginning of a period of this signal, with t1 the transition instant from Mode 1 to Mode 2 and with t2 the period ends.

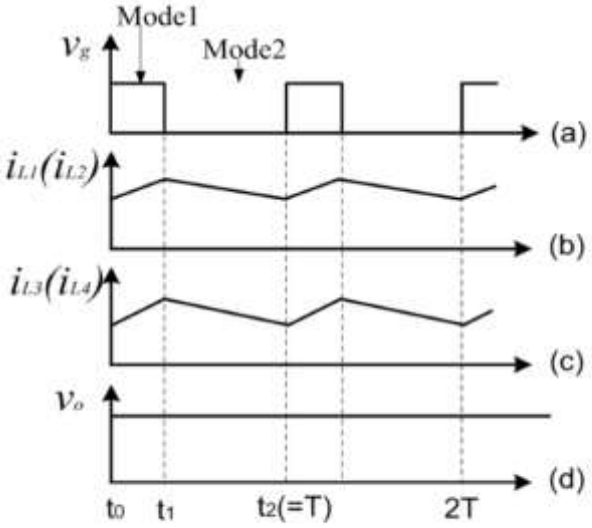

fig 2. Waveforms.

In order to describe the operation process of the converter, its key waveforms in the steady state are shown in Fig 2 where Fig 2(a) depicts the voltage vg driving switch Q. This rectangularly shaped gating signal has period T and duty-cycle D, i.e. it is on in every period for D·T time units. Fig 2(b) shows the waveform of currents L_1, L_2 through L_1 and L_2, respectively, Fig 2(c) the one of L_3, L_4 through L_3 and L_4, respectively, and Fig 2(d) presents the proposed converter's output voltage.

2.1.1

As shown in Fig. 2(a), there are three loops in the circuit, and the arrows in the circuit diagram refer to the current directions in each loop. As Q turns on, the diodes D1 and D3 assume positive voltages and turn on synchronously; meanwhile, D2 bears negative voltage and turns off. Thereafter, L1 and L2 are connected in parallel and, then, cascaded with C1, Q and Vs to form Loop 1. The source Vs discharges energy to L1 and L2, then currents iL1 and iL2 increase, and L1 and L2 store the energy. The waveforms of iL1 and iL2 are shown in Fig. 3(b), where iL1 = iL2 due to the symmetrical structure of Z-network 1. Moreover, Loop 1 marked with red line in Mode 1.

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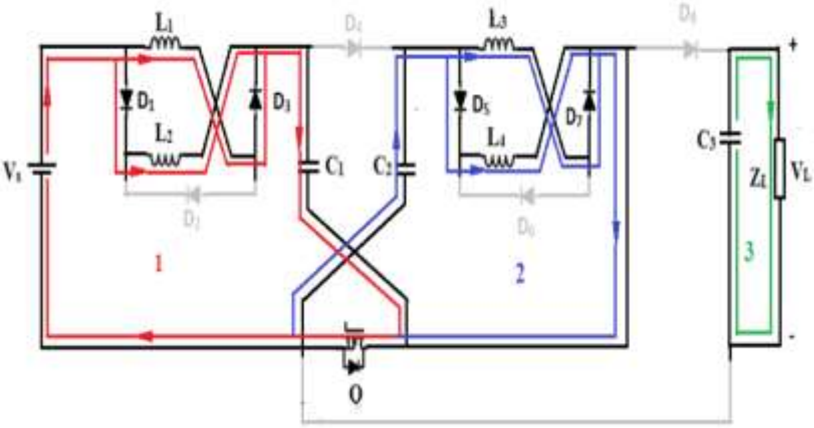


fig 3. Mode 1(Equivalent circuit)

where v_{L1}, v_{L2} and V_{C1} are the voltages at L_1, L_2 and C_1, respectively. In the meantime, D_4 and D_6 assume negative voltages and turn off, while D_5 and D_7 endure positive voltages and turn on. Accordingly, L_3 and L_4 are connected in parallel and, then, cascaded with Q and C_2 to form Loop 2. The capacitor C_2 discharges its energy to L_3 and L_4, and currents i_{L3} and i_{L4} increase. Thus, L_3 and L_4 store energy. The waveforms of i_{L3} and i_{L4} are shown in Fig. 3(c), where $i_{L3} = i_{L4}$. Thus, according to Loop 2 marked with blue linein Mode 1, one has where v_{L3}, v_{L4} and V_{C2} are the voltages at L_3, L_4 and C_2, respectively. Meanwhile, D_8 assumes negative voltage and turns off, then capacitor C_3 and load Z_L are cascaded to form Loop 3. Here, C_3 discharges its energy to Z_L and the converter's output voltage Vo is the voltage V_{C3} at capacitor C_3:

At instant t_1, Q turns off and the mode changes from Mode 1 to Mode 2, as shown in Fig. 2(b). As Q is off, D_1, D_3, D_5, D_7 assume negative voltages and turn off, whereas D2, D4, D6 and D8 turn on and form three loops in this mode. Loop 1 marked with red line in Mode 2, discharges energy from Vs, L_1 and L_2 to C_2, hence $V_s = v_{L1}+v_{L2}+V_{C2}$. Moreover, currents i_{L1} and i_{L2} decrease as shown in Fig. 3(b). fig 4. modes of operation.

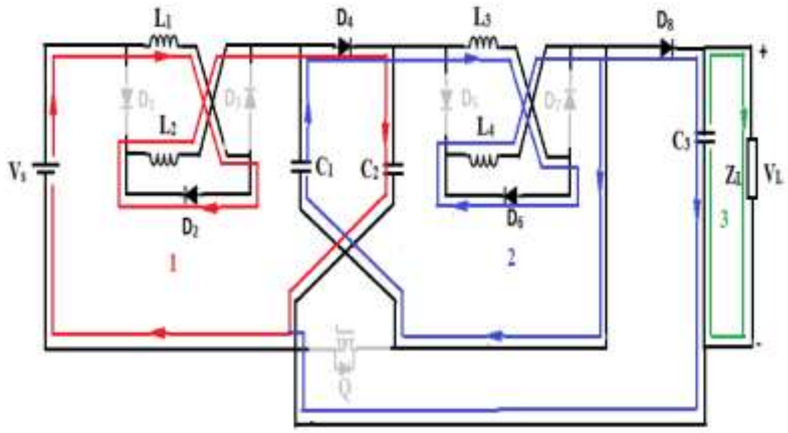


fig. 4:Mode 2(Equivalent circuit)

Loop 2 is formed by Vs, L1, D2, L2, D4, L3, D6, L4, D8 and C3, where Vs and L1,...,L4 discharge energy to C3 and ZL, hence Vs = vL1 + vL2 + vL3 + vL4 + VC3, and current iC3 decreases due to the discharge of energy to load ZL. Meanwhile Loop 2 marked with blue line in Mode 2, is formed with VC1 = vL3 + vL4 = VC2 − VC3, and currents iL3 and iL4 decrease as shown in Fig. 3(c). The currents of D6 and D8 are equal to iL3 for the cascaded connection. Then, one has vL3 + vL4 = Vs −(vL1 + vL2 + VC3), VC1 = vL3 + vL4 = VC2 −VC3.

III. IMPEDANCE NETWORKS BOOST CONVERTER FOR AC TRACTION APPLICATION

The induction motor became the workhorse in the industries. Low cost, high efficiency, high robustness, reliability and low maintenance are some the advantages of the induction motors over DC motors. When mechanical loads are changed the speed characteristics for induction motor also changes. The induction motors do not have the constant speed characteristics. There are many control methods the induction motor to provide it with the constant speed characteristics. Some of the prominent methods are scalar control, vector control etc. The popular V/f method of induction motor operation has been known over decades. It uses the stator flux and torque error to generate the stator voltage and frequency. In order to increase the reliability, flexibility and simplicity of controlling the error and therefore to provide constant speed characteristics to induction motor drives, microcontrollers are being used. In the present work, converter boost the input voltage of 15V to 150V and inverter converts it to AC and then three phase induction motor is connected. The block diagram of the circuit is shown below in Fig 5.

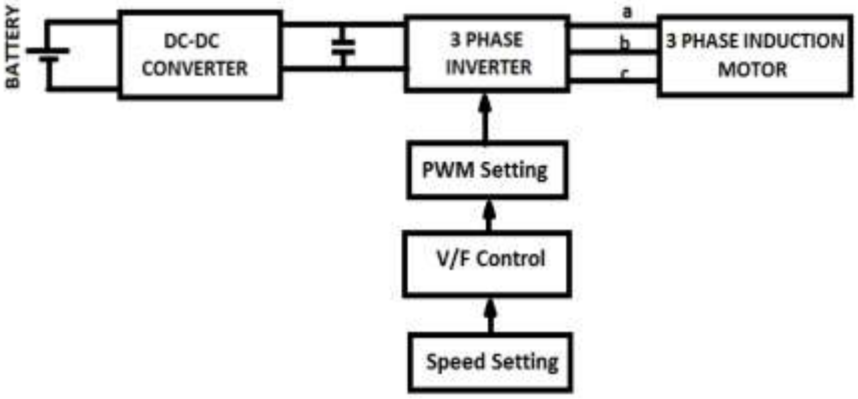


fig. 5:Block diagram for traction application.

IV. SIMULATION OF IMPEDANCE NETWORKS BOOST CONVERTER FOR AC TRACTION APPLICATION.

The simulation of impedance networks boost converter for AC Traction application was done in MATLAB/SIMULINK. The Table I below shows the Simulation parameters of converter.

Table 1: Simulation Parameters of Converter.

Parameters	Specifications
Input voltage(V_s)	48V
Output voltage(V_o)	600V
Switching frequency(f_s)	100KHZ
Capacitor C_1 and C_2	110μH
Output capacitance C_3	470μH
Inductor L_1 and L_2	200μH
Inductor L_3 and L_4	20kHz

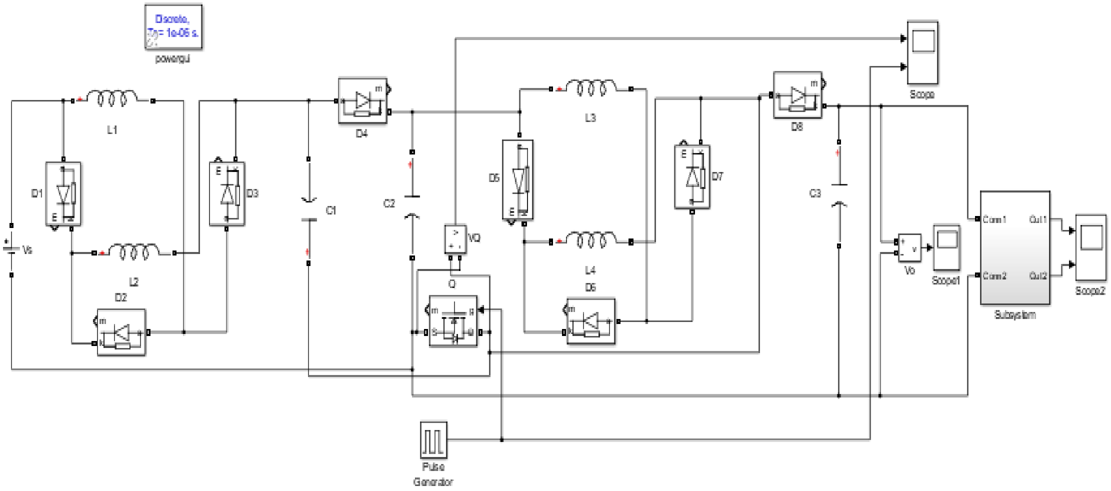
Table II below shows the simulation parameters of induction motor.

Table 2: Simulation Parameters of Induction Motor.

Parameters	Specifications
Power	1hp
Stator Resistance	11.124Ω
Stator Inductance	33.36mH
Rotor Resistance	8.8938Ω

Rotor Inductance	33.36mH
Mutual Inductance	490mH
pole pairs	1
Inertia factor	0.0018kg..m^2

The Fig. 6 shows the simulation of converter connected with an induction motor drive. . The converter will boost the DC voltage to a high value of 600V and the three phase inverter convert the DC voltage to AC voltage. The induction motor is connected to the output of the three phase inverter and it runs.



. fig.6:Simulation of converter connected with three phase induction motor drive.

The Fig 7 shows the simulation of induction motor drive. The induction motor drive was given as a subsystem in the previous simulation diagram. A three phase inverter is used here in the subsystem and gate pulse is given as another subsystem. The output from the three phase inverter is given to the three phase induction motor.

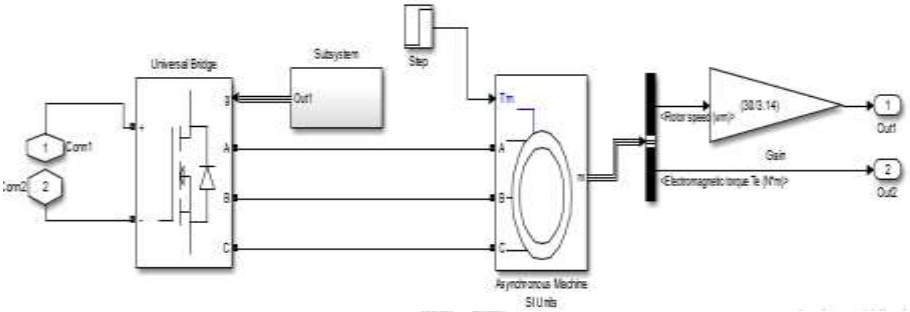


fig. 7: Simulation of induction motor drive.

The gate pulses to the three phase inverter given as a subsystem in the previous simulation diagram is given as a detailed simulation diagram as shown in the below Fig 8. A frequency control method is also done in the pulse generation circuit. The induction motor needs a V/f control for its speed control. The frequency control is achieved in this gate pulse generating subsystem.

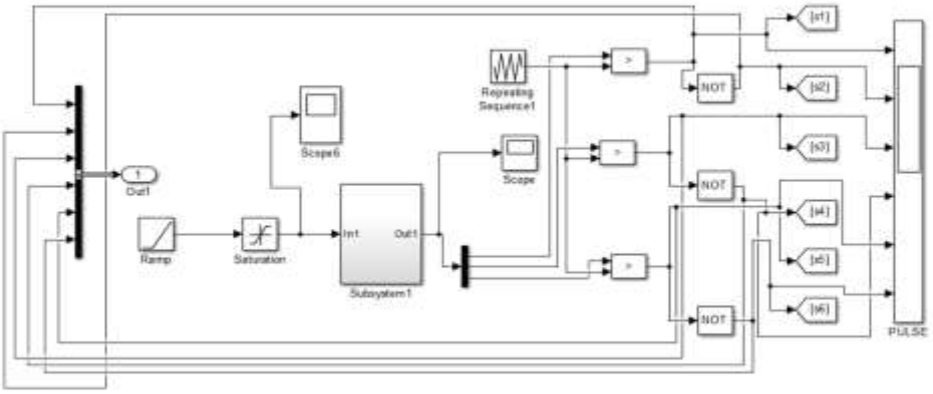


fig. 8: Simulation of switching pulse generation for inverter.

The speed of the induction motor is to be controlled. There are different control methods to control the speed of induction motor in that we are using the simple V/f control to control the speed of three phase induction motor. The simulation of V/f control is given in the Fig. 9 below.

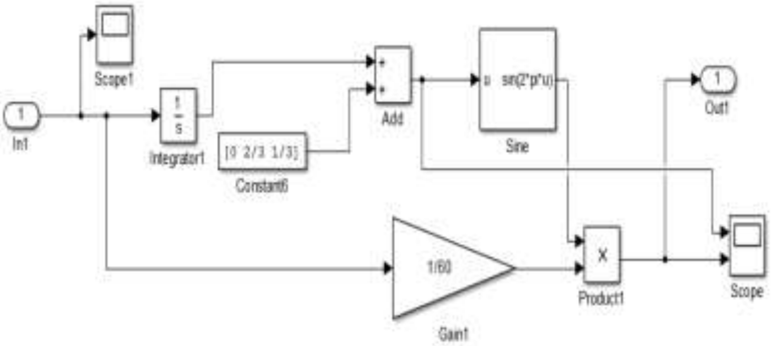


fig. 9: Simulation of V/f control in induction motor.

The Fig. 10 below shows the input voltage and the output voltage of induction motor drive system. The output is slowly reaches to the value 600V.

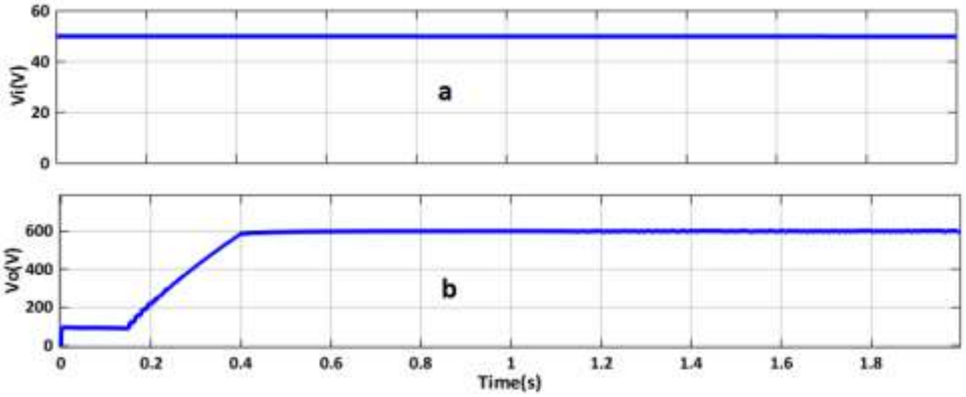


fig. 10:(a)Input voltage (b)output voltage of induction motor drive system .

The below Fig. 11 shows the rotor speed and electromagnetic torque of the induction motor. The rotor speed slowly varies from zero to 3500 rpm rated speed and then it remains their constant.

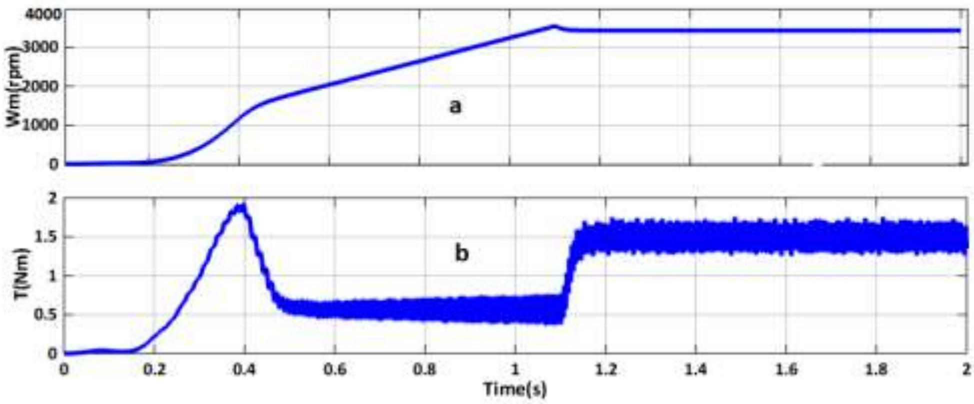


fig. 11:(a)Rotor speed (b)Electromagnetic torque

V. EXPERIMENTAL SET UP WITH RESULTS

An impedance networks boost converter is connected with an induction motor drive. The hardware is tested by giving a 15V supply. The output obtained is 150V. The switches used in the hardware is IGBT's. The control circuit used is TMS 320 processor and driver circuits used are IR2110 and TLP250. The converter is having only one switch and that switch is driven by using IR2110. The converter used in the circuit is a high gain converter which is having a gain of 10. The switches in the inverter is driven by using TLP250. The induction motor used is 0.5hp, 1390rpm. The speed of this induction motor can be changed by V/f control which is done by varying the pot connected to the controller TMS320.

The experimental setup of the hardware is given in the below figure. The experimental setup contains mainly the converter, inverter, induction motor, driver circuit, controller circuit and two DC source are used one is to give supply to the converter and other as the supply to the controller. The controller need a supply of 12 V.

fig. 12: Experimental Setup.

The pulse given to the switch in the converter is given in the Fig. 13. The duty cycle used is 0.3 in the open loop. The closed loop of the converter is also done. The pulse driving circuit is IR2110 and the pulse is generating from the TMS320.

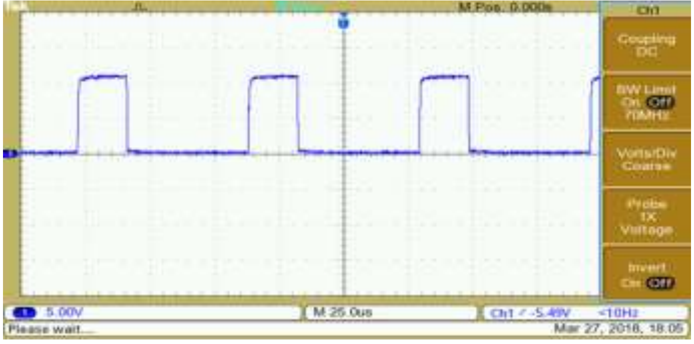


fig. 13: Control pulse for switch of converter.

The hardware is tested and when a input of 10V is given we are getting a voltage of 100V because the converter is having a voltage gain of 10. The test result is given in the following Fig. 14.

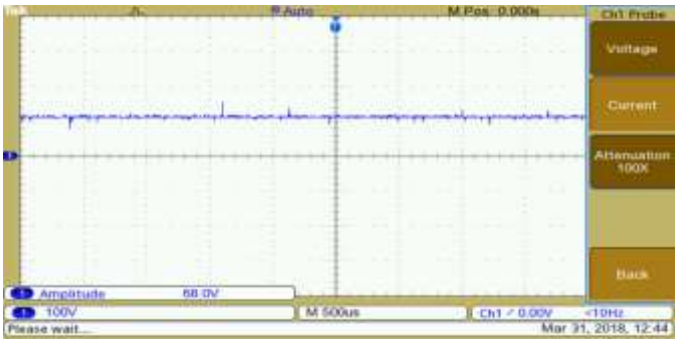


fig. 14: Output voltage of converter

The pulses needed for inverter is also generated by using TMS320. The driving circuit used is TLP250. The number of pulses needed for inverter is six. The inverter is having high voltage side switches and low voltage side switches. The low voltage side switches need just complimentary pulse of high voltage side switch and each leg of inverter should fed with ac voltage of 120 degree phase shift for proper working of inverter. The Fig 15 below shows pulses to inverter switches.

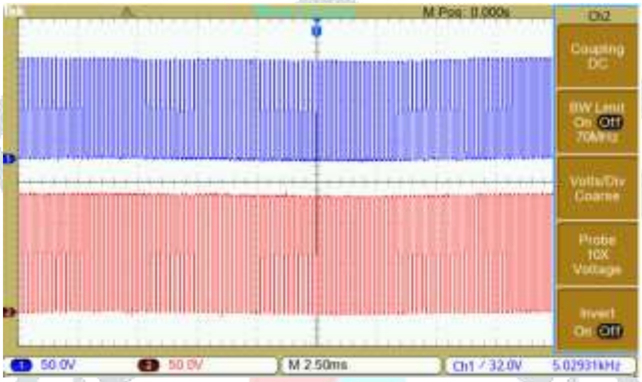


fig. 15: Pulse for inverter switches.

VI. CONCLUSIONS

An ultra high step-down converter is presented herein. By combining one coupled inductor and one energy-transferring capacitor, the corresponding voltage conversion ratio can be much lower than that of the traditional buck converter. There are three merits in this converter as following: (i) the voltage conversion ratio of this converter does not have non linearity characteristics; (ii) if one of the switches fails or is abnormally controlled, and in the meantime, any other two switches are made turned on, then the high voltage does not appear in the output terminal, so the output load can be protected; (iii) the proposed converter can be driven using existing SR buck PWM control ICs. To sum up, the structure of the proposed converter is quite simple and very suitable for industrial applications. The converter output is driving the inverter fed three phase induction motor. The simple V/F control is given to the induction motor for controlling the speed. The system can be used for traction application.

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