

Advanced Single Sensor Zeta Converter fed Induction Motor Drive System

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ABSTRACT: Induction motor has got the volatility of wide range of speed control. Power electronic converters can envisage dynamic speed control. The front end rectifier and dc to dc converter can be monitored to facilitate requisite input voltage to the inverter fed drive working at constant speed. A single phase supply followed by an uncontrolled bridge rectifier and a Zeta DC-DC converter is used to control the voltage of a DC link capacitor which is lying between the Zeta converter and a Voltage Source Inverter (VSI). Speed control is achieved by maintaining constant dc link voltage. In this drive, speed is controlled by adjusting the DC link voltage of the VSI feeding induction motor. VSI operates in a low frequency switching mode for reduced switching losses. A gate signal to VSI is obtained from hall sensors mounted on the rotor shaft of motor. A Power Factor Correction (PFC) based Zeta converter operating in discontinuous conduction mode (DCM) is used for controlling the DC link voltage of the VSI with inherent PFC at AC mains using single voltage sensor. The drive is implemented to achieve power factor at AC mains for a wide range of speed control and supply voltage fluctuations. An improved power quality is achieved with power quality indices within limits of IEC 61000-3-2 standard. Zeta converter provide improved power factor. VSI is operated in a low frequency switching mode for reduced switching losses. Matlab simulation for 230, 5A is created and results are verified.

KEYWORDS: Variable frequency drive, Zeta converter, voltage source inverter, power factor correction.

I.INTRODUCTION

Variable frequency drives are increasingly employed in industrial and traction purposes. The loads connected are constantly varying demanding speed control over wide range. Induction motor is referred as 'work horse' of industry due to its wide variety of application in industry. Be it domestic application or industry, motion control is required everywhere. A system that uses electric motors is known as an electrical drive. In electrical drives, use of various sensors and control algorithms is done to control the speed of the motor using suitable speed control methods. Induction motors are the most widely used motors for appliances, industrial control, and automation; hence, they are often called the workhorse of the motion industry. [1] They are robust, reliable, and durable. When power is supplied to an induction motor at the optional specifications, it runs at its rated speed. However, many applications need variable speed operations Drive system face lot of power quality problems like harmonics, the complex dynamics of ac machines, machine parameter variation, and the difficulties of processing feedback signals in the presences of harmonics poor power factor, noise, poor starting conditions etc. Power electronic converters are employed to improve the quality of power supplied to the drive systems. Induction motor when fed by an uncontrolled bridge rectifier with DC link capacitor results in highly distorted supply current which results in low PF (Power Factor) and high Total Harmonic Distortion (THD); hence various improved power quality AC-DC converters are used in these drive Two stage PFC converters are widely in practice in which first stage is used for the power factor correction which is preferably a boost converter and second stage for voltage regulation which can be any converter topology depending upon the requirement. Conventionally current multiplier method is employed in Continuous Conduction Mode (CCM), a voltage follower require only single sensor for voltage regulation. The sensing devices provide position feedback for adjusting frequency and amplitude of stator voltage reference properly to maintain rotation of the magnet assembly. The scheme discussed in this paper maintains high power factor and low THD of the AC source current while controlling rotor speed equal to the set reference speed. A voltage follower approach is used for the control of Zeta DC-

DC converter operating in DICM. The DC link voltage is controlled by a single voltage sensor. Sensed DC link voltage (V_{dc}) is compared with reference voltage (V_{dc}^*) to generate an error signal which is the difference of V_{dc}^* and V_{dc} . The error signal is given to a PI (Proportional Integral) controller to give a controlled output. Finally, the controlled output is compared with the high frequency saw tooth signal to generate PWM (Pulse Width Modulation) pulse for the MOSFET of the Zeta converter. A rate limiter is used to limit the stator current during step change in speed [2]. Paper is organized as section II describes volts per hertz control of induction motor, section III explains zeta converter fed induction motor drive, section IV briefs simulation results. Finally, Section V presents conclusion.

II. VOLTS PER HERTZ CONTROL OF INDUCTION MOTOR

Synchronous speed can be controlled by varying the supply frequency. Voltage induced in the stator is given in (1)

$$E_1 \propto \phi f \tag{1}$$

Where ϕ is flux and f is frequency. On neglecting the stator voltage drop then terminal voltage is given as

$$V_1 \propto \phi f \tag{2}$$

Thus reducing the frequency without changing the supply voltage will lead to an increase in the air-gap flux which is undesirable. Hence whenever frequency is varied in order to control speed, the terminal voltage is also varied so as to maintain the v/f ratio constant. By maintaining a constant v/f ratio, the maximum torque of the motor becomes constant for changing speed. As can be seen, when v/f Control is implemented, for various frequencies inside the operating region, the maximum torque remains the same as the speed varies. Thus, maintaining the v/f ratio constant helps us to maintain a constant maximum torque while controlling the speed as per our requirement. Volts per hertz control can be implemented in two ways, they are described below.

a) Open loop v/f control

The open loop V/F control of an induction motor is the most common method of speed control because of its simplicity and these types of motors are widely used in industry. Traditionally, induction motors have been used with open loop, 50Hz power supplies for constant speed applications [3]. For adjustable speed drive applications, frequency control is natural. However, voltage is required to be proportional to frequency so that the stator flux remains constant if the stator resistance is neglected. The power circuit consists of a diode rectifier with a single or three-phase ac supply, filter and PWM voltage-fed inverter. Ideally no feedback signals are required for this control scheme. The PWM converter is merged with the inverter block. Block diagram of open loop control is shown in fig 1

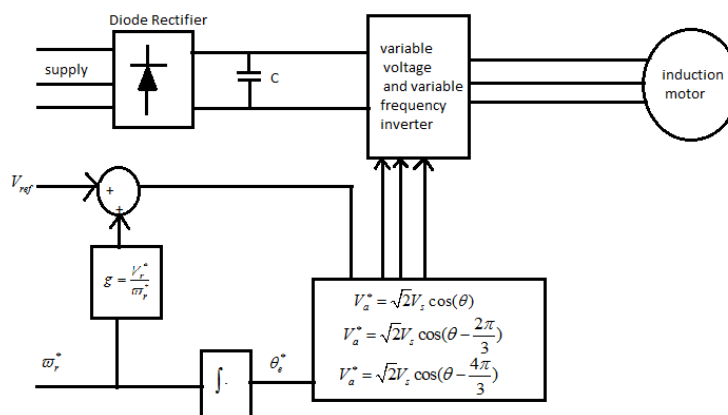


Fig.1. Block diagram of open loop control of induction motor.

The speed of the motor cannot be controlled precisely, because the rotor speed will be slightly less than the synchronous speed and that in this scheme the stator frequency and hence the synchronous speed is the only control variable. The slip speed, being the difference between the synchronous speed and the electrical rotor speed, cannot be maintained, as the rotor speed is not measured in this scheme. This can lead to operation in the unstable region of the

torque-speed characteristics. The effect of the above can make the stator currents exceed the rated current by a large amount thus endangering the inverter converter combination.

(b) Closed Loop Speed Control

The demerits of open loop are to be suppress by having an outer loop in the induction motor drive, in which the actual rotor speed is compared with its commanded value, and the error is processed through a controller usually a PI controller and a limiter is used to obtain the slip-speed command [4]. A speed sensor or a shaft position encoder is used to obtain the actual speed of the motor. It is then compared to a reference speed. The difference between the two generates an error and the error so obtained is processed in a Proportional controller and its output sets the inverter frequency. The synchronous speed, obtained by adding actual speed and the slip speed determines the inverter frequency. The reference signal for the closed-loop control of the machine terminal voltage. Block diagram of closed loop control is given in fig.2.

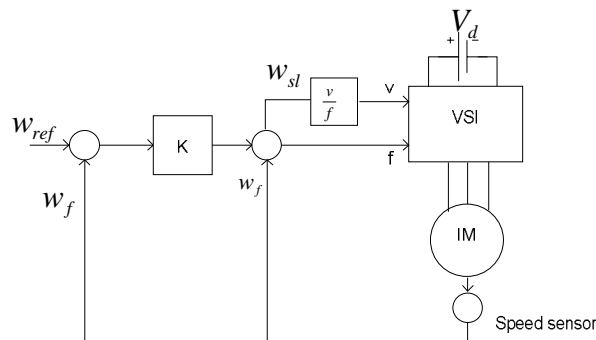


Fig.2 Block diagram of closed loop control of induction motor.

In constant v/f control, by use of rectifier and PWM inverter, we can vary the supply voltage as well as the supply frequency such that the ratio remains constant so that the flux remains constant too. So we can get different operating zone for various speeds and torques and also we can get different synchronous speed with almost same maximum torque. Thus the motor is completely utilized and also we have a good range of speed control. This paper presents a new approach of v/f control, which is based on current feedback to improve the stability of the conventional v/f control. The proposed approach is based on the stator current derivatives. This new method has successfully damped the torque and speed oscillations in V/f control for low power IM drive system. However, applying this method for high voltage IM resulted in more oscillations and lead to a highly unstable drive system. This paper analyses the causes of this instability and proposes a damper to suppress the undesirable oscillations. The proposed damper is easy to implement and helps eliminate the oscillations which causes the instability of V/f for high voltage IM.

III. ZETA CONVERTER FED INDUCTION MOTOR DRIVE

The proposed scheme for the sensor less induction motor drive fed by a Zeta based PFC converter operating in DICM mode is shown in Fig. 3. The Zeta converter keeps the DC link voltage to a certain set reference value. In Zeta converter the switching operation is done at high switching frequency for effective control which results in the reduction of size of components like inductors. The detection of rotor position for electronic commutation is done by a sensor less approach. A blind startup is used for starting the induction motor. A suitable MOSFET having a high frequency rating is used in the front end converter for its high frequency operation whereas for the low frequency operation of VSI IGBTs (Insulated Gate Bipolar Transistor) are used [5]. The proposed scheme maintains high power factor and low THD of the AC source current while controlling rotor speed equal to the set reference speed. Here the zeta converter uses a voltage follower approach which is used for the control the converter operating in DICM. The DC link voltage is controlled by a single voltage sensor. V_{dc} (sensed DC link voltage) is compared with V_{dc}^* (reference voltage) to generate an error signal which is the difference of V_{dc}^* and V_{dc} . The error signal is given to a Proportional Integral (PI) controller to give a controlled output. The controlled output is compared with the high frequency saw

tooth signal to generate Pulse Width Modulation (PWM) pulse for the MOSFET of the Zeta converter. To limit the stator current a rate limiter is used during step change in speed.

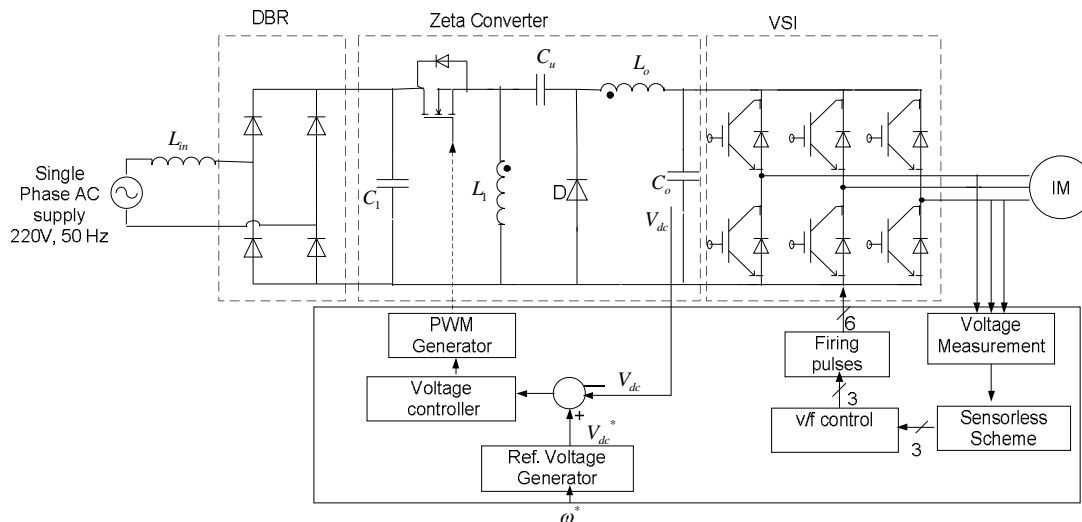


Fig.3. Block diagram of open loop control of induction motor

OPERATION OF ZETA CONVERTER

The ZETA converter topology provides a positive output voltage from an input voltage that varies above and below the output voltage. The ZETA converter also needs two inductors and a series capacitor, sometimes called a flying capacitor. Unlike the SEPIC converter, which is configured with a standard boost converter, the ZETA converter is configured from a buck controller that drives a high-side PMOS FET [6]. The ZETA converter is another option for regulating an unregulated input-power supply, like a low-cost wall wart. To minimize board space, a coupled inductor can be used.

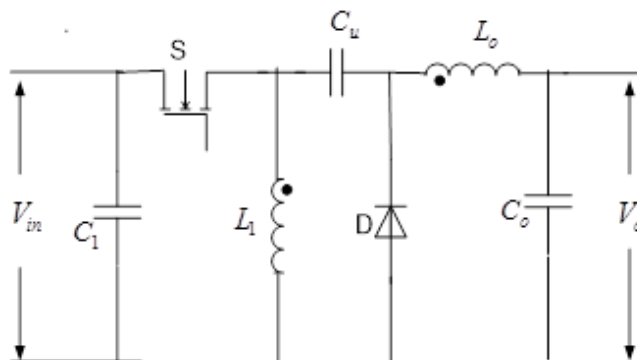


Fig.4. Circuit diagram of zeta converter

MODES OF OPERATION

Fig. 4 shows the circuit diagram of a ZETA converter. It consists of an input capacitor C_1 , an output capacitor, C_0 , coupled inductors L_1 and L_0 , an AC coupling capacitor, C_u , a power MOSFET, S , and a diode, D . Fig.5a shows the ZETA converter operating in CCM when S is on and fig. 5b shows the ZETA converter operating in CCM when switch is off. It is important to analyze the circuit at DC when both switches are off to understand the voltages at the various [7] circuit nodes. C_u is charged to the output voltage, V_o , during steady-state CCM since capacitor C_u is in parallel with C_0 . Figure 5.2 shows the waveforms of voltages across L_1 and L_1 during CCM operation. When S is off,

the voltage across L_1 is V_o since it is in parallel with C_o . The voltage across S when S is off is $V_{in} + V_o$, therefore the voltage across L_1 is V_o relative to the drain of S . When switch S is on, capacitor C_u , charged to V_o , is connected in series with L_1 , so the voltage across L_1 is $+V_{in}$, and diode D sees $V_{in} + V_o$.

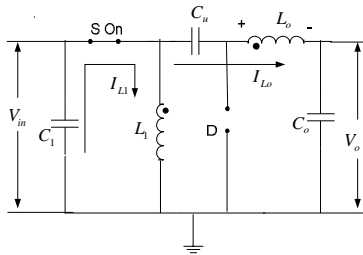


Fig.5a: When switch S is on

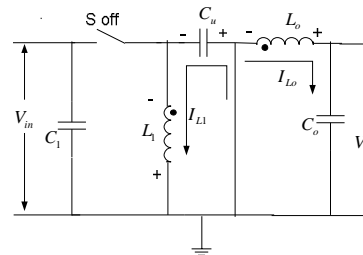


Fig.5b: When switch S is off

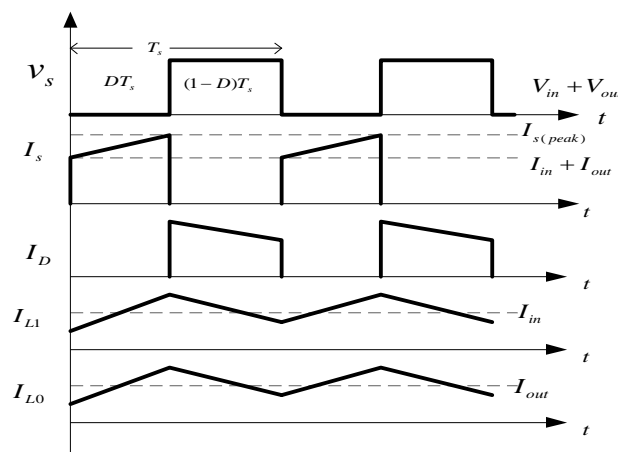


Fig.6: output waveform of zeta converter

IV. SIMULATION AND RESULTS

An isolated PFC Zeta converter is designed to operate in discontinuous conduction mode (DCM) such that the current flowing in magnetizing inductance of HFT (L_m) becomes discontinuous in a switching period. A PFC converter of 300W is designed for the selected PMSM. For a wide range of speed control, the DC link voltage is controlled from a low value of 50V to a rated voltage of 130V with supply voltage variation from 170V to 270 V. The input voltage, V_s applied to the PFC converter as,

$$V_s(t) = V_m \sin(\omega_L t) = 220\sqrt{2} \sin(314t) \text{ V} \quad (3)$$

Where, V_m is peak input voltage and $\omega_L = 2\pi f_L$; f_L is the line frequency i.e. 50 Hz.

The instantaneous output voltage of DBR is given as,

$$V_{in}(t) = |V_m \sin(2\pi f_L t)| = |220\sqrt{2} \sin(314t)| \text{ V} \quad (4)$$

The instantaneous value of duty ratio, $D(t)$ depends on the input voltage, $V_{in}(t)$ and required DC link voltage, V_{dc} . An instantaneous duty ratio, $D(t)$ is obtained as

$$D(t) = \frac{V_{dc}}{\frac{N_2}{N_1}V_{in}(t)+V_{dc}} = \frac{V_{dc}}{\frac{N_2}{N_1}|V_m \sin(\omega t)|+V_{dc}} \quad (5)$$

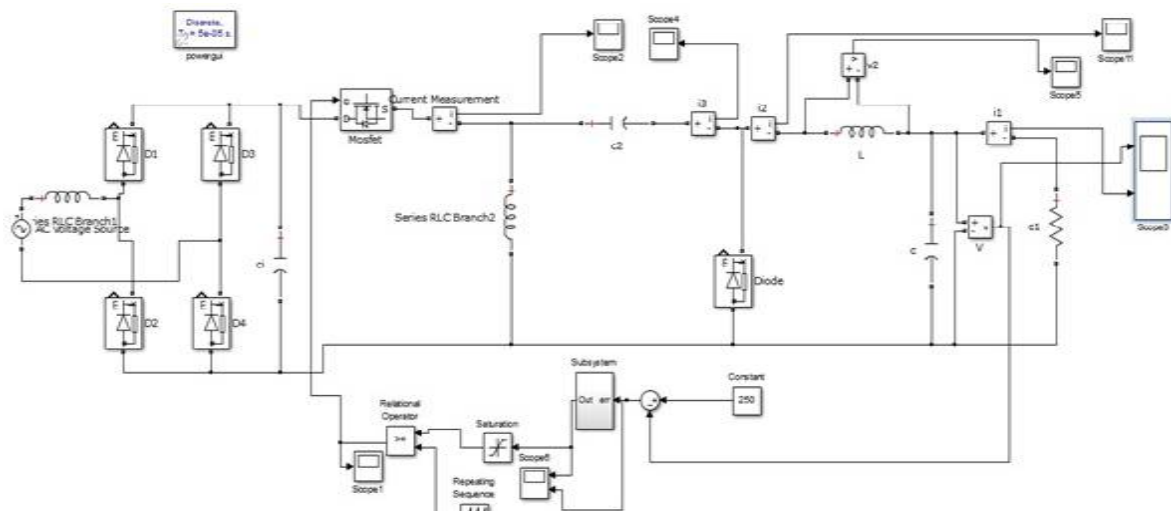


Fig.7. Simulink diagram of closed loop zeta converter

Design Parameters

Simulation is created using Simulink blocks with the following parameters:

$$D = V_{dc} / (V_{in} + V_{dc})$$

$$L_i = D \cdot V_{in} / \{f_s \cdot (\Delta i_{L_i})\}$$

$$L_{o(critical)} = (1-D) V_{dc} / \{f_s \cdot (2 \cdot I_{dc})\}$$

$$C_1 = D \cdot I_{dc} / \{f_s \cdot (\Delta V_{C1})\}$$

RMS Value of line-to-line supply voltage= 415V

No. of poles= 4

Stator Resistance= 0.075

Rotor Resistance= 0.1

Frequency= 50 Hz

Stator Reactance (at 50 Hz) = 0.45

Rotor Reactance (at 50 Hz) = 0.45

A converter of rating 250W is designed for operating at 50-200V at source voltage $V_s = 220V$ for switching frequency of 5 kHz. The ripple in input inductor (Δi_{L_i}) current is considered to be 5% and ripple in DC link voltage (ΔV_{dc}) as 5%. The design values thus obtained are $L_i = 5mH$, $L_o = 60 \mu H$, $C_1 = 330 nF$, $C_u = 1.1 \mu F$ and $C_0 = 2200 \mu F$

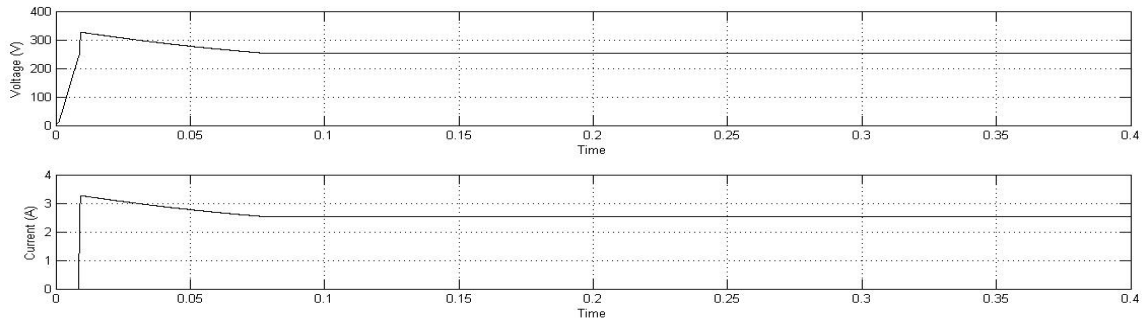


Fig.8. Simulation result of zeta converter

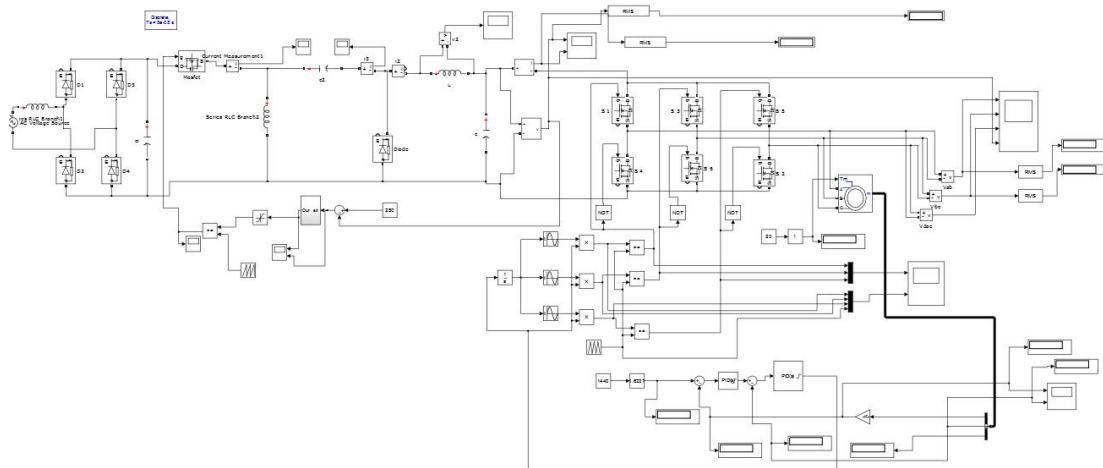


Fig.9. Simulink diagram of zeta converter fed induction motor

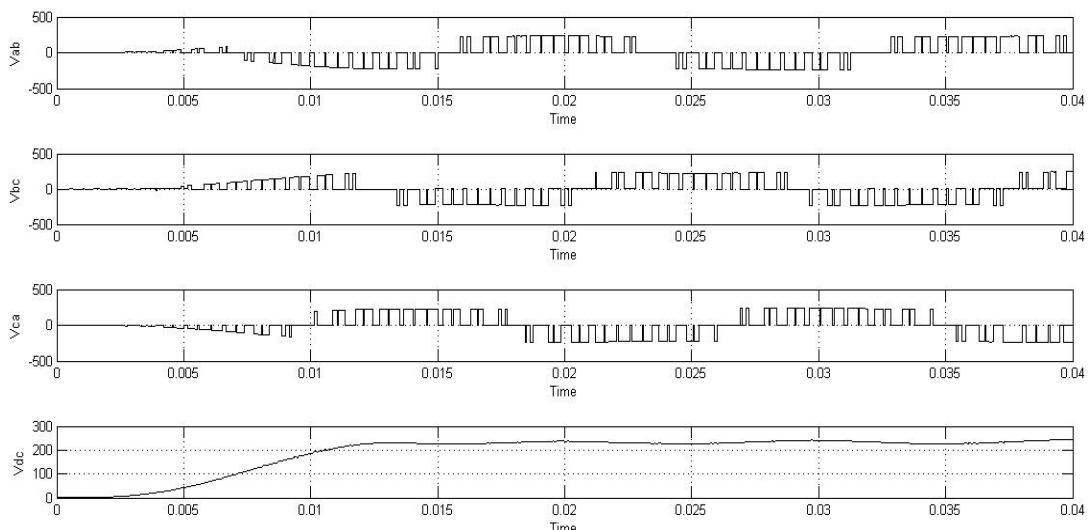


Fig.10. Simulation output of zeta converter fed induction motor

V. CONCLUSION

A simple control using a voltage follower approach has been used for voltage control of zeta converter fed induction motor drive. Speed control using voltz per hertz control is discussed and is verified by simulations. A sensor less operation minimizes the system complexity and reduces the cost of overall system. DC to DC operation of zeta converter improves the quality of power supplied to the motor. Zeta converter can perform both step up as well as step down operation depending on the time for which gate is triggered. Power factor of the overall system has improved. The voltage and current profile satisfy various voltage and current standards. The speed of induction motor is found to be regulated within the stipulated levels. Torque ripples are minimized by the closed loop operation of voltz per hertz control. The system is capable of providing good torque- slip characteristics of the motor.

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