Current Control Technique for Voltage-Source PWM Converter Applied for a Slip Energy Recovery Drive

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1. Introduction

Induction motor drives with full power control on the stator side are commonly used in industrial applications. Although either a cage-type or wound rotor induction machine can be used in the drive, the former is always preferred in terms of low weight, low cost, low rotor inertia, speed limitation, maintenance and reliability. One feature of the latter is that the slip power becomes easily available from the slip rings, which can be either mechanically or electronically controlled for motor speed adjustment [1]. However, for limited range speed control applications, where the slip power is only a fraction of the total power rating of machine, power rating of the converter is reduced, hence reduction in cost. The wound rotor induction motor takes this advantage. Slip power for adjusting the motor speed can be recovered through static converters instead of useless dissipation on resistors. Slip power recovery drives have been used in some applications such as large-capacity pumps and fan drives, variable-speed wind energy systems, shipboard variable-speed/constant-frequency systems, variable-speed hydro pumps/generators and utility system flywheel energy storage systems. The slip energy recovery drives (SERD) known as Scherbius system [2-3], offer low cost, simple control circuitry and high efficiency even at a low speed range. The SERD consists of a wound-rotor induction machine, a diode-bridge rectifier, a large link inductance, a thyristor-bridge inverter and an optional 3 phase transformer. A SERD transfers power that is normally wasted in the rotor of an induction machine back to the ac mains supply to improve overall drive efficiency. In addition, by inserting a step-down transformer between the ac supply and the inverter module, the voltage ratings of the inverter and rectifier devices may be made significantly smaller than the rated machine stator voltages. Thus, in contrast with a stator-voltage-controlled induction machine drive, the relative power electronic units of the SERD may be designed to be smaller, lighter and less expensive. The choice of the turns-ratio of the optional transformer is based on a compromise between achieving the desired speed control range and optimizing the drive power factor [1]. For smaller values of inverter firing angle, the rotor speed is higher. Then inverter draws substantial reactive power and the inverter returns less real power to the mains. Thus the drive power factor is reduced. The drive power factor is found to be optimized for applications requiring a narrow range of speed control and a large load torque, where significant real power is returned via the inverter. A problem of SERD is having lower power factor in general 0.4 to 0.6 more or less.

Drawbacks of SERD such as, 1) low power factor, 2) high current harmonic, and 3) a poor capability of the reactive power on the ac side, can be avoided by using a pulse width modulation (PWM) voltage source inverter. The drive system can control the active and reactive power on the ac line by a current-controlled technique in conjunction with the first and second a boost chopper for DC link voltage. The voltage source inverter is used to increase power factor of the system and to reduce low order harmonics of the input line current.

This paper presents a simple configuration that can completely solve the first and second problems and partially solve the fourth problem. Although there are a number of articles which analyze the SERD with dc voltage intermediate circuit. The system proposed in this paper differs from previously discussed approaches in the following ways. 1) There is a boost chopper on the intermediate circuit providing control of the machine. 2) A decoupled control system is achieved. Effectively, the machine speed is controlled by the boost chopper and the inverter controls the reactive power on the ac side. 3) The current harmonics on the mains are reduced by a VSI based on PWM [11].

The aim of this paper is two-fold. The first is that the harmonics of line current waveforms are reduced by using the VSI. The second aim is to improve the power factor of the drive by the IGBT type boost chopper applied across the DC terminal. The boost DC voltage is connected to the voltage source inverter and the reactor circuit. This scheme leads to be able to adjust the speed of the motor by varying the duty cycle of the boost chopper operating in a PWM mode.

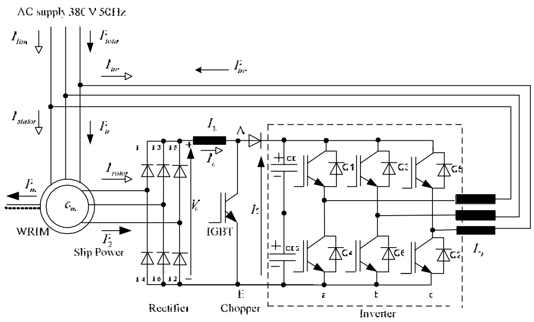

Fig. 1. Schematic of the proposed slip energy recovery drive with current control voltage source inverter.

2. Current Control Techniques for Voltage-Source PWM Converter

The proposed system configuration is illustrated in Fig. 2. It's consists of an IGBT boost chopper, a diode D, a dc link capacitors and a PWM type VSI. The voltage, E is controlled at a constant value by the IGBT boost chopper. Consequently variation of torque and speed is achieved by operation of the boost chopper.[4]

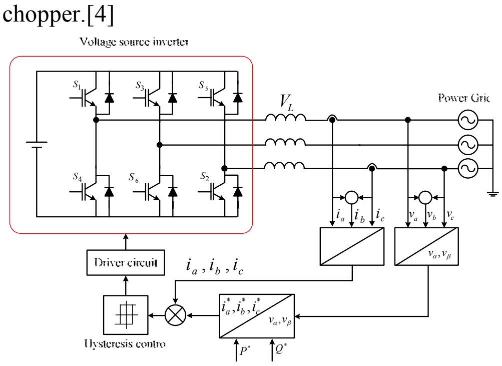

Fig. 2. Current Control Techniques for PWM Converter.

Using the diode bridge connecting the rotor of the machine to the electronic circuit allows a simplified control system. The active and reactive power can be controlled by controlling the voltage and phase angle between the voltage source inverter side and ac line side connected with the reactor circuits. An inductance L_d can be added on the dc side to decrease the switching frequency or the dc current ripple[2].

From fig. 2 the grid voltage can be written to equation 1

$$v_{grid} = v_{conv} + v_L \tag{1}$$

The active and reactive power flow between grid side and converter side can be written to equation 2 and 3 [4-8]

$$P = \frac{V_{grid}^2}{\omega L}\left(\frac{V_{conv}}{V_{grid}}\sin\delta\right) \tag{2}$$

$$Q = \frac{V_{grid}^2}{\omega L}\left(1 - \frac{V_{conv}}{V_{grid}}\cos\delta\right) \tag{3}$$

Where apparent power is

$$S = vi^* = P + jQ \tag{4}$$

The instantaneous real and imaginary power are part to the instantaneous complex power defined equation 5

$$S = \left(v_\alpha i_\alpha + v_\beta i_\beta\right) + j\left(v_\beta i_\alpha + v_\alpha i_\beta\right) \tag{5}$$

From the transformation matrixes, the Clark transformation and its inverse transformation become

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \tag{6}$$

The instantaneous power of the $p-q$ theory

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{7}$$

In the following explanation, the $\alpha\beta$ currents will be set as functions of voltage and the real and imaginary power P and Q. This is very suitable for better explaining the physical meaning of the powers defined in the $p-q$ theory, it is possible to write

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2}\begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix}\begin{bmatrix} P \\ Q \end{bmatrix} \tag{8}$$

The inverse Clark transformation can be decomposed into the sum of two terms, as follows

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \frac{2}{3}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{9}$$

3. Simulation Result

Current control technique for voltage-source PWM converter applied for a slip energy recovery drive was simulated in the Matlab/Simulink software. The wound rotor induction motor is rated at 1 kW, 4 pole with a 380 V, 50Hz as shown in figure 3.

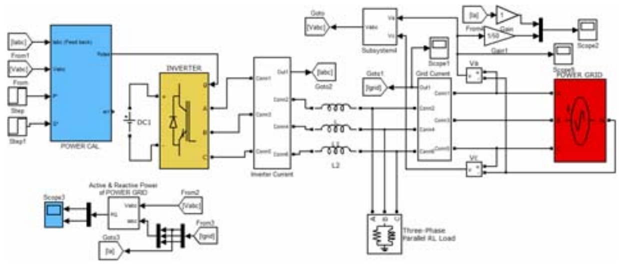

Fig. 3. Simulation of current control technique for voltage-source PWM converter.

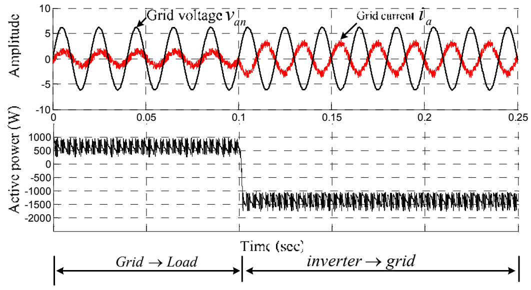

Fig. 4. Voltage and current waveforms, with the grid side converter.

4. Conclusion

This paper has proposed a control strategy of current control technique for voltage-source PWM converter applied for a slip energy recovery drive. The objective of grid side converter control is to maintain the dc-link voltage and independent active and reactive power flow. The performance simulations show that this strategy is able to a good dynamic responses and high accuracy to the active and reactive power control.

Acknowledgements

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