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Two-Phase Three-Leg Voltage Source Converter Fed Asymmetrical Parameter Type Two-Phase Induction Machine Operating in Motoring and Generating Modes

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***Abstract*—This paper presents performance evaluation of an asymmetrical parameter type two-phase induction machine drive using two-phase three-leg voltage source converter (VSC) operating in motoring and generating modes. A system is simulated using MATLAB/SIMULINK. The proposed converter system includes a machine side converter using a three-leg VSC and a front end converter using a single-phase full bridge switched mode converter. The overall converter system is able to operate in a bidirectional power flow mode. For the front end converter, hysteresis band current control is utilized to maintain the DC link voltage constant. The machine side converter provides both unbalanced and balanced two-phase output voltages for the machine based on a sinusoidal pulse-width modulation (SPWM) technique. The comparative performance evaluation of the whole system between balanced and unbalanced two-phase motor voltages is given.**

***Index* Bidirectional power flow, Asymmetrical parameter Type Two-Phase Induction machine , Three-Leg Voltage Source I converter**

I. Introduction

A single-phase induction machine is always used as a motor rather than a generator due to ease of use and better performance. However, the single-phase induction generator is attractive to researchers for small scale renewable energy applications [1]. Single-phase induction motors (SPIMs) are most widely used in home appliances and industrial such as air conditioners, washing machines, motors, pumps, blenders, fruit and so on. Some applications do not require variable speed. As a consequence single-phase mains supply is likely to be used to provide nominal motor voltage. For variable speed applications, power electronic equipment such as a voltage controller using thyristor phase control and an inverter is preferable for an energy saving concern. The inverter offering variable voltage and variable frequency (VVVF) is considered as a first choice in terms of various advantages like high starting torque, a wide range of speed adjustment.

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Control of single-phase-to-three-phase ac/dc/ac PWM converter with various topologies for three-phase induction motor is used in residential appliances, farming, and low-power industrial applications where only a single-phase utility is available[2],[3]. Three-leg VSI fed unbalanced parameter type two-phase induction motor modified from the existing SPIM can be found in [4]. Although the performance evaluation of a three-leg VSI fed two-phase induction motor drive was conducted, the machine acting as a generator and bidirectional power flow for the front end converter has not been reported yet. Generally a front end converter with bidirectional power flow is needed for high performance drives to allow regenerative energy to feedback to the mains supply. The switched mode converter is commonly used to obtain nearly sinusoidal current and nearly power factor for both rectifying mode for supplying energy from the mains supply to the motor and inverting mode for receiving energy from the machine back to the mains supply called as regenerative braking. Therefore, in this paper, the converter system as mentioned earlier will be controlled in the motoring mode with V/Hz control for start-up, no load and on load conditions and in the generating mode by applying mechanical power in opposite direction with the motoring mode. Therefore the machine can act as either a motor or a generator depending on the direction of the mechanical power (i.e. input or output). More importantly, the performance comparison between balance and unbalanced machine voltages is given which the work [4] has not been conducted in the generating mode. The proposed system is shown in Fig.1. It consists of an IGBT full-bridge switched mode converter and a IGBT two-phase three-leg converter. The DC-Link voltage is controlled to keep constant. The block diagram for a closed loop control system of the DC link voltage based on proportional and integral, PI control is also illustrated in Fig. 1. A fixed band hysteresis current controller is used. The switched mode converter can operate either rectification mode or inversion mode depending on either power absorb or delivery of the machine. With the proposed control, nearly sinusoidal current waveform and nearly unity power factor is achieved. The IGBT two-phase three-leg converter is able to provide either balanced or unbalanced output voltages for both main and auxiliary windings. A SPWM technique with classical V/F control is used.

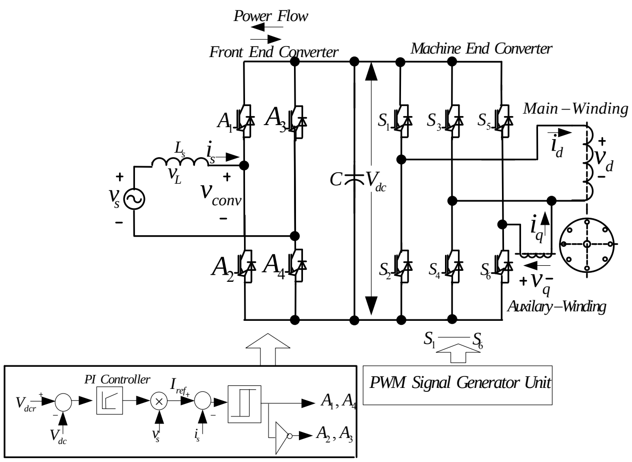

Figure 1 Overall system

II Dynamic Model of Asymmetrical Parameter type Two- Phase Induction Machine

A mathematical model of unbalanced two-phase machines in the stationary frame neglecting core saturation and iron losses can be expressed as the following equations [4]

$$v_{sd}^s = R_{sd} i_{sd}^s + \frac{d\lambda_{sd}^s}{dt} \tag{1}$$

$$v_{sq}^s = R_{sq} i_{sq}^s + \frac{d\lambda_{sq}^s}{dt} \tag{2}$$

$$0 = R_r i_{sd}^s + \frac{d\lambda_{rd}^s}{dt} + \omega_r \lambda_{rq}^s \tag{3}$$

$$0 = R_r i_{sq}^s + \frac{d\lambda_{rq}^s}{dt} - \omega_r \lambda_{rd}^s \tag{4}$$

$$\lambda_{sd}^s = L_{sd} i_{sd}^s + M_{srd} i_{rd}^s \tag{5}$$

$$\lambda_{sq}^s = L_{sq} i_{sq}^s + M_{srq} i_{rq}^s \tag{6}$$

$$\lambda_{rd}^s = L_r i_{rd}^s + M_{srd} i_{sd}^s \tag{7}$$

$$\lambda_{rq}^s = L_r i_{rq}^s + M_{srq} i_{sq}^s \tag{8}$$

Where $v_{sd}^s, v_{sq}^s, i_{sd}^s, i_{sq}^s, i_{rd}^s, i_{rq}^s, \lambda_{sd}^s, \lambda_{sq}^s, \lambda_{rd}^s$ and λ_{rq}^s are d-q axis voltages, current and fluxes of stator and rotor in the stator reference frame. R_{sd}, R_{sq} and R_r are the stator and rotor resistances. $L_{sd}, L_{sq}, L_r, M_{srd}$ and M_{srq} are the stator and the rotor self and mutual inductances. ω_r is the rotor speed in rad/s.

The instantaneous electromagnetic torque produced by the machine is then given by

$$T_e = P(i_{sq}^s i_{rd}^s M_{srq} - i_{sd}^s i_{rq}^s M_{srd}) \tag{9}$$

The electromechanical equation of the machine is presented as

$$P(T_e - T_L) = J\frac{d\omega_r}{dt} + B\omega_r \tag{10}$$

Where P, J and B are the machine pole pairs, inertia and viscous friction coefficient, respectively.

Due to an asymmetrical feature, mutual inductance M_{srd} is not equation to M_{srq} As a result, the electromagnetic torque ripple seriously occurs. In order to eliminate the ripple of the electromagnetic torque, an appropriate control of the stator currents is required.

The mathematical expression of the electromagnetic torque can be rearranged in the terms of machine parameters and rotor fluxes through (1)-(8) as

$$\begin{aligned} T_e &= P[i_{sq}^s \left(\frac{\lambda_{rd}^s - M_{srd} i_{sd}^s}{L_r}\right) M_{msq} \\ &\quad - i_{sd}^s \left(\frac{\lambda_{rq}^s - M_{srq} i_{sq}^s}{L_r}\right) M_{msq} \\ &= \frac{P}{L_r}(i_{sq}^s \lambda_{rd}^s M_{srq} - i_{sd}^s \lambda_{rq}^s M_{srd}) \end{aligned} \tag{11}$$

Where $i_{rd}^s = \dfrac{\lambda_{rd}^s - M_{srd} i_{sd}^s}{L_r}$ and $i_{rq}^s = \dfrac{\lambda_{rq}^s - M_{srq} i_{sq}^s}{L_r}$

$$Te == \frac{P}{L_r}(i_{sq}^s \lambda_{rd}^s M_{srq} - i_{sd}^s \lambda_{rq}^s M_{srd}) \tag{12}$$

Then, the improved stator currents can be given as

$$i_{sd}^{s'} = i_{sd}^s \tag{13}$$

$$i_{sq}^{s'} = \alpha i_{sq}^s \tag{14}$$

Where α is the turns ratio between the auxiliary winding to the main winding. This expression of (14) is equivalent to that of the symmetrical machine in which the oscillating term disappears in the steady state resulting in a circularly rotating flux vector. It means that the magnitude of $i_{sd}^{s'}$ is equal to that of $i_{sq}^{s'}$. According to (13) and (14), the relationship between current magnitudes of both windings for an asymmetrical parameter type is

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$$I_d = \alpha I_q \tag{15}$$

I_q must lead I_d by $90°$. Then, based on the view of power balance, the relation of supplied voltage for both windings is approximately as

$$V_q = \alpha V_d \tag{16}$$

This relation is used for unbalanced voltage case. Note that for balanced voltage case, V_d is equal to V_q

III. Simulation Results

The simulation of the proposed system was conducted by MATLAB/SIMULINK. Figs. 2 and 3 show dynamic response of the rotor speed for the balanced voltages and unbalanced voltages for both windings of the machine, respectively. There are three stages of machine operation, namely, start-up without load, on load with rated torque of 9 N.m at 0.6 seconds and generator mode with 9 Nm external negative at 1 seconds. As can be seen that the rotor speed decreases to 1450 rpm rated speed during on load. At 1.0 sec. the external mechanical load of 9 Nm is applied to the machine. Then the machine acts as a generator resulting in an increase in the rotor speed. The rotor speed reaches 1550 rpm which is higher than the synchronous speed of 1500 rpm. Obviously, as shown in Fig.2 for balanced voltages, the speed ripple occurs for all operation stages. In contrast to Fig.2, the less speed ripple is achieved for all stages of operation as shown in Fig.3 for unbalanced voltages. These results confirm that the applied unbalanced voltages of the asymmetrical type two-phase induction motor offers better performance in terms of speed ripple. Note that the assumption is that friction and windage losses are excluded.

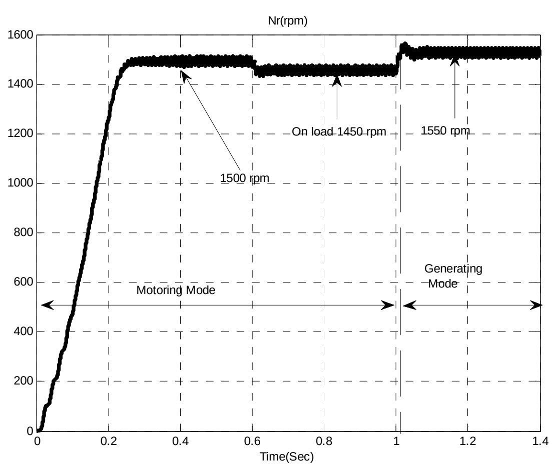

Figure 2 Dynamic response of the rotor speed for balanced voltages for both windings of the machine..

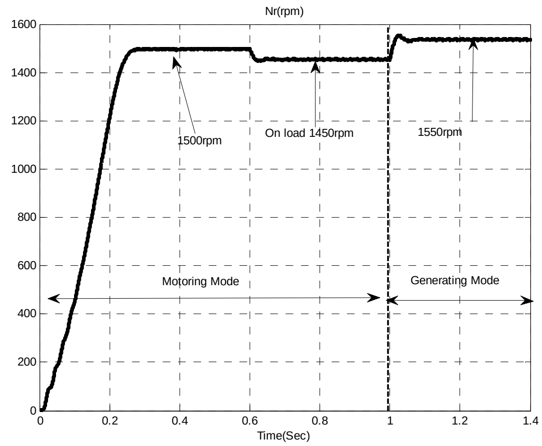

Figure 3 Dynamic response of the rotor speed for unbalanced voltages for both windings of the machine.

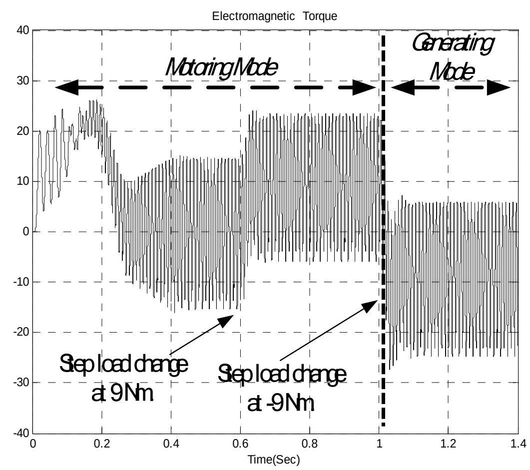

Figure 4 Electromagnetic torque for balanced voltages for both windings of the machine.

According to Figs. 4 and 5, the electromagnetic torque for the unbalanced voltages provides dramatically lower torque pulsation resulting in significantly lower speed ripple (see Figs. 3 and 4). According to Figs. 5 and 6, when comparing performance of the front end converter with the same parameter control like dc link voltage vale and PI controller for both balanced and unbalanced voltages for the machines during motoring and generating modes. When the machine operates in the motoring mode, the front end converter operates in a rectifying mode. The input current waveform is nearly sinusoidal and almost in-phase with the input voltage waveform particularly for fig.7. When the machine. When the machine operates in the generating mode or acts as a generator, the front end converter operates in the inversion mode which allows power from the machine return to the 1-phase mains supply. As a consequence, the dc link voltage is kept constant at about 700 V. The current waveforms are out of phase with the voltage waveform for both Figs. 6 and 7. Quite clearly, the input current waveform for unbalanced motor voltages is more nearly sinusoidal

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waveform than that for balanced motor voltages. These results confirm that the overall system performances provided by the unbalanced motor voltages are better than those provided by the balanced motor voltages.

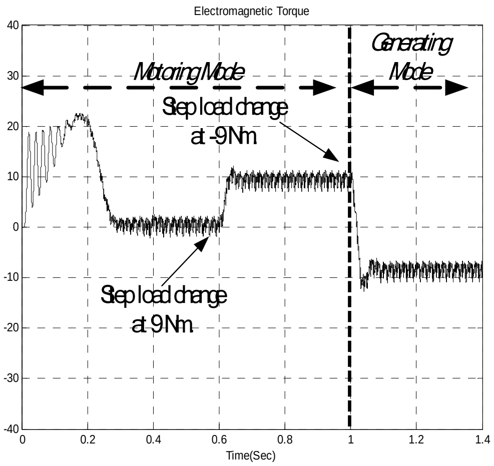

Figure 5 Electromagnetic torque for unbalanced voltages for both windings of the machine.

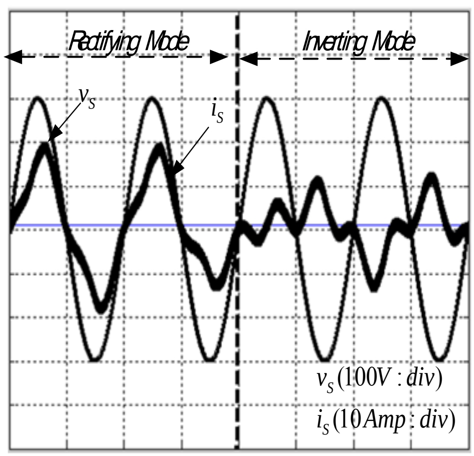

Figure 6 Corresponding input voltage and current of the switched mode converter for balanced voltages for both windings of the machine

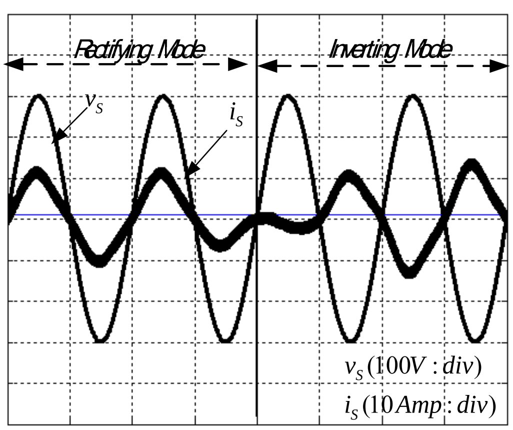

Figure 7 Corresponding input voltage and current of the switched mode converter for unbalanced voltages for both windings of the machine.

IV. Conclusions

This paper has presented the performance evaluation of the system of an asymmetrical parameter type two-phase induction motor drive operating in motoring and generating modes supplied by the balanced and unbalanced motor voltages using three-leg VSI.. The simulation results show the better performances in terms of speed, electromagnetic torque, the front end converter capability provided by the unbalanced motor voltages over by the balanced motor voltages. The front end converter is controlled to operate in rectification and inversion modes for the machine operating in motoring and generating modes, respectively.

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Appendex A.

Table 1. Asymmetrical two-phase induction motor parameters

Main Widing	Auxilary Widing
$R_{sd}=1.59\Omega$; $L_{sd}=5.96$mH	$R_{sq}=5.10\Omega$, $L_{sq}=15.91$mH
Rotor $R_r=1.59\Omega$, $L_r=5.96$mH	$J=0.025\text{kg.m}^2$, $P=2$ $a=1.566$

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