Asymmetrical Parameter Type Two-Phase Induction Machine Drive System Operating in Motoring and Generating Modes

Surachat Leeragreephol, Papol Sardyoung, Chaiwut Choorak and Vijit Kinnares

***Abstract*—This paper presents an asymmetrical parameter type two-phase induction machine drive system operating in motoring and generating modes. A system is simulated using MATLAB/SIMULINK. The proposed converter system includes a machine side converter using a two-leg half-bridge voltage source converter (VSC) and a front end converter using a half-bridge switched mode converter capable of bidirectional power flow, nearly unity input power factor and a dc bus voltage increase. For the front end converter, hysteresis current control is utilized to maintain the DC link voltage constant. The simulation results show that the system allows the machine operates in either motoring or generation modes with satisfactory performance.**

***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 industry such as air conditioners, washing machines, motors, pumps, blenders, fruit and so on [2-6]. 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 phase control and an variable frequency 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 such as high starting torque, a wide range of speed adjustment. Asymmetrical parameter type two-phase induction motor can be achieved by removing starting and running capacitors from a conventional single-phase induction motor in order to applicable to variable frequency drives.

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Unbalanced voltages for both windings have been proved for better performance over balanced voltages by several publications [2-6]. Power electronic topologies for two-phase induction motors can be found in [4]. 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. Similar to [6] for high performance vector control drive, the main power circuit configuration treated in this paper is shown in Fig.1 which is suitable for a three-phase bridge module like intelligent power module (IPM) available in commercial. It consists of an IGBT half-bridge switched mode converter and an IGBT two-leg half-bridge VSC. The DC-Link voltage between those converters is controlled to be constant. The block diagram for the 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 control method is used. The switched mode converter can operate either rectification mode or inversion mode depending on the DC link voltage value affected by the machine energy (i.e. consumption or delivery). With the proposed control, nearly sinusoidal current waveform and nearly unity power factor is achieved. The IGBT two-leg two-phase converter is able to provide unbalanced output voltages for both main and auxiliary windings. A SPWM technique with classical V/F control is used. 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).

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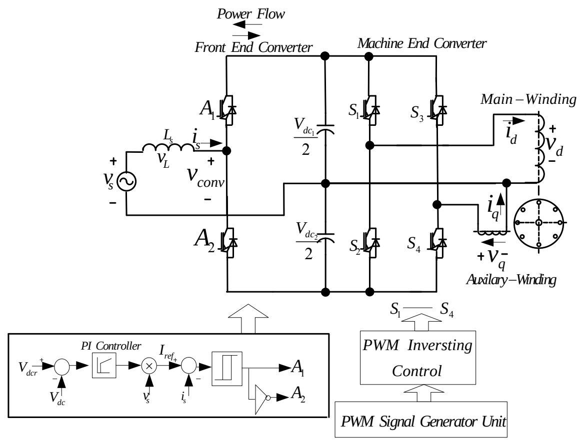

Figure 1 Overall system

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 described as the following equations [2]

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

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

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

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

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

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

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

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

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

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

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

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

Then, the improved stator currents can be given as

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

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

This expression 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 relation between current magnitudes of both windings for an asymmetrical parameter type is

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

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

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

III. SIMULATION RESULTS

The simulation was conducted using MATLAB/SIMULINK. The parameters of the machine for the simulation are given in Appendix A. Figs. 2 and 3 show dynamic response of the rotor speed and the electromagnetic torque, respectively. Within 0.2 s, the machine operates as a motor during start-up without load. The rotor speed climes up and reaches 1500 rpm which is the synchronous speed. Note that the assumption is that friction and windages losses are excluded Speed ripple occurs. At 0.6 s, the machine is loaded with full load torque of 9 Nm. As can be seen, the rotor speed decreases from 1500 rpm to 1450 rpm. Then at 1 s. the external mechanical load is applied in the opposite direction of the motoring mode. The rotor speed rapidly increases from 1450 rpm to 1550 rpm above the synchronous speed. In this interval, the machine change the operation from the motor to the generator Apparently, the substantial torque pulsation occurs for the instantaneous torque resulting in the speed ripple due to the topology of the converter. The better performance can be improved if a three-leg two-phase induction motor drive [2]. However, the cost increases due to the number of the switching devices. The average steady state torque is equal to load torque. . Obviously the dc link voltage level is kept constant at 650 V during motoring (i.e. start-up and on load) and generation modes of operation of the machine. During start-up the dc link voltage has overshoot above the required value of 660 V. It takes few seconds for reaching steady state. the dc For a step load change of the motor operation, the dc link voltage decreases rapidly about 3 V. Then, it climbs rapidly up to 650 V of command voltage. It takes shorter time than the start-up for approaching the steady state. During a change in operation from motoring to generating modes. The dc link voltage increases rapidly about 5 V above the command voltage. Then, it returns rapidly back to 650 V. This performance shows that the closed loop control is effective.

Fig. 5 shows the average dc link current. Clearly, at t=1.02 s the current value is changed from positive into negative. This confirms that the power is positive and negative values for the operation of the motor and the generator, respectively. With the effective control, it is very fast in the transition. Voltage and current waveforms are shown in Fig. 6.

The current is in-phase with the mains supply voltage for the motoring mode. The switched mode converter operates in the rectification mode. This means that the electrical power is transferred to the motor and the supply power factor is nearly unity. When the machine operates in the generating mode, the current is out of phase with the supply voltage. This means that the switched mode converter operates in the inverting mode, the mechanical power is converted into electrical power and it is transferred to the mains supply. The supply power factor is also nearly unity. The input current waveform of the mains supply for the machine operating in the generating mode is worse than the motoring mode.

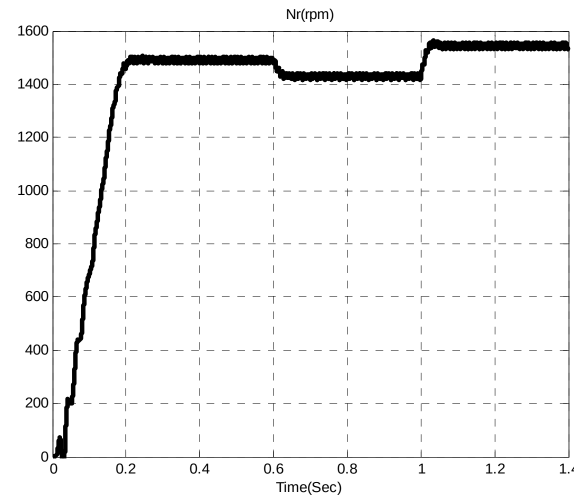

Figure 2 Dynamic response of the rotor speed.

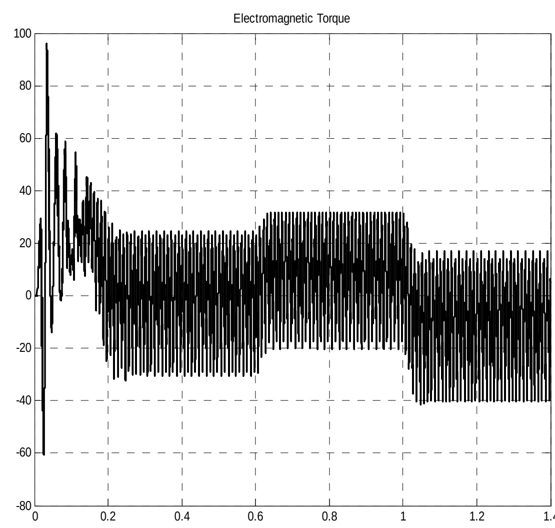

Figure 3 Dynamic response of electromagnetic torque.

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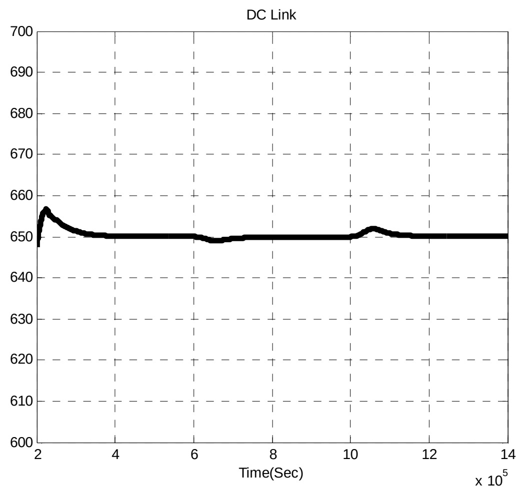

Figure 4 DC link voltage during motoring mode: start-up, step load change and generating mode.

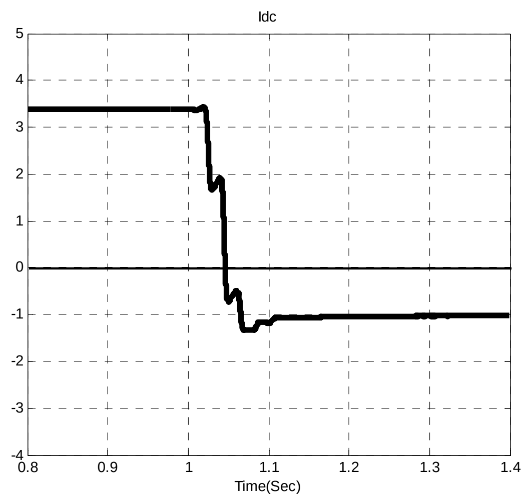

Figure 5 Average DC link current during motoring and generating modes.

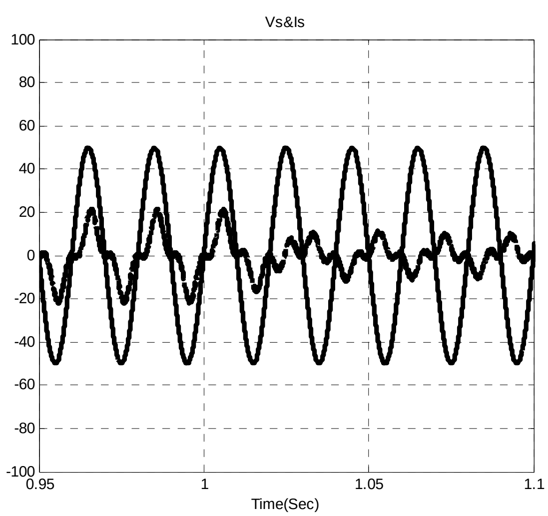

Figure 6 Input voltage and current waveforms of the mains supply during motoring and generating modes of operation of the machine..

IV. Conclusion

This paper has presented the performance evaluation of an asymmetrical parameter type two-phase induction motor drive system operating in motoring and generating modes. The topology of the main power circuit for the machine end and front end converters is suitable for a commercial power module. The system provides satisfactory performance in terms of dc link voltage, current waveform, power factor and so on for a step change of operating conditions particularly either motoring mode or generating mode.

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Appendix A.

Table 1. Asymmetrical two-phase induction motor parameters

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

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