GENERAL REFERENCE FRAME MODELLING OF THE DOUBLY FED TWIN STATOR INDUCTION MACHINE USING SPACE VECTORS

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Abstract

This paper discusses the modelling of the doubly fed twin stator induction machine in the general reference frame using space vectors based on the cascade connection of two wound rotor induction machines that have, in general, unequal pole numbers. The effects of the different interconnection of the two rotor windings are discussed, as is the mechanical alignment of the rotor shafts. Examples of stator currents in different reference frame are given.

NOMENCLATURE

A. Main Variables

a	Spatial operator $e^{j2\pi/3}$
f	Frequency (Hz)
g	General space vector
i	Instantaneous current (A)
j	Imaginary operator
L	Inductance (H)
N	Mechanical speed (rpm)
p	Differentiation with respect to time
P	Number of pole pairs
$\Re$	Real part of complex quantity
R	Resistance (Ω)
τ	Instantaneous torque (Nm)
v	Instantaneous voltage (V)
θ	Angular position (rad)
ω	Angular velocity (rad/s)
Z	Impedance (Ω)
Ψ	Flux linkage (Wb)

B. Subscript and Superscript Variables

c	Control machine
e	Electrical
g	General
l	Leakage
m	Mechanical
M	Mutual
n	Natural
p	Power machine
r	Rotor
s	Stator
*	Complex conjugate

Bold lower case variable denotes instantaneous space phasor. Power winding refers to the stator winding of the power machine and control winding refers to the stator winding of the control machine.

1. INTRODUCTION

Many applications require a variable speed drive to operate efficiently, often over a narrow speed range. An early method of speed control was the so-called cascade connection of two machines sharing a common shaft and load, variation of speed being made by resistors connected to the stator of the second machine. This cascade doubly fed machine is called the doubly fed twin stator induction machine (DFTSIM). The DFTSIM is being investigated as a variable speed drive [1,2]. One of the benefits of the DFTSIM is it exhibits synchronous behaviour at a pre determined, user settable, variable speed using a variable frequency converter of fractional rating. The DFTSIM being studied consists of two wound rotor induction machines, shown schematically in Fig.1. The rotors of the machines are mechanically coupled and the rotor windings are connected so as to produce contra rotating magnetic fields in the separate machine sections.

Because the two rotors are physically coupled, as depicted in Fig. 1, permanent connections may be made, rendering the brushes redundant except for providing a convenient means of measuring the rotor quantities. Under these conditions the DFTSIM is brushless. A number of studies have been conducted on the performance modelling of the brushless doubly fed machine (BDFM) [3-5], which is functionally equivalent to the DFTSIM.

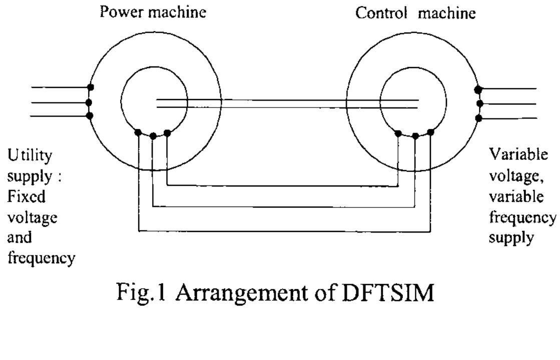


Fig.1 Arrangement of DFTSIM

When the DFTSIM operates in the synchronous mode, there is a single frequency of current in the rotor, and the rotor speed is a simple function of the stator supply frequencies and numbers of pole pairs, as follows:

$$N_m = 60\left(f_p + f_c\right)/\left(P_p + P_c\right) \tag{1}$$

The so called natural or synchronous speed, N_n, occurs with dc applied to the control winding.

This paper investigates the interconnection of the two induction machines that form the DFTSIM and presents a model of it in the general reference frame.

2. DYNAMIC MODELLING

2.1 General Assumptions

In the analysis, the following assumptions were made:

(a) Balanced three phase windings are distributed to produce sinusoidal space variation of flux density;
(b) Only the fundamental components of voltage and current are considered;
(c) The magnetic circuits are linear, i.e. the effects of saturation and hysteresis are neglected;
(d) Zero sequence quantities are not present;
(e) The only losses are copper losses;

2.2 Dynamic Voltage Equations

There are many possible methods for calculating the transient performance of electrical machines, including matrix calculation. The space vector method is a simple but mathematically precise method that allows the physical phenomena of the machine to be seen. The space vector concept is a mathematical abstraction that is useful in the study of electrical machines. The voltage and flux linkage space vectors are related to the flux density, **B**, which is a vector quantity. The current space vector is related to the m.m.f. which in turn is related to another vector quantity, the magnetic field intensity, **H**.

The two-axis theory of the three phase induction motor is well developed and is used as the starting point for the development of the dynamic equations of the DFTSIM. The dynamic voltage equation of the power machine, in the general reference frame, is written as [6]:

$$\begin{bmatrix} \mathbf{v}_s^g \\ \mathbf{v}_r^g \end{bmatrix} = \begin{bmatrix} R_s + \left(p + j\omega_g\right)L_s & \left(p + j\omega_g\right)L_M \\ \left(p + j\left(\omega_g - \omega_r\right)\right)L_M & R_r + \left(p + j\left(\omega_g - \omega_r\right)\right)L_r \end{bmatrix} \begin{bmatrix} \mathbf{i}_s^g \\ \mathbf{i}_r^g \end{bmatrix} \tag{2}$$

where

$$\mathbf{v}_s^g = \mathbf{v}_s e^{-j\theta_g},\ \mathbf{v}_r^g = \mathbf{v}_r e^{-j\left(\theta_g - \theta_r\right)},$$
$$\mathbf{i}_s^g = \mathbf{i}_s e^{-j\theta_g},\ \mathbf{i}_r^g = \mathbf{i}_r e^{-j\left(\theta_g - \theta_r\right)},$$

$$\mathbf{v}_s = 2/3\left(v_{sa}(t) + \mathbf{a}v_{sb}(t) + \mathbf{a}^2 v_{sc}(t)\right),$$
$$\mathbf{v}_r = 2/3\left(v_{ra}(t) + \mathbf{a}v_{rb}(t) + \mathbf{a}^2 v_{rc}(t)\right),$$
$$\mathbf{i}_s = 2/3\left(i_{sa}(t) + \mathbf{a}i_{sb}(t) + \mathbf{a}^2 i_{sc}(t)\right),$$
$$\mathbf{i}_r = 2/3\left(i_{ra}(t) + \mathbf{a}i_{rb}(t) + \mathbf{a}^2 i_{rc}(t)\right),\ \theta_r = P_p\theta_m$$

The instantaneous electromagnetic torque is

$$\tau_e = 3/2\, P_p \boldsymbol{\Psi}_s^g \times \mathbf{i}_s^g = 3/2\, P_p L_M \mathbf{i}_r^g \times \mathbf{i}_s^g \tag{3}$$

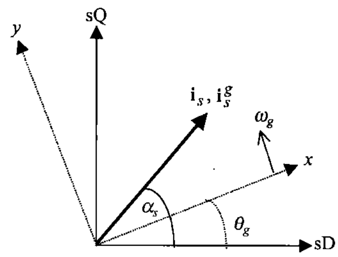
where

$$\boldsymbol{\Psi}_s^g = L_s \mathbf{i}_s^g + L_r \mathbf{i}_r^g$$

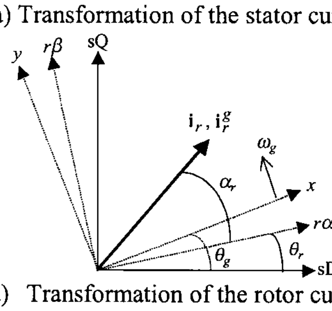
The space vectors $\mathbf{v}_s$ and $\mathbf{i}_s$ are respectively the stator voltage and stator current in the stator reference frame. The space vectors $\mathbf{v}_r$ and $\mathbf{i}_r$ are respectively the rotor voltage and current in the rotor reference frame. To analyze the machine it is necessary to have a common reference frame for the stator and rotor quantities. This is the only way to overcome the mathematical and physical difficulties of discussing their interactions and of finding simple solutions for the relevant differential equations. The transformation of the stator and rotor current space vectors from their natural reference frames to the general reference frame is depicted in Fig. 2.

2.3 Rotor Electrical Interconnections

The DFTSIM comprises, and is modelled as, two induction machines connected in cascade. The principle of operation of the DFTSIM requires that there be contra rotating magnetic fields in the two rotor windings. This section describes the ways in which the rotors may be connected to produce contra rotating fields. There are six ways in which the two rotor windings can be interconnected.



(a) Transformation of the stator current



(a) Transformation of the rotor current

Fig.2 Application of the general reference frame

In the first instance let the DFTSIM comprise component machines in which both have rotor windings of the same sense, as shown in Fig. 3(a) or (b). The shafts are mechanically coupled so that both *a* phase windings are aligned. The machines are coupled facing the same direction. Under these conditions the control machine rotor current and voltage space vectors are as shown in Table 1, in terms of the power machine rotor quantities. Table 2 shows the control machine space vectors when the machines are mechanically coupled back to back, as in Fig. 3(d).

The schematics shown in Tables 1 and 2 depict the power and control machine rotor windings connected as shown in Fig. 3(a) for convenience only. In this case and for the case in which both windings are connected as shown in Fig. 3(b) this is described in Tables 1 and 2 as windings having the same sense. Where one of the rotor windings is as shown in Fig. 3(a) and the other as shown in Fig. 3(b) this is described as windings of the opposite sense. The effect of having windings of opposite sense is to reverse the control machine space vector. There is no direct effect on the conjugation of a particular space vector

The conjugation of the space vector is a result of a change in only two of the three phases. If there is no phase change, as in the first row of Table 1, or a change in all three phases there is no conjugation. It should be noted at this stage there is no direct time dependence incorporated into the space vectors. They are completely general in nature and are valid equally for dc or any form of ac temporal excitation. If a balanced three phase voltage is applied to the power machine stator the voltages and currents in the rotor will also form a balanced three phase set. The resultant space vectors will, in the steady state, rotate at constant angular velocity. The result of these, power machine rotor, rotating space vectors on the control machine rotor space vectors is that those without conjugation give rise to space vectors that rotate in the same direction as the power machine quantities. Those control machine rotor space vectors that are conjugated give rise to space vectors that rotate in the opposite direction to the power machine rotor quantities. Conjugation of a space vector, relative to another, is a necessary condition if the two space vectors are to rotate in opposite directions.

In Tables 1 and 2 the power machine space vectors are in a frame of reference attached to the power machine rotor and hence rotate at a velocity equal to the electrical angular velocity of the power machine. Similarly, the control machine space vectors are in a frame of reference attached to the control machine rotor and they move with the velocity of the control machine electrical quantities. In general, the velocity of the power machine rotor quantities does not equal the control machine quantities because the number of pole pairs is different on the power and control machines. For the BDFM this is always the case.

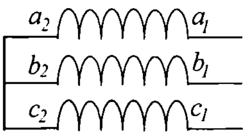
The power and control machines may be coupled in one of two ways, viz. facing the same direction, as shown in Fig. 3(c), or back to back, as shown in Fig. 3(d). If the machines face the same direction then in order to have contra rotating fields in the two rotor windings, only connections 2, 4, and 6 from Table 1 may be used. It is common practice, for purposes of convenience, to couple the two machines so they face each other as in Fig. 3(d). The effect of turning one machine to face the other is equivalent to rotating the space vector about the vertical axis. If the original space vector is denoted $\mathbf{g}_{\text{orig}}$ and the transformed space vector $\mathbf{g}_{\text{rotv}}$ the two vectors are related as

$$\mathbf{g}_{\text{rotv}} = -\mathbf{g}_{\text{orig}}^{*} . \tag{4}$$

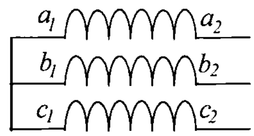
With the machines coupled back to back the other connections from Table 1, connections 1,3, and 5 may be used as shown in Table 2.

In developing the space vectors of the interconnected rotor windings it has been assumed the shafts of the two machines have been coupled with the magnetic axes of the respective windings aligned. If this is not the case another transformation is required to accommodate the non-alignment. If the aligned space vector is denoted $\mathbf{g}_{\text{align}}$ and the non-aligned space vector $\mathbf{g}_{\text{non}}$ the two vectors are related as

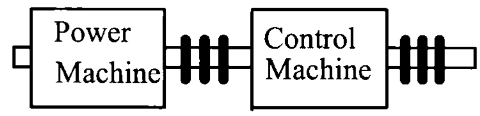
$$\mathbf{g}_{\text{non}} = \mathbf{g}_{\text{align}} e^{-j\theta_a} , \tag{5}$$



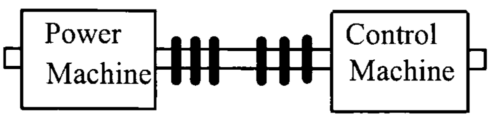
(a) Star connection to produce circular locus of space vector



(b) Alternative connection to (a)



(c) Machines coupled facing same direction



(d) Machines coupled back to back

Fig. 3 Coupling and connection of rotor windings

Table 1. Control machine rotor space vectors in terms of power machine rotor quantities. Machines coupled facing same direction.

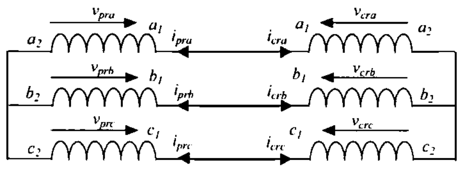
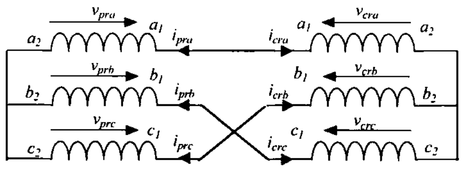
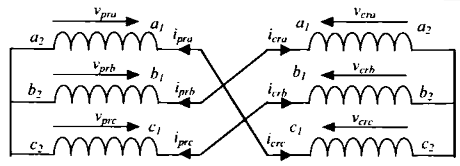
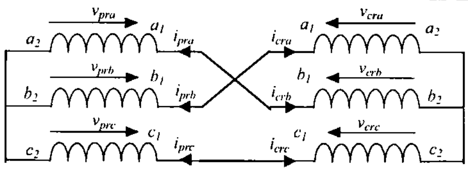
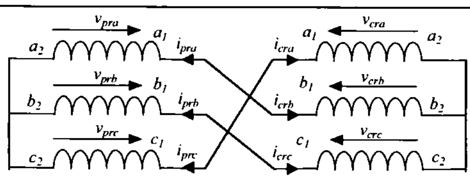
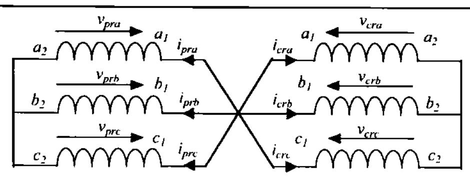
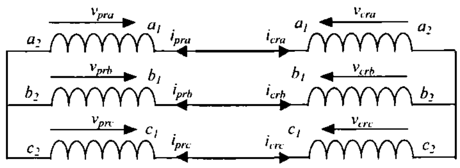
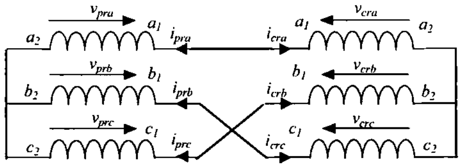
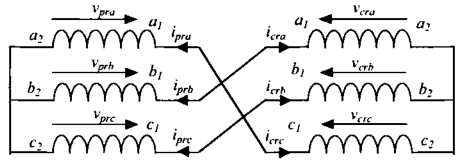
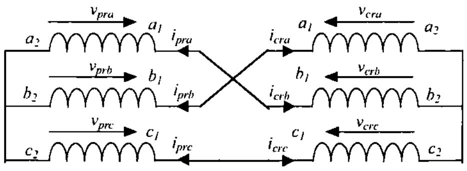
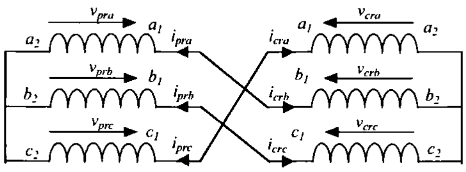
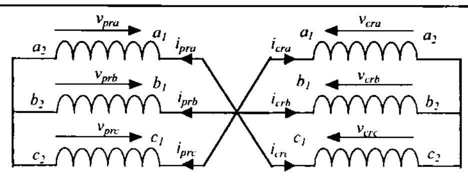
#	Interconnection Schematic
1	 Windings of same sense $\mathbf{i}_{cr} = -\mathbf{i}_{pr}$, $\mathbf{v}_{cr} = \mathbf{v}_{pr}$ Windings of opposite sense $\mathbf{i}_{cr} = \mathbf{i}_{pr}$, $\mathbf{v}_{cr} = -\mathbf{v}_{pr}$
2	 Windings of same sense $\mathbf{i}_{cr} = -\mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = \mathbf{v}_{pr}^*$ Windings of opposite sense $\mathbf{i}_{cr} = \mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = -\mathbf{v}_{pr}^*$
3	 Windings of same sense $\mathbf{i}_{cr} = -\mathbf{a}^2\, \mathbf{i}_{pr}$, $\mathbf{v}_{cr} = \mathbf{a}^2\, \mathbf{v}_{pr}$ Windings of opposite sense $\mathbf{i}_{cr} = \mathbf{a}^2\, \mathbf{i}_{pr}$, $\mathbf{v}_{cr} = -\mathbf{a}^2\, \mathbf{v}_{pr}$
4	 Windings of same sense $\mathbf{i}_{cr} = -\mathbf{a}^2\, \mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = \mathbf{a}^2\, \mathbf{v}_{pr}^*$ Windings of opposite sense $\mathbf{i}_{cr} = \mathbf{a}^2\, \mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = -\mathbf{a}^2\, \mathbf{v}_{pr}^*$
5	 Windings of same sense $\mathbf{i}_{cr} = -\mathbf{a}\, \mathbf{i}_{pr}$, $\mathbf{v}_{cr} = \mathbf{a}\, \mathbf{v}_{pr}$ Windings of opposite sense $\mathbf{i}_{cr} = \mathbf{a}\, \mathbf{i}_{pr}$, $\mathbf{v}_{cr} = -\mathbf{a}\, \mathbf{v}_{pr}$
6	 Windings of same sense $\mathbf{i}_{cr} = -\mathbf{a}\, \mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = \mathbf{a}\, \mathbf{v}_{pr}^*$ Windings of opposite sense $\mathbf{i}_{cr} = \mathbf{a}\, \mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = -\mathbf{a}\, \mathbf{v}_{pr}^*$

Table 2. Control machine rotor space vectors in terms of power machine rotor quantities. Machines coupled facing back to back.

#	Interconnection Schematic
1	 Windings of same sense $\mathbf{i}_{cr} = \mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = -\mathbf{v}_{pr}^*$ Windings of opposite sense $\mathbf{i}_{cr} = -\mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = \mathbf{v}_{pr}^*$
2	 Windings of same sense $\mathbf{i}_{cr} = \mathbf{i}_{pr}$, $\mathbf{v}_{cr} = -\mathbf{v}_{pr}$ Windings of opposite sense $\mathbf{i}_{cr} = -\mathbf{i}_{pr}$, $\mathbf{v}_{cr} = \mathbf{v}_{pr}$
3	 Windings of same sense $\mathbf{i}_{cr} = \mathbf{a}^2\, \mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = -\mathbf{a}^2\, \mathbf{v}_{pr}^*$ Windings of opposite sense $\mathbf{i}_{cr} = -\mathbf{a}^2\, \mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = \mathbf{a}^2\, \mathbf{v}_{pr}^*$
4	 Windings of same sense $\mathbf{i}_{cr} = \mathbf{a}^2\, \mathbf{i}_{pr}$, $\mathbf{v}_{cr} = -\mathbf{a}^2\, \mathbf{v}_{pr}$ Windings of opposite sense $\mathbf{i}_{cr} = -\mathbf{a}^2\, \mathbf{i}_{pr}$, $\mathbf{v}_{cr} = \mathbf{a}^2\, \mathbf{v}_{pr}$
5	 Windings of same sense $\mathbf{i}_{cr} = \mathbf{a}\, \mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = -\mathbf{a}\, \mathbf{v}_{pr}^*$ Windings of opposite sense $\mathbf{i}_{cr} = -\mathbf{a}\, \mathbf{i}_{pr}^*$, $\mathbf{v}_{cr} = \mathbf{a}\, \mathbf{v}_{pr}^*$
6	 Windings of same sense $\mathbf{i}_{cr} = \mathbf{a}\, \mathbf{i}_{pr}$, $\mathbf{v}_{cr} = -\mathbf{a}\, \mathbf{v}_{pr}$ Windings of opposite sense $\mathbf{i}_{cr} = -\mathbf{a}\, \mathbf{i}_{pr}$, $\mathbf{v}_{cr} = \mathbf{a}\, \mathbf{v}_{pr}$

where θ_a is the electrical angle by which the rotor winding axes are not aligned and

$\theta_a = \theta_m P/2$.

It is a necessary condition for operation of the DFTSIM that

$$\mathbf{g}_{cr} = \left(\mathbf{g}_{pr} e^{j\varphi}\right)^* \tag{6}$$

where $\varphi = v + \theta_a,\quad v = \frac{n\pi}{3};\quad n \in \{0, 1, 2, 3, 4, 5\}$,

The phase shift, φ, is the spatial orientation of the control machine rotor space vector when the power machine rotor is coincident on the d axis.

2.4 Formation of DFTSIM

For the control machine, with P_c pole pairs, where in general $P_p \neq P_c$, the dynamic voltage equations are,

$$\left[\mathbf{v}_c^g\right] = \left[Z_c^g\right]\left[\mathbf{i}_c^g\right] \tag{7}$$

where

$$\left[\mathbf{v}_c^g\right] = \left[\mathbf{v}_{cs} e^{-j\theta_g} \quad \mathbf{v}_{cr} e^{-j(\theta_g - P_c\theta_m)}\right]^T,$$

$$\left[\mathbf{i}_c^g\right] = \left[\mathbf{i}_{cs} e^{-j\theta_g} \quad \mathbf{i}_{cr} e^{-j(\theta_g - P_c\theta_m)}\right]^T$$

$$\left[Z_c^g\right] = \begin{bmatrix} R_{cs} + (p + j\omega_g)L_{cs} & (p + j\omega_g)L_{cM} \\ (p + j(\omega_g - P_c\omega_m))L_{cM} & R_{cr} + (p + j(\omega_g - P_c\omega_m))L_{cr} \end{bmatrix}$$

When the machines are coupled to form a DFTSIM the power machine and control machine rotor currents in their respective rotor reference frame are related as

$$\mathbf{i}_{cr} = \left(\mathbf{i}_{pr} e^{j\varphi}\right)^* \text{ and } \mathbf{v}_{cr} = -\left(\mathbf{v}_{pr} e^{j\varphi}\right)^* \tag{8}$$

The control machine rotor space vectors in the general reference frame can be written in terms of the power machine rotor space vectors as

$$\mathbf{i}_{cr}^g = \left(\mathbf{i}_{pr} e^{j\varphi}\right)^* e^{-j(\theta_g - P_c\theta_m)},\ \mathbf{v}_{cr}^g = -\left(\mathbf{v}_{pr} e^{j\varphi}\right)^* e^{-j(\theta_g - P_c\theta_m)}, \tag{9}$$

The power machine rotor space vectors and the control machine rotor space vectors are not in the same reference frame, because in general $P_p \neq P_c$. To analyze the machine all rotor and stator quantities must be in the same reference frame. The same reference frame can be achieved by a further reference frame frequency transformation.

$$\mathbf{i}_{cr}^g = \left(\mathbf{i}_{pr}^g e^{j\theta_h}\right)^* \text{ and } \mathbf{v}_{cr}^g = -\left(\mathbf{v}_{pr}^g e^{j\theta_h}\right)^* \tag{10}$$

where

$$\theta_h = 2\theta_g - P_p\theta_m - P_c\theta_m + \varphi$$

The angle θ_h is the transformation that maps the control machine rotor space vectors, including current, voltage and flux linkage, on to the same reference frame as the power machine rotor space vectors.

In the same reference frame as the power machine (7) becomes

$$\left[\mathbf{v}_c^g\right] = \left[Z_c^g\right]\left[\mathbf{i}_c^g\right] \tag{10}$$

where

$$\left[\mathbf{v}_c^g\right] = \left[\left(\mathbf{v}_{cs}^g e^{-j\theta_h}\right)^* \quad -\mathbf{v}_{pr}^g\right]^T,\ \left[\mathbf{i}_c^g\right] = \left[\left(\mathbf{i}_{cs}^g e^{-j\theta_h}\right)^* \quad \mathbf{i}_{pr}^g\right]^T,$$

$$Z_{11} = R_{cs} + (p + j(\omega_g - P_p\omega_m - P_c\omega_m))L_{cs}$$

$$Z_{12} = (p + j(\omega_g - P_p\omega_m - P_c\omega_m))L_{cM}$$

$$Z_{21} = (p + j(\omega_g - P_p\omega_m))L_{cM}$$

$$Z_{22} = R_{cr} + (p + j(\omega_g - P_p\omega_m))L_{cr}$$

In the first row of the impedance matrix (10) there is now reference to the number of pairs of poles on both the power machine and the control machine whilst no direct reference to the number of pairs of poles on the control machine is present in the second row.

For the DFTSIM to exhibit synchronous behaviour the frequency of the current induced in both the power machine rotor and the control machine rotor must be the same. Under these conditions

$$\theta_c = (P_p + P_c)\theta_m - \theta_p \tag{11}$$

Combining the power and control machines, by adding (2) and (10), and dropping the subscripts relating to stator currents gives (12), for the DFTSIM. In (12) $R_r = R_{pr} + R_{cr}$ and $L_r = L_{pr} + L_{cr}$

The total electromagnetic torque is

$$\boldsymbol{\tau}_e = 3/2\, P_p L_{pM}\left(\mathbf{i}_{pr}^g \times \mathbf{i}_p^g\right) + 3/2\, P_c L_{cM}\left(\mathbf{i}_{cr}^g \times \mathbf{i}_c^g\right) \tag{13}$$

The first term of (13) represents the torque contributed by the power machine and the second the torque contributed by the control machine.

The foregoing equations are valid for all input voltages including dc and all ac waveforms. With sinusoidal excitation on the power and control windings

$$\mathbf{v}_{ps}^g = V_{ps} e^{j(\theta_p - \theta_g)},\quad \mathbf{v}_{cs}^{g\,*} = V_{cs} e^{-j(\theta_c - \theta_g)} \tag{14}$$

$$\begin{bmatrix} \mathbf{v}_p^g \\ \left(\mathbf{v}_c^g e^{j\theta_h}\right)^* \\ 0 \end{bmatrix} = \begin{bmatrix} R_{ps} + (p + j\omega_g)L_{ps} & 0 & (p + j\omega_g)L_{pM} \\ 0 & R_{cs} + (p + j(\omega_g - P_p\omega_m - P_c\omega_m))L_{cs} & (p + j(\omega_g - P_p\omega_m - P_c\omega_m))L_{cM} \\ (p + j(\omega_g - P_p\omega_m))L_{pM} & (p + j(\omega_g - P_p\omega_m))L_{cM} & R_r + (p + j(\omega_g - P_p\omega_m))L_r \end{bmatrix} \begin{bmatrix} \mathbf{i}_p^g \\ \left(\mathbf{i}_c^g e^{j\theta_h}\right)^* \\ \mathbf{i}_{pr}^g \end{bmatrix} \tag{12}$$

2.5 Effect of Reference Frame

The effect of different reference frames is illustrated in Fig. 4, which shows the acceleration characteristics of two identical 1.5kW/100V 50Hz six pole machines with the parameters shown in Table 3. In each case the speed-torque response is identical. The difference is with the currents and voltages in the various reference frames. Fig 4(b) shows the power winding current in the rotor reference frame from which it can be seen the frequency is variable and corresponds to the rotor electrical frequency. In the synchronous reference frame, Fig. 4(c) all electrical quantities are dc, which is useful for control purposes, and in the stationary reference frame, Fig. 4(d) all electrical quantities are at mains frequency. Changing reference frame can be considered to be a frequency transformation.

Table 3
Parameters of the Power and Control Machines

L_s mH	L_M mH	L_r mH	R_s Ω	R_r Ω	P
64	57	64	0.627	1.29	3

CONCLUSIONS

A model of the DFTSIM has been developed, using space vectors, in the general reference frame based on the cascade connection of two wound rotor induction machines of, in general, unequal pole numbers. The effects of the interconnection of the two rotor windings have been discussed as has the effect of mechanical coupling with misalignment of the rotor windings. The effect of the choice of reference frame on one of the currents has been discussed briefly.

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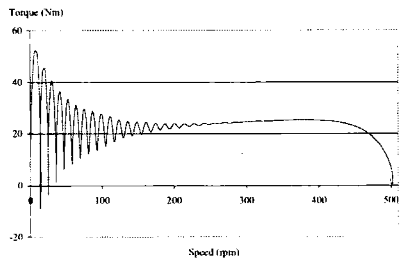
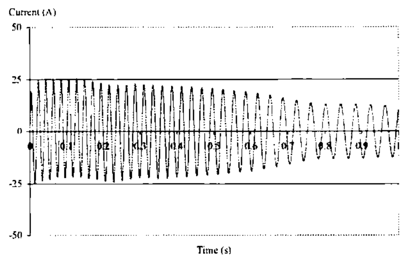
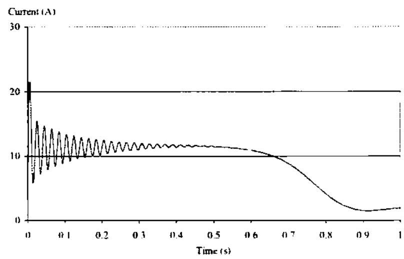


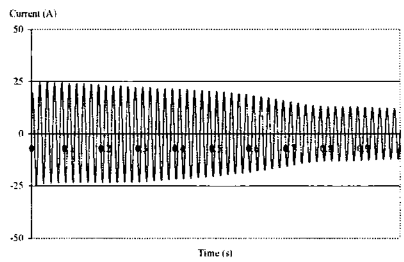
(a) Torque *vs* speed



(b) Power Winding Current in Rotor Reference Frame



(d) Power Winding Current in Synchronous Reference Frame



(c) Power Winding Current in Stationary Reference Frame

Fig. 4 Effect of Reference Frame on Power Winding Current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Message from the Conference Chairman

It gives me great pleasure to welcome you all to the Australasian Universities Power Engineering Conference (AUPEC 2002). AUPEC traditionally rotates among the venues in the Australasian region and we are delighted to host the 2002 conference at Monash University, Melbourne Australia.

AUPEC is the only annual conference organised by the Australasian Committee for Power Engineering (ACPE). The primary aim of this conference is to provide a national forum for academia and industry to share innovation, development and experiences in a friendly environment. The other key aim of AUPEC is to provide postgraduate students with the opportunity to present their research findings in front of experts from both academia and industry for scholarly feedback. It also provides university academics and Industry the opportunity to interact with the technical community, to share experiences and gain the benefit from the latest developments in technology presented at the conference.

We were very pleased with the response received from our call for papers. The conference secretariat received more than 180 abstracts from prospective authors from various countries including Australia, New Zealand, Canada, Malaysia, Singapore, Japan, India, China, Finland, Egypt, Czech Republic and Iran. Members of the organizing committee selected 158 abstracts suitable for presentation at the AUPEC conference. Papers were reviewed by 60 independent reviewers from around the world. Finally, after a two-stage independent peer review process, 138 papers successfully passed the process and were accepted for presentation and discussion at the 27 technical sessions of the conference. All papers published in the conference proceedings for AUPEC 2002 have been fully refereed, having satisfied the requirements of this peer review process. My sincere thanks to all the reviewers for their time and effort toward the review process.

We are also very pleased to put forward four outstanding keynote speakers in the mornings of day one and day two of the conference.

Finally, I would like to thank all the members of the AUPEC 2002 organizing committee for their dedication and effort, without which the conference would not have been possible.

On behalf of the conference committee let me welcome you to AUPEC 2002, which is all set to be a rewarding experience in all respects.

Dr. A. Zahedi
Chairman - AUPEC 2002
29 September 2002

A NOVEL ANALYSIS AND MODELLING OF AN ISOLATED SELF-EXCITED INDUCTION GENERATOR TAKING IRON LOSS INTO ACCOUNT
D. Seyoum, C. Grantham and F. Rahman

AN EXPERT SYSTEM APPLICATION FOR HYDRO ELECTRIC GENERATOR SCHEDULING IN TASMANIA
Cameron Potter and Michael Negnevitsky

AN IMPROVED FLUX ESTIMATION IN INDUCTION MACHINE FOR CONTROL APPLICATION
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ANALYSIS OF THE STEADY STATE PERFORMANCE OF DOUBLY FED INDUCTION MACHINES
G. Boardman, J. G. Zhu, and Q.P. Ha

GENERAL REFERENCE FRAME MODELLING OF THE DOUBLY FED TWIN STATOR INDUCTION MACHINE USING SPACE VECTORS
G. Boardman, J. G. Zhu, and Q.P. Ha

SELECTION OF GENERATOR FAULT IMPEDANCES FOR ENHANCEMENT OF NETWORK-WIDE FAULT BEHAVIOUR
J. D. F. McDonald, T.K. Saha

9. Modeling, Simulation and Artificial Intelligent Applications

MEDIUM-FREQUENCY MODELLING OF TRANSMISSION SYSTEMS: APPLICATION TO TRACTION SYSTEMS
Anthony B. Morton and Robert E. Morrison

FORECASTING INTER AND INTRA REGIONAL TRANSMISSION LINE POWER FLOWS IN BOTH RADIAL AND MESHED ELECTRICAL NETWORKS
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