

# ANALYSIS OF THE STEADY STATE PERFORMANCE OF DOUBLY FED INDUCTION MACHINES

G. Boardman, J. G. Zhu, and Q.P. Ha

Faculty of Engineering, University of Technology, Sydney  
P.O. Box 123 Broadway NSW 2007 Australia

## Abstract

This paper discusses the steady state maximum and minimum torque outputs and the operation at unity power factor of the doubly fed twin stator induction machine and the doubly fed induction machine using equations with analytical solutions. Speeds above and below the natural or synchronous speed are discussed. The results of simulations, based on a laboratory machine comprising two nominally identical wound rotor induction machines, are presented. It is shown that the maximum torque for the doubly fed machine is independent of speed and for the doubly fed twin stator induction machine there are variable maxima and minima dependent on speed.

## NOMENCLATURE

### A. Main Variables

$f$	Frequency (Hz)
$I$	RMS current (A)
$\Im$	Imaginary part of complex quantity
$j$	Imaginary operator
$L$	Inductance (H)
$N$	Mechanical speed (rpm)
$P$	Number of pole pairs
$R$	Resistance ( $\Omega$ )
$s$	Slip
$T$	Steady state torque (Nm)
$V$	RMS voltage (V)
$\omega$	Angular velocity (rad/s)
$X$	Reactance ( $\Omega$ )
$Y$	Admittance (S)
$Z$	Impedance ( $\Omega$ )

### B. Subscript and Superscript Variables

$c$	Control machine
$e$	Electrical
$f$	Field
$i$	Current controlled
$l$	Leakage
$m$	Mechanical
$M$	Mutual
$n$	Natural
$p$	Power machine
$r$	Rotor
$s$	Stator
$T$	Transpose of matrix
$syn$	Synchronous
$*$	Complex conjugate

Bold upper case variable denotes rms 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

Under normal conditions, with fixed supply voltage and frequency, the speed of an induction motor is almost constant, though it varies slightly with load. To vary the speed of the motor efficiently, a variable voltage, variable frequency (VVVF) supply or converter is required. If the converter is connected to the stator of the machine, it must be rated for the full motor power and is correspondingly expensive (3 to 4 times the motor cost). If the converter is connected to the rotor of the machine, through brushes and slip rings, it may be rated for less than the full motor power depending on the speed range required and the load and the machine is called the doubly fed induction machine (DFIM).

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 that is connected to the stator of one of the machines. The DFTSIM being studied consists of two, nominally identical, 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. The BDFM is implemented in a single frame, using a cage type rotor.

In this paper, a positive control winding frequency denotes a balanced three phase set which produces a magnetic field that rotates in the same direction as that produced by the power winding voltages. A negative frequency denotes a voltage set that produces rotation in the opposite direction.

This paper compares some aspects of the steady state performance of the DFIM and the DFTSIM.

## 2. DOUBLY FED INDUCTION MACHINES

Doubly fed induction machines, the DFIM and the DFTSIM, share certain characteristics and operational principles and they have differences. With proper control they can both exhibit synchronous behaviour over a wide speed range. In this context synchronous behaviour means the machines can support a range of torque at a speed determined by the two supply frequencies. The DFIM has its stator connected to the utility supply and its wound rotor connected, via slip rings, to a VVVF supply. To achieve the reliability and safety of the stator fed brushless system and the low cost of the DFIM the DFTSIM is being investigated [1], [2]. The power machine supplies the majority of the power requirement, unprocessed, from the utility supply at fixed voltage and frequency. The control machine, together with an appropriate converter, acts as a type of bi-directional slip energy converter. The DFTSIM can operate in the synchronous mode, in which 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:

$$N_m = 60 (f_p + f_c) / (P_p + P_c) \quad (1)$$

With dc applied to the control winding,  $f_c = 0$ , the DFTSIM will run at the so called natural or synchronous speed,  $N_n$ .

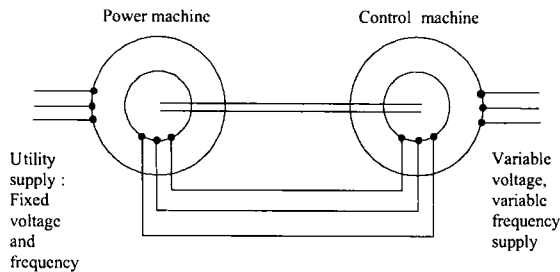


Fig.1 Arrangement of the DFTSIM

## 3. STEADY STATE EQUATIONS

### 3.1 General

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;
- (f) The rotors of the two machines comprising the DFTSIM are mechanically coupled with their 'a' phases aligned and the windings are connected in reverse sequence so as to produce contra rotating fields that are coincident on the magnetic axis of the 'a' phase.

### 3.2 DFIM

The per phase steady state equations for a DFIM without core loss are

$$[\mathbf{I}] = [\mathbf{Y}][\mathbf{V}] \quad (2)$$

where

$$[\mathbf{I}] = [\mathbf{I}_s \quad \mathbf{I}_r]^T, \quad [\mathbf{V}] = [\mathbf{V}_s \quad \mathbf{V}_r]^T$$

$$[\mathbf{Y}] = \begin{bmatrix} R_s + jX_s & jX_M \\ jX_M & R_r/s_r + jX_r \end{bmatrix}^{-1}$$

$$X_s = \omega_e L_s, X_r = \omega_e L_r, X_M = \omega_e L_M, s_r = \omega_r / \omega_s.$$

$$\mathbf{V}_s = V_s e^{j\theta_s}, \quad \mathbf{V}_r = V_r e^{j\theta_r}, \quad \omega_s = \omega_e / P$$

The magnitude of the electromagnetic torque is

$$T_e = 3PL_M \Im(\mathbf{I}_s \mathbf{I}_r^*) = -3PL_M \Im(\mathbf{I}_s^* \mathbf{I}_r) \quad (3)$$

The equivalent circuit in Fig. 2 may represent equation (3).

When operated as a DFIM the controlled variable may be the rotor voltage, both in magnitude and phase. The torque equation (3) can be written in terms of the rotor voltage as

$$T_e = 3PL_M \Im((Y_{11} \mathbf{V}_s + Y_{12} \mathbf{V}_r)(Y_{21}^* \mathbf{V}_s^* + Y_{22}^* \mathbf{V}_r^*)) \quad (4)$$

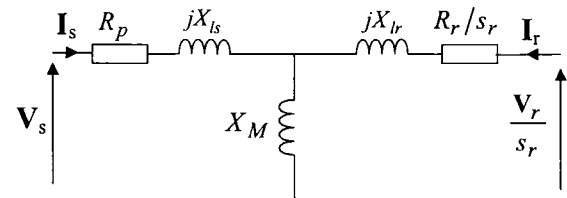


Fig.2. Per Phase Steady State Equivalent Circuit of the DFIM

Equation (4) may be written in the following form where all the variables are real quantities

$$T_e = a V_r^2 + b \cos(\theta - \delta) V_r + c, \quad (5)$$

where

$$\theta = \theta_r - \theta_s$$

$$a = 3 P L_M (\Im(Y_{12}) \Re(Y_{22}) - \Re(Y_{12}) \Im(Y_{22})),$$

$$b = \sqrt{A^2 + B^2},$$

$$A = 3 V_s P L_M \begin{pmatrix} \Im(Y_{12}) \Re(Y_{21}) + \Im(Y_{11}) \Re(Y_{22}) \\ -\Re(Y_{12}) \Im(Y_{21}) - \Re(Y_{11}) \Im(Y_{22}) \end{pmatrix}$$

$$B = 3 V_s P L_M \begin{pmatrix} \Re(Y_{12}) \Re(Y_{21}) + \Im(Y_{12}) \Im(Y_{21}) \\ -\Re(Y_{11}) \Re(Y_{22}) - \Im(Y_{11}) \Im(Y_{22}) \end{pmatrix},$$

$$c = 3 V_s^2 P L_M (\Im(Y_{11}) \Re(Y_{21}) - \Re(Y_{11}) \Im(Y_{21})),$$

$$\tan \delta = B/A.$$

The angle  $\theta$  is the difference between the phase of the rotor voltage and the stator voltage.

In doubly fed mode the torque is a function of two variables, the magnitude and the phase of the rotor voltage. In this mode the machine exhibits synchronous behaviour in that it can support a range of torque at a constant speed, on the proviso the frequency of the impressed rotor voltage equals that induced by the stator.

With the rotor voltage set to zero the torque equation (5) reduces to  $T_e = c$ , which is the classical equation of the singly fed induction machine.

$$T_e = 3 V_{th}^2 \frac{R_r/s_r}{\omega_s ((R_{th} + R_r/s_r)^2 + (X_{th} + X_r - X_M)^2)} \quad (6)$$

where,

$$V_{th}^2 = V_s^2 \frac{X_M^2}{R_s^2 + jX_s^2},$$

$$Z_{th} = R_{th} + jX_{th} = \frac{R_s X_M}{R_s^2 + X_s^2} + j \frac{X_M (R_s X_M + X_s X_M)}{R_s^2 + X_s^2}$$

The pronumeral  $c$  is not a function of the rotor voltage and may be considered to be the induction torque component. The pronumerals  $a$ ,  $b$ ,  $c$  and  $\delta$  are, in general, functions of the slip  $s_r$ . When the DFIM is operated at the synchronous speed the induction torque  $c$  is zero and (5) reduces to

$$T_e = a_{syn} V_r^2 + b_{syn} \cos(\theta - \delta_{syn}) V_r, \quad (7)$$

where, at synchronous speed,

$$a_{syn} = -\frac{3 X_M^2 R_s}{\omega_s R_r^2 (R_s^2 + X_s^2)}, \quad b_{syn} = \frac{3 X_M V_s}{\omega_s R_r \sqrt{R_s^2 + X_s^2}}$$

$$\tan \delta_{syn} = -R_s/X_s$$

Equation (7) is a rearrangement of the classical equation of the cylindrical rotor synchronous machine with armature resistance, with the addition of the term  $\theta$ , and where the generated emf caused by the relative motion of the field and the armature is

$$E_f = j V_r X_M / R_r \quad (8)$$

For the case where the armature resistance is zero,  $a$  is zero at all speeds and because  $\delta_{syn}$  is  $-\pi$  under these conditions (7) reduces to, at synchronous speed

$$T_e = -b_{syn} V_r \cos \theta = \frac{3 E_f V_s}{\omega_s X_s} \sin \theta \quad (9)$$

Equation (9) is the classical equation of the synchronous machine with lossless armature. In this case  $\theta$  is the load angle.

### 3.3 DFTSIM

#### 3.3.1 Voltage Controlled Mode

The per phase equations of the DFTSIM in the steady state are [1]

$$[V_{pc}] = [Z_{pc}] [I_{pc}] \quad (10)$$

where

$$[V_{pc}] = [V_p \quad V_c^*/s \quad 0]^T, \quad [I_{pc}] = [I_p \quad I_c^* \quad I_r]^T,$$

and

$$[Z_{pc}] = \begin{bmatrix} (R_{ps} + jX_{ps}) & 0 & jX_{pM} \\ 0 & (R_{cs} - jX_{cs}) & -jX_{cM} \\ jX_{pM} & jX_{cM} & (R_r/s_r + jX_r) \end{bmatrix}$$

where

$$s = \omega_p/\omega_c, \quad I_r = I_{cr}^* = I_{pr}$$

In steady state, the electromagnetic torque is, using *rms* values,

$$T_e = 3 P_p L_{pM} \Im(I_p I_r^*) + 3 P_c L_{cM} \Im(I_c I_r) \quad (11)$$

The equivalent circuit in Fig. 3 may represent (10).

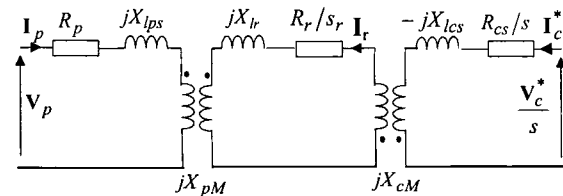


Fig.3 Steady state per-phase equivalent circuit of the DFTSIM in voltage controlled mode

### 3.2.3 Current Controlled Mode

When the control winding is connected to a current source the steady state current equations are

$$[\mathbf{I}] = [\mathbf{Y}][\mathbf{V}] \quad (12)$$

where

$$[\mathbf{I}] = [\mathbf{I}_p \quad \mathbf{I}_r]^T, [\mathbf{V}] = [\mathbf{V}_p \quad -jX_{cM}\mathbf{I}_c^*]^T$$

$$[\mathbf{Y}] = \begin{bmatrix} R_{ps} + jX_{ps} & jX_{pM} \\ jX_{pM} & R_r/s_r + jX_r \end{bmatrix}^{-1}$$

$$X_s = \omega_p L_s, X_r = \omega_p L_r, X_{pM} = \omega_p L_{pM},$$

$$X_{cM} = \omega_p L_{cM}, s_r = \omega_r / \omega_p.$$

The equivalent circuit in Fig. 4 may represent (12).

Equations (2) and (12) are, prima facie, very similar. A voltage related to the control winding current replaces the impressed rotor voltage in (2). The conjugate of the control winding current appears in (12) because of the contra rotating fields on the separate rotor windings in the power and control machine sections of the DFTSIM [6].

The torque in current controlled mode is the same as in (11). In terms of the controlled variable, which is the control winding current, the torque is

$$T_e = a_i I_c^2 + b_i \cos(\theta_i - \delta_i) I_c + c_i, \quad (13)$$

where

$$\mathbf{V}_p = V_p e^{j\theta_p}, \quad \mathbf{I}_c = I_c e^{j\theta_c}, \quad \theta_i = \theta_p + \theta_c$$

$$a_i = 3P_p L_{pM} X_{cM}^2 (\Im(Y_{i12}) \Re(Y_{i22}) - \Re(Y_{i12}) \Im(Y_{i22})) \\ + 3P_c L_{cM} X_{cM} \Re(Y_{i22})$$

$$b_i = \sqrt{A_i^2 + B_i^2}$$

$$A_i = 3V_p \left( P_p L_{pM} X_{cM} \left( \Re(Y_{i22}) \Re(Y_{i11}) + \Im(Y_{i22}) \Im(Y_{i11}) \right) - \Re(Y_{i12}) \Re(Y_{i21}) - \Im(Y_{i12}) \Im(Y_{i21}) \right) \\ - P_c L_{cM} \Im(Y_{i21})$$

$$B_i = 3V_p \left( P_p L_{pM} X_{cM} \left( \Im(Y_{i22}) \Re(Y_{i11}) - \Re(Y_{i22}) \Im(Y_{i11}) \right) + \Im(Y_{i21}) \Re(Y_{i12}) - \Re(Y_{i12}) \Im(Y_{i21}) \right) \\ - P_c L_{cM} \Re(Y_{i21})$$

$$\tan \delta_i = B_i / A_i$$

$$c_i = 3V_s^2 P_p L_{pM} (\Im(Y_{i11}) \Re(Y_{i21}) - \Re(Y_{i11}) \Im(Y_{i21}))$$

Equation (13) gives a closed form analytical solution for the DFTSIM in terms of the controlled variable.

In the DFIM  $\theta$  is the phase difference between the stator voltage and the impressed rotor voltage. In the DFTSIM  $\theta$  is the sum of the phase of the power winding voltage and the phase of the controlled variable. This effect is again caused by conjugation.

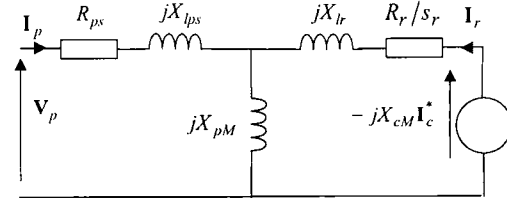


Fig.4 Steady state per-phase equivalent circuit of the DFTSIM in current controlled mode

In (13) each of  $a_i$ ,  $b_i$ , and  $\delta_i$  contain terms related to the control machine while  $c_i$  does not. In (12) there is an extra torque component contributed by the control machine compared with the DFIM.

When the control winding current is zero the torque equation, (12), again becomes equal to the  $c$  term. This reduces the machine to the equivalent of the single machine with increased rotor resistance and rotor leakage reactance. It is noted the  $c$  term for the single machine is the same as the power winding component of the DFTSIM, with the higher rotor quantities. There are no control winding terms in the  $c$  term although they are present in the  $a$ ,  $b$ , and  $\delta$  parameters

If the control winding voltage is the controlled variable a similar torque equation is obtained but the  $a$ ,  $b$ ,  $c$  and  $\delta$  parameters are different from those in (13) because they are related to the inverse of the impedance matrix in (10).

## 4. SIMULATION STUDY

### 4.1 Machine Parameters

The machine parameters used in the simulations were those of a laboratory machine with a wound rotor,  $\Delta/Y$  connected, 4 pole, 22.5kW, 240Nm, 415V, 50Hz, 40.8A. The parameters of the machines, estimated off line, on a per-phase, star equivalent, basis with all quantities referred to the rotor, and reactance calculated at 50 Hz, are as follows.  $R_s=0.205 \Omega$ ,  $X_s=27.4 \Omega$ ,  $X_M=26.7 \Omega$ ,  $R_r=0.205 \Omega$ ,  $X_r=27.4 \Omega$ .

### 4.2 Maximum and Minimum Torque

In singly fed mode the induction machine can generate only for speeds greater than synchronous speed. In doubly fed mode the induction machine can generate at all speeds. The theoretical maximum torque the DFIM can sustain is obtained from (5) and is shown, together with the torque under singly fed conditions, in Fig 5(a). In singly fed mode there is a single operating torque for each speed and this is denoted by  $c$ ; any change in the load torque will result in a change of speed. As a DFIM, if the load torque changes then, by adjustment of the rotor voltage, the speed can be

maintained constant within certain limits. The maximum torque shown in Fig. 5(a) thus represents the boundary of the operating region. It is noted the bounding value of torque is always positive for the DFIM, given by the sign of  $a$ , and this implies there is no theoretical limit to the operation of the machine as a generator at all speeds. It is noted the theoretical maximum torque is constant over the entire speed range, both sub-synchronous and super-synchronous for the DFIM. The maximum electromagnetic torque, in terms of the  $a$ ,  $b$  and  $c$  parameters is given by

$$T_{e\max} = c - b^2/4a. \quad (14)$$

While the maximum torque of the DFIM is constant over the entire speed range each of the parameters,  $a$ ,  $b$  and  $c$ , varies with speed and that the parameters are not symmetrical about the synchronous speed.

Fig. 5(a) also shows for the DFTSIM there is a maximum torque for speeds below the synchronous speed of the power machine while for speeds above this there is a minimum. These turning points are a function of speed in the DFTSIM and for the machine being studied the maximum torque is less than the torque of a single machine for speeds  $1300 < N < 1500$  rpm. The DFTSIM cannot support torque at the synchronous speed of the power winding because production of torque is always by induction action.

In practice these maxima and minima of torque can never be achieved because the thermal rating of the machine would be exceeded and the magnetic circuits would be saturated. It is also true that the maximum torque for singly fed machines can not be achieved for the same reasons.

The pronumeral  $\delta$  may be considered to be the phase of the controlled variable for operation at maximum or minimum torque, noting the differences of  $\theta$  in (5) and (13). In the DFIM  $\delta$  varies with speed, Fig. 5(b), as does the magnitude of the rotor voltage. Both the resulting rotor current and stator current are fixed both in magnitude and phase over the entire speed range. The stator current is in phase with the stator voltage at maximum torque. Although  $\delta$  and  $V_r$  both vary with speed the locus of  $V_r$  is a straight line as shown in Fig. 5(c). The phase of the rotor current differs from the phase of the stator voltage by  $\delta_{syn}$ . In the DFTSIM  $\delta_i$  is constant over the entire speed range, being very close to zero. In a DFTSIM in which  $P_p = P_c$ , the value of  $\delta_i$  is given by

$$\tan \delta_i = \frac{R_{ps} X_r}{X_{pM}^2 - X_{ps} X_r} \quad (15)$$

#### 4. Operation at Unity Power Factor

The power factor of a singly fed induction machine is always less than unity. It is often desirable to operate the machine with a power factor close to unity or even at a leading power factor. Changing the phase of the rotor voltage can vary the power factor of the DFIM. When operated with the stator at unity power factor the rotor current and rotor voltage are also at almost unity power factor. Figure 6 shows the variation of quantities with the machine operating at constant torque but with the phase of rotor voltage varied to achieve unity power factor on the stator. The magnitude of the rotor voltage varies linearly with speed, with a small, non-zero, minimum occurring at approximately 1455 rpm for 180 Nm. The phase of the rotor voltage is fairly constant except around the synchronous speed, where it undergoes a rapid change of  $\pi$ , but without discontinuity. The current at fixed torque is constant, being 40.8 A for 180 Nm, throughout the entire speed range. This suggests the machine can operate over a very wide range of speeds with a load torque of up to 180 Nm. The locus of the rotor voltage describes a straight line.

The power factor of the power winding of the DFTSIM may be similarly controlled by variation of the phase of the control winding current. The DFTSIM currents at unity power factor on the stator winding for a motoring load of 180 Nm are depicted in Fig. 7. Over most of the speed range the currents are fairly constant in both magnitude and phase. There is a discontinuity in the currents near the synchronous speed of the power machine because the machine cannot support this torque, as shown in Fig. 5(a). At all speeds the magnitude of the control winding current has the greatest magnitude of the currents. This is significant because the control machine is likely to saturate first. The locus of the power winding current does not vary much but the loci of the rotor and control winding currents are heavily influenced by the operation around the synchronous speed, as shown in Fig. 7(c).

#### 5 CONCLUSIONS

Equations describing the relationship between the electromagnetic torque and the controlled variable for both the DFIM and the DFTSIM have been developed. These equations have analytical solutions in both cases. In each case the equations are similar in form. For the DFIM the equations allow the induction torque and the synchronous torque components to be identified. A comparison has been presented between the machines in terms of the maximum torque and of the operation at unity power factor. It is shown for the DFIM that the currents at unity power factor and fixed load are independent of the speed of operation. For the DFTSIM the magnitude of the control winding current is high. Further studies are planned to evaluate the performance limits and efficiency of the DFTSIM.

## REFERENCES

- [1] G. Boardman, J. G. Zhu, and Q.P. Ha, "Power Flow in Doubly Fed Induction Machines", *Proc. of the Australasian Power Engineering Conference (AUPEC'2001)*, Perth Australia, September 2001, pp.37-42
- [2] G. Boardman, J. G. Zhu, and Q.P. Ha, "Dynamic and Steady State Modelling of Brushless Doubly Fed Induction Machines", *Proc. of the Int. Conference on Electrical Machines and Systems (ICEMS'2001)*, Shenyang China, August 2001, pp.412-415
- [3] R. Li, A. Wallace, R. Spée, and Y. Wang, "Two-axis model development of cage-rotor brushless doubly fed machines", *IEEE Trans. on Energy Conversion*, Vol. 6, No. 3, 1991, pp. 453-460.
- [4] S. Williamson, A. C. Ferreira and A. K. Wallace, "Generalised theory of the brushless doubly-fed machine. Part 1: Analysis", *IEE Proc. Electrical Power Applications*, 1997 144 (2), pp.111-121
- [5] S. Williamson, and A. C. Ferreira, "Generalised theory of the brushless doubly-fed machine. Part 2: Model verification and performance", *IEE Proc. Electrical Power Applications*, 1997 144 (2), pp.123-129
- [6] G. Boardman, J. G. Zhu, and Q.P. Ha, "General Reference Frame Modelling of the Doubly Fed Induction Machine Using Space Vectors", *Proc. of the Australasian Power Engineering Conference (AUPEC'2002)*, Melbourne Australia, September 2002.

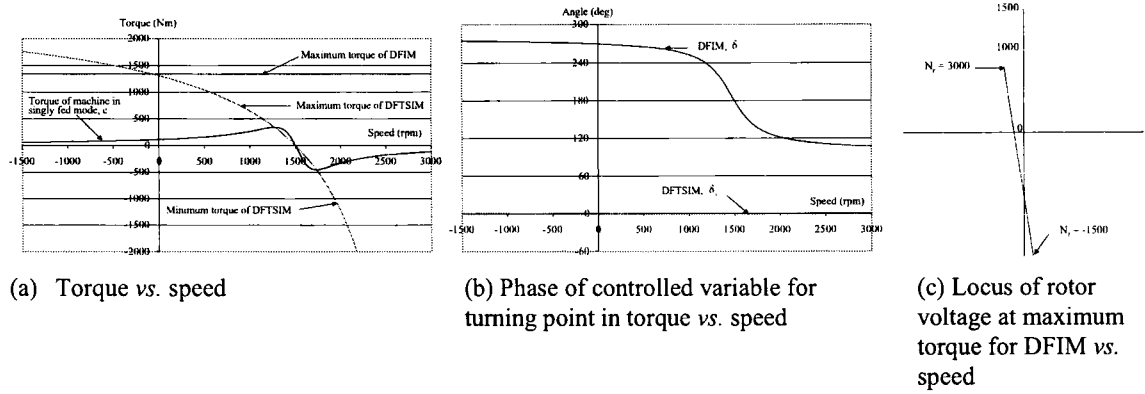


Fig.5 Operation at turning points of torque

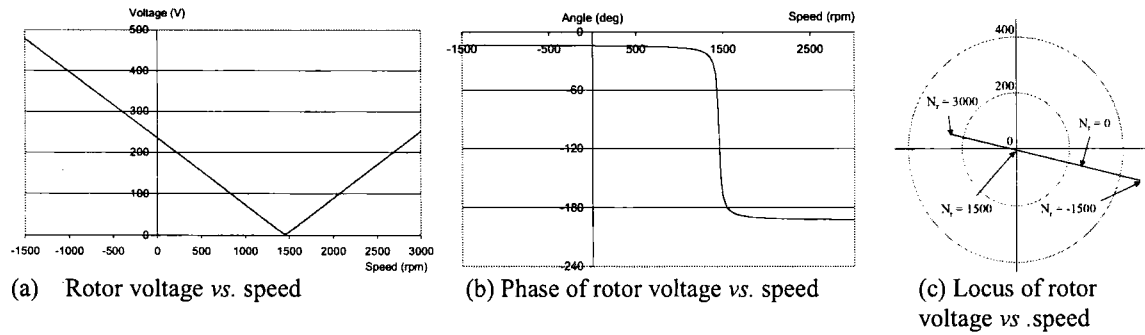


Fig.6 Operation of DFIM at unity power factor,  $T_e=180$  Nm

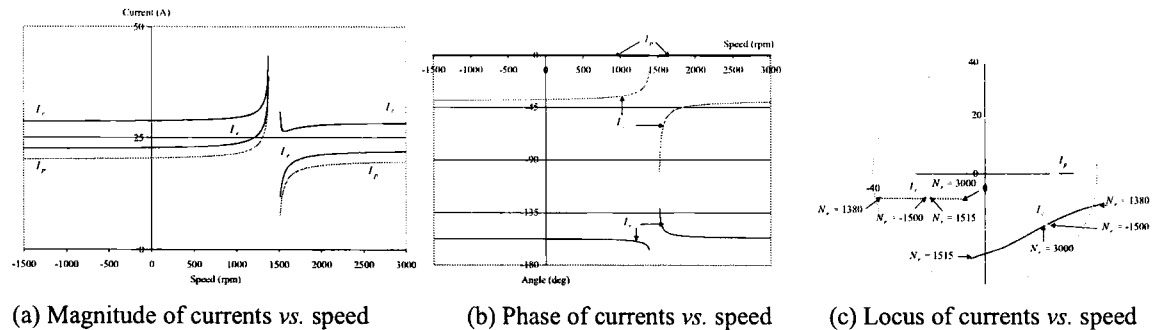


Fig.7 Operation of DFTSIM at unity power factor,  $T_e=180$  Nm

Australasian Universities Power Engineering Conference (AUPEC)  
**AUPEC2002**

**Producing Quality Electricity for Mankind**



Melbourne, Australia  
29<sup>th</sup> September to 2<sup>nd</sup> October 2002

## 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**

D. Seyoum, F. Rahman and C. Grantham

**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**

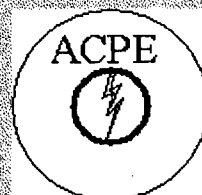
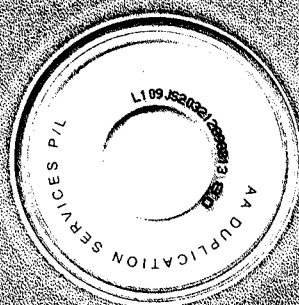
A. S. Peard, T. K. Saha, D. C. Sansom

**AUPEC 2002**

**Melbourne, Australia**

**29<sup>th</sup> September to 2<sup>nd</sup> October 2002**

**ISBN 0-7326-2206-9**



**MONASH**  
UNIVERSITY

**Origin**  
energy