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DUAL TWO PHASE MODEL OF SIX PHASE INDUCTION MOTOR

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ABSTRACT:
In the earlier works the three phase induction motor is replaced by its two phase equivalent by the phase transformation of unified machine theory [1]. This brings about a remarkable simplification in the mathematical form of the voltage equations of the machine. To derive the three phase to two phase transformation, magneto motive force distributions inside the machine is considered. On similar lines, six phase induction motor is replaced by dual two phase equivalent by dual two phase transformation C_1, Both Stator & Rotor equations are transformed by the dual two phase transformation C_1. Then the complete transformed Impedance Matrix is obtained. For normal conditions of operation and for most abnormal ones, zero sequence currents cannot flow. So, the zero sequence equations can conveniently be neglected. Finally, the voltage equations for the dual two phase wound rotor induction Motor with dual two phase rotor are obtained.

INTRODUCTION

Induction Motors can be built with any number of phases. The reason for considering more phases is to improve reliability since loss of a few of many phases does not prevent the motor from starting and running. Among the advantages are lower current per phase for a given voltage rating. Machines having more than three phases may be referred to as High Phase Order (HPO) machines. Unified machine theory can be applied to analyse the performance of all the diverse types of machines in terms of the voltage & Torque equations of basic machine. The reference [1] deals with unified theory of three phase Induction motor resolving into two phase components of α and β. On similar lines the six phase Induction motor is subjected to dual two phase transformation based on unified machine theory. Four component (Stator, rotor and mutuals) transformed Impedance Matrices are combined to give complete transformed Impedance Matrix. It can be rearranged to represent two systems, zero sequences and α, β, γ, δ sequences represented by their voltage equations. For normal conditions of operation and for most abnormal ones, zero sequence currents cannot flow, So, the zero sequence equations can conveniently be neglected. Remaining equations represent the dual two phase wound rotor Induction motor with dual two phase rotor. Results are verified with dual three phase transformation wherein the six phase system has been treated as two mutually coupled three phase systems [2] and are found to agree.

SIX PHASE INDUCTION MOTOR – DUAL TWO PHASE TRANSFORMATION C_1

The machine will first of all be subjected to the Dual two phase transformation C1. This has the effect of bringing the voltage equations, originally quite different, into closely similar form. The six phase wound rotor induction motor equations developed from first principles are transformed into significant equations of the equivalent dual two phase machine. The windings of the six phase Induction Motor are represented diagrammatically as shown in figure 1.

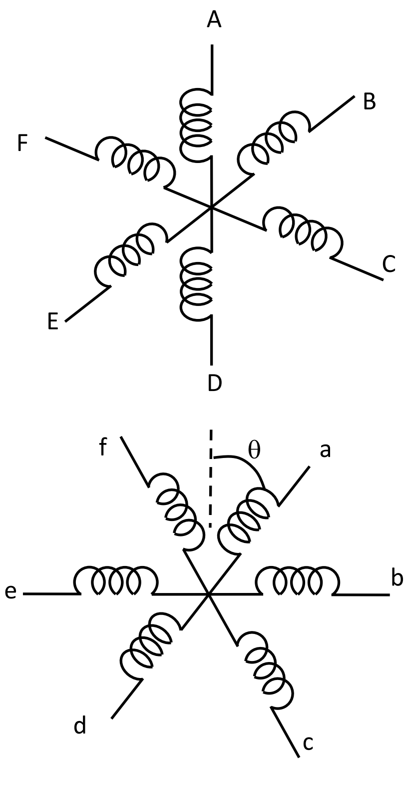

Figure 1

There are twelve voltage equations. The impedance Matrix therefore consists of 144 non-zero terms. To simplify the presentation of these equations, Compound Matrices will be used, the suffixes 1 and 2 being used for the stator and rotor windings respectively. Individual phase windings will be distinguished by capital letters A, B, C, D E, F for the stator and by small letters a, b, c, d, e, f for the rotor. The clockwise direction of rotation will be taken as positive. θ is the angle between Stator phase A and Rotor phase a.

In compound Matrix form the Voltage equation reads.

$$\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

Where V1 is the six phase Stator Voltage Column Vector, V2 is the six phase Rotor Voltage Column Vector

Both stator and rotor will later be transformed by the Dual two phase transformation C1 and it is convenient to derive the general form of the transformed impedance matrix at this point. The complete transformation in compound form is

$$\mathrm{C} = \begin{bmatrix} C_1 & \\ & C_1 \end{bmatrix}$$

So that the transformed impedance matrix becomes

$$Z^1 = C_t Z C = \begin{bmatrix} C_{1t} Z_{11} C_1 & C_{1t} Z_{12} C_1 \\ C_{1t} Z_{21} C_1 & C_{1t} Z_{22} C_1 \end{bmatrix}$$

Each element of the impedance matrix therefore transforms in the same and normal manner.

A. Stator/Stator Impedance Z_{11}

For the particular case where the rotor currents are zero, that is with the rotor windings on open circuit, the relationship between the stator voltages and stator currents is

$$V_1 = Z_{11}\, I_1$$

From first principles that is Faraday's law. The general form of this equation is known to be

$$\begin{bmatrix} V_A \\ V_B \\ V_C \\ V_D \\ V_E \\ V_F \end{bmatrix} = \begin{array}{c} \\ A \\ B \\ C \\ D \\ E \\ F \end{array} \begin{array}{c} \begin{array}{cccccc} A & B & C & D & E & F \end{array} \\ \begin{bmatrix} R_A + PL_A & PM_{AB} & PM_{AC} & PM_{AD} & PM_{AE} & PM_{AF} \\ PM_{BA} & R_B + PL_B & PM_{BC} & PM_{BD} & PM_{BE} & PM_{BF} \\ PM_{CA} & PM_{CB} & R_C + PL_C & PM_{CD} & PM_{CE} & PM_{CF} \\ PM_{DA} & PM_{DB} & PM_{DC} & R_D + PL_D & PM_{DE} & PM_{DF} \\ PM_{EA} & PM_{EB} & PM_{EC} & PM_{ED} & R_E + PL_E & PM_{EF} \\ PM_{FA} & PM_{FB} & PM_{FC} & PM_{FD} & PM_{FE} & R_F + PL_f \end{bmatrix} \end{array} \begin{bmatrix} i_A \\ i_B \\ i_C \\ i_D \\ i_E \\ i_F \end{bmatrix}$$

For the balanced six phase winding certain assumptions are made

1. The six windings have the same resistance & self inductance

2. Because of spatial symmetry the coefficients of mutual inductance are all same
3. Since in the case of a machine, a cylindrical air gap is being assumed, both the L & M terms will be independent of rotor position θ, and hence may be moved to the left of the operator p.

   Then the matrix assumes the symmetrical form

$$Z_{11} = \begin{array}{c} \\ A \\ B \\ C \\ D \\ E \\ F \end{array} \begin{array}{c} \begin{array}{cccccc} A & B & C & D & E & F \end{array} \\ \begin{bmatrix} R_1+L_1P & \overline{M}_1P & \overline{M}_1P & \overline{M}_1P & \overline{M}_1P & \overline{M}_1P \\ \overline{M}_1P & R_1+L_1P & \overline{M}_1P & \overline{M}_1P & \overline{M}_1P & \overline{M}_1P \\ \overline{M}_1P & \overline{M}_1P & R_1+L_1P & \overline{M}_1P & \overline{M}_1P & \overline{M}_1P \\ \overline{M}_1P & \overline{M}_1P & \overline{M}_1P & R_1+L_1P & \overline{M}_1P & \overline{M}_1P \\ \overline{M}_1P & \overline{M}_1P & \overline{M}_1P & \overline{M}_1P & R_1+L_1P & \overline{M}_1P \\ \overline{M}_1P & \overline{M}_1P & \overline{M}_1P & \overline{M}_1P & \overline{M}_1P & R_1+L_1P \end{bmatrix} \end{array}$$

The next step in the analysis is to transform this impedance matrix with the dual two phase transformation C1. This is a passive orthogonal Transformation

$$Z_{11}^1 = C_{1t}Z_{1t}C_1 = \begin{array}{c} \\ 0 \\ \gamma \\ \delta \\ 0^1 \\ \gamma^1 \\ \delta^1 \end{array} \begin{array}{c} \begin{array}{cccccc} 0 & \gamma & \delta & 0^1 & \gamma^1 & \delta^1 \end{array} \\ \begin{bmatrix} R_1+L_{10}P & 0 & 0 & 3M_1P & 0 & 0 \\ 0 & R_1+L_1P & 0 & 0 & 0 & 0 \\ 0 & 0 & R_1+L_1P & 0 & 0 & 0 \\ 3M_1P & 0 & 0 & R_1+L_{10}P & 0 & 0 \\ 0 & 0 & 0 & 0 & R_1+L_1P & 0 \\ 0 & 0 & 0 & 0 & 0 & R_1+L_1P \end{bmatrix} \end{array}$$

Where $L_{10} = L_1 + 2\overline{M_1}$ $\quad$ $L_1 = L_1 - \overline{M_1}$

B. Rotor to Stator Impedance Z_{21}

The mutual inductance between stator and rotor are the keystone of induction motor performance. The coefficients of mutual inductance vary with rotor position and for the particular case of two phases $M_{a,A}$ was assumed to be of the form $M_{a,A} = \overline{M}\cos\theta + \overline{M_3}\cos 3\theta$ where θ is the angle between Stator phase A and Rotor Phase a.

Identical curves were found for $M_{b,B}$, $M_{c,C}$, $M_{d,D}$, $M_{e,E}$, $M_{f,F}$

The six curves for Mb,A, Mc,B, Md,C, Me,D, Mf,E, Ma,F were also equal to each other and of the form

$M_{b,A} = \overline{M}P\ \mathrm{Cos}\ \theta_2 - \overline{M_3}P\ \mathrm{Cos}\ 3\theta$

Where $\theta_2 = \theta + 60^0$

The six curves for Mc,A, Md,B, Me,C,Mf,D, Ma,E, Mb,F were also equal to each other and of the form

$M_{c,A} = \overline{M}P\ \mathrm{Cos}\ \theta_3 + \overline{M_3}P\ \mathrm{Cos}\ 3\theta$

Where $\theta_3 = \theta + 120^0$

The six curves for Md,A, Me,B,Mf,C, Ma,D, Mb,E, Mc,F were also equal to each other and of the form

$M_{d,A} = -\overline{M}P\ \mathrm{Cos}\ \theta - \overline{M_3}P\ \mathrm{Cos}\ 3\theta$

The six curves for Me,A, Mf,B,Ma,C, Mb,D, Mc,E, Md,F were also equal to each other and of the form

$M_{e,A} = -\bar{M}\,P\ \mathrm{Cos}\ \theta_2 + \bar{M}_3 P\ \mathrm{Cos}\,3\theta$

The six curves for Mf,A, Ma,B,Mb,C, Mc,D, Md,E, Me,F were also equal to each other and of the form

$M_{f,A} = -\bar{M}\,P\ \mathrm{Cos}\ \theta_3 - \bar{M}_3 P\ \mathrm{Cos}\,3\theta$

The complete Impedance Matrix may be written

$$Z_{21} = \begin{array}{c} \\ a \\ b \\ c \\ d \\ e \\ f \end{array} \begin{array}{c} \begin{array}{ccc} A & B & C \end{array} \\ \left[\begin{array}{ccc}
\bar{M}P\mathrm{Cos}\theta + \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta_3 - \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta_2 + \bar{M}_3P\mathrm{Cos}3\theta \\
\bar{M}P\mathrm{Cos}\theta_2 - \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta + \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta_3 - \bar{M}_3P\mathrm{Cos}3\theta \\
\bar{M}P\mathrm{Cos}\theta_3 + \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta_2 - \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta + \bar{M}_3P\mathrm{Cos}3\theta \\
-\bar{M}P\mathrm{Cos}\theta - \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta_3 + \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta_2 - \bar{M}_3P\mathrm{Cos}3\theta \\
-\bar{M}P\mathrm{Cos}\theta_2 + \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta - \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta_3 + \bar{M}_3P\mathrm{Cos}3\theta \\
-\bar{M}P\mathrm{Cos}\theta_3 - \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta_2 + \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta_3 - \bar{M}_3P\mathrm{Cos}3\theta
\end{array}\right. \end{array}$$

$$\begin{array}{c} \begin{array}{ccc} D & E & F \end{array} \\ \left.\begin{array}{ccc}
-\bar{M}P\mathrm{Cos}\theta - \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta_3 + \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta_2 - \bar{M}_3P\mathrm{Cos}3\theta \\
-\bar{M}P\mathrm{Cos}\theta_2 + \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta - \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta_3 + \bar{M}_3P\mathrm{Cos}3\theta \\
-\bar{M}P\mathrm{Cos}\theta_3 - \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta_2 + \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta - \bar{M}_3P\mathrm{Cos}3\theta \\
\bar{M}P\mathrm{Cos}\theta + \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta_3 - \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta_2 + \bar{M}_3P\mathrm{Cos}3\theta \\
\bar{M}P\mathrm{Cos}\theta_2 - \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta + \bar{M}_3P\mathrm{Cos}3\theta & -\bar{M}P\mathrm{Cos}\theta_3 - \bar{M}_3P\mathrm{Cos}3\theta \\
\bar{M}P\mathrm{Cos}\theta_3 + \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta_2 - \bar{M}_3P\mathrm{Cos}3\theta & \bar{M}P\mathrm{Cos}\theta + \bar{M}_3P\mathrm{Cos}3\theta
\end{array}\right] \end{array}$$

It is convenient to carry out the transformation for the fundamental and third harmonic separately. The first stage in the transformation of the fundamental is

$$C_{1t}Z_{21}C_1 = M \begin{array}{c} \\ 0 \\ \alpha \\ \beta \\ 0^1 \\ \alpha^1 \\ \beta^1 \end{array} \begin{array}{c} \begin{array}{cccccc} 0 & \gamma & \delta & 0^1 & \gamma^1 & \delta^1 \end{array} \\ \left[\begin{array}{cccccc}
0 & 0 & 0 & 0 & 0 & 0 \\
0 & P\mathrm{Cos}\theta & P\mathrm{Sin}\theta & 0 & P\mathrm{Cos}\theta & P\mathrm{Sin}\theta \\
0 & -P\mathrm{Sin}\theta & P\mathrm{Cos}\theta & 0 & -P\mathrm{Sin}\theta & P\mathrm{Cos}\theta \\
0 & 0 & 0 & 0 & 0 & 0 \\
0 & P\mathrm{Cos}\theta & P\mathrm{Sin}\theta & 0 & P\mathrm{Cos}\theta & P\mathrm{Sin}\,\theta \\
0 & -P\mathrm{Sin}\theta & P\mathrm{Cos}\theta & 0 & -P\mathrm{Sin}\theta & P\mathrm{Cos}\theta
\end{array}\right] \end{array}$$

$$\text{Where } M = \frac{3}{2}\bar{M}$$

Transformation with C1 therefore appreciably simplifies the form of the fundamental component twenty terms becoming zero, the remaining sixteen being sine and cosine functions of θ, the angles θ2 and θ3 having disappeared. Transformation of the third harmonic terms is simplified by the fact that the quantity $\bar{M}_3 P\mathrm{Cos}\,3\theta$ is a constant factor in the multiplication. The first stage gives

$$0\ \alpha\ \beta\ 0^1\ \alpha^1\ \beta^1$$

$$C_{1t} Z_{21} C_1 = M_3 P\,Cos 3\theta \quad \begin{array}{c} 0 \\ \alpha \\ \beta \\ 0^1 \\ \alpha^1 \\ \beta^1 \end{array} \begin{bmatrix} 1 & 0 & 0 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Where $M_3 = 3\overline{M}_3$

The simplifications in the third harmonic terms are appreciable, only four terms remaining. Adding the fundamental and third harmonic terms gives the complete transformed matrix.

$$Z^1_{21} = \begin{array}{c} \\ 0 \\ \alpha \\ \beta \\ 0^1 \\ \alpha^1 \\ \beta^1 \end{array} \begin{array}{c} \begin{array}{cccccc} 0 & \gamma & \delta & 0^1 & \gamma^1 & \delta^1 \end{array} \\ \begin{bmatrix} M_3 P Cos 3\theta & 0 & 0 & -M_3 P\ Cos 3\theta & 0 & 0 \\ 0 & MP\ Cos\theta & MP\ Sin\theta & 0 & MP Cos\theta & MP Sin\theta \\ 0 & -MP Sin\theta & MP\ Cos\ \theta & 0 & -MP Sin\theta & MP Cos\theta \\ -M_3 P Cos 3\theta & 0 & 0 & M_3 P\ Cos 3\theta & 0 & 0 \\ 0 & MP\ Cos\ \theta & MP\ Sin\ \theta & 0 & MP Cos\theta & MP\ Sin\ \theta \\ 0 & -MP\ Sin\ \theta & MP Cos\theta & 0 & -MP Sin\theta & MP\ Cos\theta \end{bmatrix} \end{array}$$

C. Stator / Rotor Impedance Z^{12}

The Impedance Matrix Z12 is therefore the impedance Z21 with its elements transposed, that is with rows & columns interchanged

$$Z_{12} = Z_{21t}$$
$$Z^1_{12} = C_{1t} Z_{12} C_1$$
$$= (C_{1t} Z_{12t} C_1)_t$$
$$= (C_{1t} Z_{21} C_1)_t$$
$$= Z^1_{21t}$$

The transform of Z12 is therefore the transpose of the transform of Z21

D. Rotor/Rotor Impedance: Z_{22}

Each rotor phase winding is assumed to have the same resistance and self-inductance, Because of the smooth air gap all the coefficients are independent of angular position θ.

The rotor self impedance matrix Z22 may therefore be written in the form

$$Z_{22} = \begin{array}{c} \\ a \\ b \\ c \\ d \\ e \\ f \end{array} \begin{array}{c} \begin{array}{cccccc} a & b & c & d & e & f \end{array} \\ \begin{bmatrix} R_2 + L_2 P & \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P \\ \overline{M}_2 P & R_2 + L_2 P & \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P \\ \overline{M}_2 P & \overline{M}_2 P & R_2 + L_2 P & \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P \\ \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P & R_2 + L_2 P & \overline{M}_2 P & \overline{M}_2 P \\ \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P & R_2 + L_2 P & \overline{M}_2 P \\ \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P & \overline{M}_2 P & R_2 + L_2 P \end{bmatrix} \end{array}$$

The Transformed impedance Matrix is

$$0\ \alpha\ \beta\ 0^1\ \alpha^1\ \beta^1$$

$$Z_{22}^1 = C_{1t} Z_{22} C_1 = \begin{array}{c} 0 \\ \alpha \\ \beta \\ 0^1 \\ \alpha^1 \\ \beta^1 \end{array} \begin{bmatrix} R_2 + L_{20}P & 0 & 0 & 3M_2 P & 0 & 0 \\ 0 & R_2 + L_2 P & 0 & 0 & 0 & 0 \\ 0 & 0 & R_2 + L_2 P & 0 & 0 & 0 \\ 3M_2 P & 0 & 0 & R_2 + L_{20}P & 0 & 0 \\ 0 & 0 & 0 & 0 & R_2 + L_2 P & 0 \\ 0 & 0 & 0 & 0 & 0 & R_2 + L_2 P \end{bmatrix}$$

Where $L_{20} = L_2 + 2\overline{M}_2 \qquad L_2 = L_2 - \overline{M}_2$

COMPLETE TRANSFORMED IMPEDANCE MATRIX

It is now possible to combine the four component (stator, rotor with mutuals) transformed impedance matrices together to form the complete transformed matrix. The result is

$$z^1 = \begin{array}{c} \\ 0 \\ \gamma \\ \delta \\ 0^1 \\ \gamma^1 \\ \delta^1 \\ 0 \\ \alpha \\ \beta \\ 0^1 \\ \alpha^1 \\ \beta^1 \end{array} \begin{array}{c} \begin{array}{cccccccccccc} 0 & \gamma & \delta & 0^1 & \gamma^1 & \delta^1 & 0 & \alpha & \beta & 0^1 & \alpha^1 & \beta^1 \end{array} \\ \begin{bmatrix} R_1 + L_{10}P & 0 & 0 & 3M_1P & 0 & 0 & M_3PCos3\theta & 0 & 0 & -M_3PCos3\theta & 0 & 0 \\ 0 & R_1 + L_1P & 0 & 0 & 0 & 0 & 0 & MPCos\theta & -MP\sin\theta & 0 & MPCos\theta & -MP\sin\theta \\ 0 & 0 & R_1 + L_1P & 0 & 0 & 0 & 0 & MP\sin\theta & MP\cos\theta & 0 & MP\sin\theta & MP\cos\theta \\ 3M_1P & 0 & 0 & R_1 + L_{10}P & 0 & 0 & -M_3PCos3\theta & 0 & 0 & M_3PCos3\theta & 0 & 0 \\ 0 & 0 & 0 & 0 & R_1 + L_1P & 0 & 0 & MPCos\theta & -MPSin\theta & 0 & MPCos\theta & -MP\sin\theta \\ 0 & 0 & 0 & 0 & 0 & R_1 + L_1P & 0 & MP\sin\theta & MP\cos\theta & 0 & MPSin\theta & MP\cos\theta \\ M_3PCos3\theta & 0 & 0 & -M_3PCos3\theta & 0 & 0 & R_2 + L_{20}P & 0 & 0 & 3M_2P & 0 & 0 \\ 0 & MPCos\theta & -MPSin\theta & 0 & MPCos\theta & MPSin\theta & 0 & R_2 + L_2P & 0 & 0 & 0 & 0 \\ 0 & -MPSin\theta & MPCos\theta & 0 & -MPSin\theta & MPCos\theta & 0 & 0 & R_2 + L_2P & 0 & 0 & 0 \\ -M_3PCos3\theta & 0 & 0 & M_3PCos3\theta & 0 & 0 & 3M_2P & 0 & 0 & R_2 + L_{20}P & 0 & 0 \\ 0 & MPCos\theta & MPSin\theta & 0 & MPCos\theta & MPSin\theta & 0 & 0 & 0 & 0 & R_2 + L_2P & 0 \\ 0 & -MPSin\theta & MPCos\theta & 0 & -MPSin\theta & MPCos\theta & 0 & 0 & 0 & 0 & 0 & R_2 + L_2P \end{bmatrix} \end{array}$$

When the fourth, seventh and tenth rows & columns are moved up to second, third and fourth positions, a compound matrix of the form

$$Z^1 = \begin{bmatrix} z_0 & \\ & z \end{bmatrix}$$

Results, which possess the important property of having, terms on the leading diagonal only. It follows that the two systems represented by the two voltage equations

$$V_0 = Z_0 I_0$$
$$V = ZI$$

Have no connection or mutual reaction between them and may therefore be treated quite independently. The complete voltage equation for the zero sequence quantities reads

$$\begin{bmatrix} v_{10} \\ v_{20} \\ v_{30} \\ v_{40} \end{bmatrix} = \begin{bmatrix} R_1 + L_{10}P & 3M_1P & M_3P\,Cos3\theta & -M_3P\,Cos3\theta \\ 3M_1P & R_1 + L_{10}P & -M_3P\,Cos3\theta & M_3P\,Cos3\theta \\ M_3P\,Cos3\theta & -M_3P\,Cos3\theta & R_2 + L_{20}P & 3M_2P \\ -M_3P\,Cos3\theta & M_3P\,Cos3\theta & 3M_2P & R_2 + L_{20}P \end{bmatrix} \begin{bmatrix} i_{10} \\ i_{20} \\ i_{30} \\ i_{40} \end{bmatrix}$$

At present it is sufficient to notice that a zero sequence current can only flow in the rotor if there is an external (slip ring) connection to the star point and that this is not a condition, which obtain in a practical machine.

Furthermore a stator zero sequence current can only flow if there is a six phase seven wire supply. Not only must the seventh wire be present but there must be a steady out-of-balance current in the wire. It follows that for normal conditions of operation and for most abnormal ones zero sequence currents cannot flow. The equation above may therefore conveniently be neglected. There remains the voltage equation.

$$\begin{array}{cccc} & & & \begin{array}{cccc} \gamma & \delta & \gamma^1 & \delta^1 \end{array} \\ \begin{bmatrix} v_{\gamma} \\ v_{\delta} \\ v_{\gamma^1} \\ v_{\delta^1} \\ v_{\alpha} \\ v_{\beta} \\ v_{\alpha^1} \\ v_{\beta^1} \end{bmatrix} & = & \begin{array}{c} \gamma \\ \delta \\ \gamma^1 \\ \delta^1 \\ \alpha \\ \beta \\ \alpha^1 \\ \beta^1 \end{array} & \left[\begin{array}{cccc} R_1 + L_1P & 0 & 0 & 0 \\ 0 & R_1 + L_1P & 0 & 0 \\ 0 & 0 & R_1 + L_1P & 0 \\ 0 & 0 & 0 & R_1 + L_1P \\ MPCos\theta & MP\sin\theta & MPCos\theta & MPSin\theta \\ -MPSin\theta & MPCos\theta & -MPSin\theta & MPCos\theta \\ MPCos\theta & MPSin\theta & MPCos\theta & MPSin\theta \\ -MPSin\theta & MPCos\theta & -MPSin\theta & MPCos\theta \end{array} \right. \end{array}$$

$$\begin{array}{ccc} \begin{array}{cccc} \alpha & \beta & \alpha^1 & \beta^1 \end{array} & & \\ \left. \begin{array}{cccc} MPCos\theta & -MPSin\theta & MPCos\theta & -MPSin\theta \\ MPSin\theta & MPCos\theta & MPSin\theta & MPCos\theta \\ MPCos\theta & -MPSin\theta & MPCos\theta & -MPSin\theta \\ MPSin\theta & MPCos\theta & MPSin\theta & MPCos\theta \\ R_2 + L_2P & 0 & 0 & 0 \\ 0 & R_2 + L_2P & 0 & 0 \\ 0 & 0 & R_2 + L_2P & 0 \\ 0 & 0 & 0 & R_2 + L_2P \end{array} \right] & = & \begin{bmatrix} i_{\gamma} \\ i_{\delta} \\ i_{\gamma^1} \\ i_{\delta^1} \\ i_{\beta} \\ i_{\alpha} \\ i_{\alpha^1} \\ i_{\beta^1} \end{bmatrix} \end{array}$$

This is the voltage equation for the dual two-phase wound rotor induction motor with dual two phase rotor and represented diagrammatically in Figure 2.

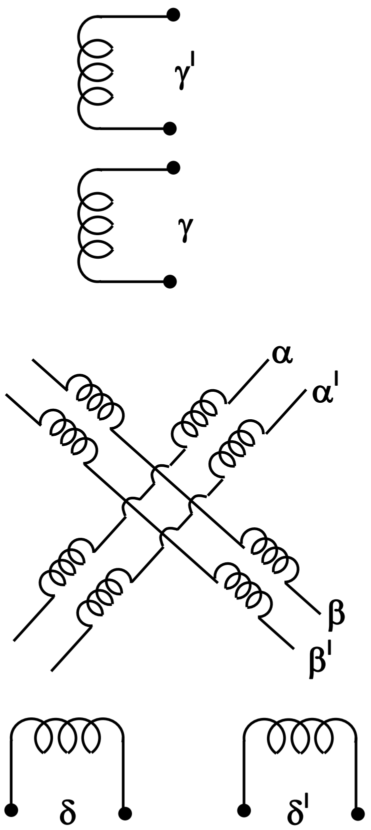

Figure 2

COMPARISON WITH DTPT METHOD

The transformed impedance matrices for Stator/Stator, Rotor/Rotor, Stator to Rotor, Rotor to Stator are found by Dual two phase transformation C1. The four component matrices (Stator, Rotor with mutuals) are combined to form complete transformed impedance matrix. For normal conditions of operation and for most abnormal ones, zero sequence currents cannot flow. So, the zero sequence equations are conveniently neglected. Finally the voltage equations for the Dual two phase wound rotor Induction Motor with Dual two phase rotor are obtained. The above results are verified by the Dual three phase transformation (DTPT) method where the six phase system has been treated as two mutually coupled three phase systems [2] and are found to agree.

CONCLUSIONS

The voltage equations of the Dual two phase model of six phase Induction motor have been developed and the results fully agree with the Dual three phase transformation (DTPT) method where the six phase system has been treated as two mutually coupled three phase systems [2].

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