ABSTRACT

In the earlier works the Three Phase Induction Motor is replaced by its two phase equivalent by the two phase transformation of unified theory of Electrical Machines. To arrive at the three phase to two phase transformation magnetomotive force distributions inside the machine is considered. This brings about a remarkable simplification in the mathematical form of the voltage equations of the machine. In the three phase Induction motor the stator quantities are resolved into two phase axes γ and δ & rotor quantities into α and β axes. Similarly for six phase Induction motor the stator quantities are resolved into dual two phase axes γ, δ : γ ₁, δ ₁ where as rotor quantities are resolved into dual two phase axes α , β : α ₁, β ₁ ( α , α ₁ are in phase so also β, β ₁, γ, γ ₁ and δ, δ ₁) treating six phase system as two mutually coupled three phase system to get dual two phase transformation matrix C₁. Both stator & rotor equations are subjected to the dual two phase transformation using dual two phase transformation matrix C₁. It is now possible to combine four component ( stator, rotor with mutuals ) transformed impedance matrices together to form the complete transformed impedance matrix. The complete transformed impedance matrix can be rearranged to represent two systems, zero sequences and dual two phase wound rotor Induction motor with dual two phase rotor. For normal conditions of operation and for most abnormal ones, zero sequence currents can not 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 . These equations are functions of θ where θ is the angle between stator phase A and rotor phase a.

As the machine rotates, θ varies with rotor position and hence with time. Alternating currents and Inductance coefficients also vary with time. The machine equations are non linear because of the presence of functions of rotor angle θ. Another transformation called commutator Transformation C₂ is applied to eliminate functions of θ from the impedance matrix but the angular velocity of the machine makes its appearance. This will linearize the equations to determine the performance of the
The performance of six phase Induction motor under balanced conditions of operation is considered. A rotating m.m.f wave of constant amplitude is produced when six phase windings are excited by balanced six phase currents when the respective phases are wound \( (2\pi/6) \) electrical radians apart in space. For normal balanced operation of six phase Induction motor, the voltage equations are obtained by assuming that all the currents and voltages in both the stator and rotor are balanced and sinusoidal. In the voltage equations, four of the equations are constant multiples \((-j)\) of the other four equations meaning that in the equivalent dual two phase machine the currents and voltages are balanced two phase quantities. The voltage equations are simplified and equivalent circuit is drawn. Torque is calculated from the equivalent circuit. Torque is also calculated from the basic torque equation. The results fully agree with each other. The torque is found to be twice the torque developed by three phase Induction motor. The output (slip-Torque) characteristic of the six-phase Induction motor is drawn. At lower slip values torque is proportional to slip. At higher slip values the relationship between the slip and torque is hyperbolic.

The unbalance operation of six phase Induction motor is where the stator windings are connected to a balanced six phase supply in the normal manner but one or more out of six phases of the wound rotor are open. This may arise in practice due to a broken connection or wear & tear of the brushes. This unbalanced operation is broadly classified into four types in which a total of 56 cases are analysed. These four types are rotor with one phase open, rotor with two phases open, rotor with three phases open and rotor with four phases open. The analysis is done in terms of the familiar three phase symmetrical components using Dual Three Phase Transformation (D T P T) method where in the six phase system is treated as two mutually coupled three phase systems. The response of the six phase Induction motor to these sequence voltages are quite independent.

In the analysis of six phase system using Dual Three Phase Transformation (D T P T) it is
found that there is coupling only between the zero sequence components of the two three phase systems. Positive and negative sequence couplings are not present. The zero sequence currents in the two three phase systems flow in opposite directions. The effect of one is cancelled by the other and the heating effect due to dissipation in resistance is zero. Hence, performance is improved.

When one phase out of rotor six phases of slip ring motor is open, torque is calculated which is the sum of positive sequence torque and negative sequence torque. Torque is obtained in terms of the familiar three phase symmetrical components using Dual Three Phase Transformation (DTPT) method where in the six phase system is treated as two mutually coupled three phase systems. Torque obtained when one rotor phase is open is above 85% of normal total torque when the six phase rotor is shortcircuited. Torque is also calculated from the equivalent circuit. Both results agree with each other. Here six cases are analysed.

When two phases out of rotor six phases of slipring motor are open, torque is calculated which is the sum of positive sequence torque and negative sequence torque. Torque is obtained in terms of the familiar three phase symmetrical components using Dual Three Phase Transformation (DTPT) method where in the six phase system is treated as two mutually coupled three phase systems. Torque obtained when two rotor phases are open is above 67% of normal total torque when the six phase rotor is short circuited. Torque is also calculated from the equivalent circuit. Both results agree with each other. Here fifteen cases are analysed.

When three phases of 120° phase difference are open it works as three phase Induction motor giving 50% of the total six phase torque. When any three phases of rotor six phases are open it develops 45% of normal total torque when the six phase rotor is short circuited. Torque is also calculated from the equivalent circuit. Both the results agree with each other. Here twenty cases are analysed.

When any four phases of rotor six phases are open it develops 25% of normal total torque
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when the six phase rotor is short circuited. The total torque is also calculated from the equivalent circuit. Both the results agree with each other. Here fifteen cases are analysed.

Hence, reliability is more in the six phase Induction motor compared to the three phase Induction motor. It works satisfactorily even when four phases of the rotor are open. It works as three phase Induction motor when any three phases of rotor are open with a torque little less than the conventional three phase Induction motor.

Hence, the six phase Induction motor gives better performance, better reliability, twice the torque as compared to three phase Induction motor.
RELATED RESEARCH PAPERS

1. B. Brahmaiah, Dr. P. S. Subramanyam - 'Unbalanced operation of six phase Induction motor - Rotor with three phases open' published in the proceedings of 'International congress & Exhibition' organised by 'National Foundation of Indian Engineers', Ministry of Science and Technology, Govt. of India, Supported by ASSOCHAM, TWAS, ITALY held in New Delhi in Dec- 2000.

2. B. Brahmaiah, Dr. P. S. Subramanyam - 'Unbalanced operation of six phase Induction motor - Rotor with four phases open' published in the proceedings of 'International congress & Exhibition' organised by 'National Foundation of Indian Engineers', Ministry of Science and Technology, Govt. of India, Supported by ASSOCHAM, TWAS, ITALY held in New Delhi in Dec- 2000.

3. B. Brahmaiah, Dr. P. S. Subramanyam - 'Dual two phase Model of six phase Induction motor' communicated to 'Electric Power Systems Research' Journal USA.

4. B. Brahmaiah, Dr. P. S. Subramanyam - 'Linear Model of six phase Induction motor' communicated to 'Electric Machines & Power Systems' Journal USA.

5. B. Brahmaiah, Dr. P. S. Subramanyam - 'Six Phase Induction motor - Performance' communicated to 'Electric Machines & Power systems' Journal USA.

6. B. Brahmaiah, Dr. P. S. Subramanyam - 'Unbalanced operation of six phase Induction motor - Rotor with one phase open' communicated to 'Electric Machines & Power systems' Journal USA.

7. B. Brahmaiah, Dr. P. S. Subramanyam - 'Unbalanced operation of six phase slipring Induction-motor Rotor with Two phases Open' Communicated to 'IEE Proceedings - Electric power applications' journal, U.K.
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LIST OF NOTATIONS

$C_1$ : Dual Two phase transformation
$C_2$ : Commutator transformation
$\theta$ : Angle between stator phase 'A' and rotor phase 'a'
$\gamma, \delta$ : One set of two phase axes of stator.
$\gamma', \delta'$ : Second set of two phase axes of stator.
$\alpha, \beta$ : One set of two phase axes of rotor.
$\alpha', \beta'$ : Second set of two phase axes of rotor.
$\omega$ : Angular velocity of rotation.
$A, B, C, D, E, F$ : Winding Phases of stator.
$a, b, c, d, e, f$ : Winding Phases of rotor.
$Z_{11}$ : Stator to stator impedance
$Z_{12}$ : Stator to rotor impedance
$Z_{21}$ : Rotor to stator impedance
$Z_{22}$ : Rotor to rotor impedance
$[V_1]$ : Six phase stator voltage column vector.
$[V_2]$ : Six phase rotor voltage column vector.
$C$ : Complete transformation matrix for dual two phase transformation.
$C'$ : Complete transformation matrix for commutator transformation.
$Z'$ : Transformed impedance matrix after dual two phase transformation.
$Z''$ : Transformed impedance matrix after dual two phase transformation & commutator transformation.
d, q : One set of Stationary axes.
d', q' : Second set of stationary axes.
$F_{max}$ : Maximum value of the m.m.f. wave
$I_m$ : Maximum value of the phase current

i_a : Instantaneous value of the phase 'a' current

\( i_b \) : Instantaneous value of the phase 'b' current

\( i_c \) : Instantaneous value of the phase 'c' current

\( i_d \) : Instantaneous value of the phase 'd' current

\( i_e \) : Instantaneous value of the phase 'e' current

\( i_f \) : Instantaneous value of the phase 'f' current

\( F_{\text{m.m.f}} \) : Maximum value of m.m.f. wave of phase a

\( F(\theta) \) : Resultant m.m.f. at point \( \theta \).

\( V_1 \) : rms value of voltage in one phase of first three phase set of stator of six phase Induction motor.

\( I_1 \) : rms value of current in one phase of first three phase set of stator of six phase Induction motor.

\( V_1' \) : rms value of voltage in one phase of second three phase set of stator of six phase Induction motor.

\( I_1' \) : rms value of current in one phase of second three phase set of stator of six phase Induction motor.

\( V_2 \) : rms value of voltage in one phase of first three phase set of rotor of six phase Induction motor.

\( I_2 \) : rms value of current in one phase of first three phase set of rotor of six phase Induction motor.

\( V_2' \) : rms value of voltage in one phase of second three phase set of rotor of six phase Induction motor.

\( I_2' \) : rms value of current in one phase of second three phase set of rotor of six phase Induction motor.

\( R_1 \) : Stator Resistance/Phase

\( X_1 \) : Stator Reactance/Phase

\( R_2 \) : Rotor Resistance/Phase

\( X_2 \) : Rotor Reactance/Phase

\( R_a \) : Resistance / Phase of the busbars
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<td>$X_s$</td>
<td>Reactance / Phase of the busbars</td>
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<td>$G$</td>
<td>Matrix of set of Coefficients of $\omega$ in the impedance matrix.</td>
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<td>$S$</td>
<td>Slip</td>
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<td>$I_a$</td>
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Negative sequence Voltage of rotor of 2nd three phase set of six phase Induction motor.

Zero sequence Voltage of stator of 1st three phase set of six phase Induction motor.

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Zero sequence Current of stator of 1st three phase set of six phase Induction motor.

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Negative sequence Current of stator of 1st three phase set of six phase Induction motor.

Zero sequence Current of stator of 2nd three phase set of six phase Induction motor.

Positive sequence Current of stator of 2nd three phase set of six phase Induction motor.

Negative sequence Current of stator of 2nd three phase set of six phase Induction motor.

Positive Sequence Torque

Negative Sequence Torque

Total Torque