CHAPTER - 1

INTRODUCTION

Increase of power transfer capability of a transmission system leading to economic and efficient use of right-of-way is a problem faced by developed countries. Sooner or later this problem will be faced by developing countries as well. High Phase Order (HPO) system or Multi Phase Transmission (MPT) system or compact line design or a combination of both helps in over coming this problem. A compact six phase line can be had with a considerably small transmission corridor, because it had been found that when phase vector coincides with space vector a clearance of as little as 3 feet was found to be sufficient between adjacent lines of six phase line with 80 KV phase to ground voltage. Also conversion of existing 138 KV three phase line (The phase voltages remains same) increases the power transfer capability to 1.732 times maintaining the same conductor configuration and right-of-way with better efficiency, better voltage regulation, greater stability and greater reliability.

The above advantages led to research to switch over to multi phase (six phase) machines. 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.

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 $\gamma$ and $\delta$ & rotor quantities into $\alpha$ and $\beta$ axes. Similarly for six phase Induction motor the stator quantities are resolved into dual two phase axes $\gamma, \delta$; $\gamma', \delta'$ where as rotor quantities are resolved into dual
two phase axes $\alpha, \beta; \alpha^l, \beta^l$ ( $\alpha, \alpha^l$ are in phase so also $\beta, \beta^l$ and $\gamma, \gamma^l$ and $\delta, \delta^l$) treating six phase system as two mutually coupled three phase system to get dual two phase transformation matrix $C_1$. Both stator & rotor equations are subjected to the dual two phase transformation using dual two phase transformation matrix $C_1$. 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 $\theta$ where $\theta$ is the angle between stator phase $A$ and rotor phase $a$. As the machine rotates, $\theta$ 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 $\theta$.

The commutator transformation $C_2$ may be looked upon as the solution to the purely mathematical problem of finding a substitution which will eliminate $\theta$. This transformation is classified as live because it includes $\theta$, which is a function of time. Commutator transformation $C_2$ will only be applied to the rotor currents and voltages. The stator quantities are left unchanged by the commutator transformation $C_2$.

The physical effect of this transformation is therefore to replace the actual rotor windings, the axes of whose m.m.f's rotate with the rotor by equivalent fictitious rotor windings, the axes of whose m.m.f's remain fixed in space that is with respect to the stator. This justifies the use of the suffixes d and q. This fixing of the winding axes whilst the windings themselves rotate is more over, exactly what is accomplished physically by the fixing of a commutator to the machine. This explains
why the transformed voltage equations are those of an actual commutator machine and also justifies the name given to the transformation.

The transformation called commutator transformation $C_2$ (transformation from rotating axes to stationary axes) is applied to eliminate functions of $\theta$ 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 machine.

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. It follows that the normal vector representation may be adopted. 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 practical importance of the leakage reactance is apparent from the torque equation. It plays a predominant part in determining the maximum torque available from a particular machine. Although the maximum torque is fixed, the speed at which this torque occurs may vary.

The analysis of the performance of the six phase Induction motor under unbalanced conditions
of operation is analysed by using unified theory of Electrical machines. Torque is evaluated from the general torque equation in terms of 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.

The most interesting case of unbalanced operation for the 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 in the case of slipring Induction motor 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 (DTPT) 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 three phase symmetrical component systems, we find that positive sequence supply gives rise to the normal positive motoring torque, the negative sequence supply to a backward braking torque, whilst the zero sequence makes no contribution to the torque but is dissipated in resistance.

In the analysis of six phase system using Dual Three Phase Transformation (DTPT) method 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 slipring motor is open, torque is calculated which is the sum of positive sequence torque and negative sequence torque. Torque is evaluated from the general torque equation in 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 short circuited. The equivalent circuit is constructed from the sequence equations obtained. The total torque as distinct from its positive and negative sequence components may be determined from the equivalent circuit. Both results agree with each other. Here six cases are analysed.

When two phases out of rotor six phases of slip ring motor are open, torque is calculated. Torque is obtained from the general torque equation in 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 is above 67% of normal total torque where the six phase rotor is short circuited. The equivalent circuit is constructed from the sequence equations obtained. The total torque as distinct from its positive and negative sequence components may be determined 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. Total torque is also determined 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 when the six phase rotor is short circuited. Also the total torque is determined 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 as 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.