Comparison of Performances of Six Phase Induction Motor Consisting of Dual Three Phase Windings fed from Sinusoidal Voltage and Current Sources under Normal and Abnormal Operating Conditions

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Abstract - Multiphase induction machines have been an interesting topic of research due to their inherent architecture. In this study six phase induction machines both voltage and fed drive types were considered for analysis. Mathematical model of the drive system was developed. Control systems considering Field Orientation Control (FOC) were developed for both the voltage and current fed drives. A dual three phase machine with 20o, 30o and 40o for voltage fed machine were considered for comparison of performances. Simulation study was conducted using c++ codes. The studies for starting, speed reversal, sudden load torque disturbances and faulty conditions were conducted. The machine with 20o phase displacement showed faster response in comparison to others. In general, the voltage fed drive system exhibited faster dynamics than the current fed drive and the current fed drive shows better stability during faulty condition for the same displacement angle between the two three phase groups.
Keywords – Field orientation control, a dual three phase induction motor, vector control, direct torque and flux control.

I. INTRODUCTION

Six phase induction motors constructed from dual three phase windings with some phase shift are a very interesting type of motor. The motor has six stator phase windings. Such motors with stator windings displaced from each other by 60 degrees is basically a double three phase induction motor. With phase displacement between the consecutive windings sets another control variable for the input to be assured. Recently, some industries and transportation system require motors with more degrees of freedom and control than the conventional three phase induction motor. A dual three phase induction motor is capable to provide the above features as well as higher power per unit volume and efficiency, better reliability and capacity to serve higher power drives and crucial loads [1]. The paper studied on symmetrical six phase, dual three phase and asymmetrical structure of the machine with a special feature of three phase induction motor having reactive compensation. Multi-phase machines are inherently consisting of a large number of advantages aspects that has drawn attention of researchers in the machine drives field. Many researchers have been working on multiphase induction machines for its high power by increasing number of phases and to reduce the current rating of semiconductor switches [2]. This paper provides a design method of multiphase induction machines. A vector control algorithm, based on indirect rotor flux orientation, is described in [3]. The authors paid special attention to the current control issue, from the point of view to minimize number of current controllers. An overview of the experimental test bench that utilized phase current control in the stationary reference frame is further provided. Attainable performance is analyzed and the experimental results are presented for a number of operating regimes, including acceleration, deceleration, reversing and step loading/unloading transients. It is demonstrated that the achievable quality of high performance is excellent, while the standard benefits of the multiphase motor drives are retained. Vector control is one of the most popular control method of multiphase induction machine drives due to its excellent control over dynamic performance. It requires all phase currents that increases number of current sensors required and is one of the disadvantages of vector control in multiphase machine drives. In [4] vector control of a symmetrical six-phase induction machine with a novel configuration. A methodology is designed in a simple way that only three current sensors are needed. Analytical equations are extracted in the paper to show that some of current components which do not contribute in torque production will be eliminated due to the proposed scheme. Simulation and experimental results are provided to verify the benefits of the proposed configuration. A mathematical model for a dual three phase induction motor considering equivalent three phase windings based on same magneto motive force and power has been proposed in [5]. The authors have developed the simulation model and furnished the simulation results. A good correspondence between simulated and tested results demonstrate the acceptance of the proposed model. Fault tolerant capability is one of the amazing features of multiphase induction machines. The paper [6] addresses this feature of a six-phase energy conversion system supplied with parallel converters, deriving the current references and control strategy that need to be utilized to maximize torque/power production. The authors provide experimental results indicating that it is possible to increase the post-fault rating of the system if some degree of imbalance in the current sharing between the two sets of three-phase windings is permitted. The paper [7] presents the implementation of a testing environment for one of the most promising multi-phase solutions, the double 3-phase induction machine, as a first stage for providing the benefits

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of using this technology. The experimental results obtained from multiphase system are compared against conventional electrical machines and found satisfactory. Multi-phase induction motor drives introduce complexity in control but lowers the rating of power devices and are normally proposed for especial custom applications [8]. This paper reviews the characteristics of VSI dual three phase induction machine and with the notion of modulation strategy and control schemes. In paper [10] a modified SVPWM method is proposed for dual three-phase induction motor drive and harmonic components of four different control schemes are analyzed. Experimental results support the analytical results of the drive systems. A simulation study on Direct Torque and Flux Control (DTC) for a Six Phase Induction Machine is described in [10]. The simulation results show the effectiveness of the proposed method in both dynamic and steady state response. The simulation results indicate fast torque and flux responses and the drive system is stable for load torque disturbances. Simulation and experimental results on switching table based Field Orientation control and Direct Torque Control is presented in [11]. Combination of different vectors are observed to reduce ripple in torque response. The paper [12] describes a technique of injecting third harmonic zero sequence current components in the phase currents to improve the machine torque density. The authors provide the analytical, finite element and experimental results as a proof of that. A comparative study between a PI regulator and fuzzy regulator based speed control system of a Dual Star Induction Machine supplied with a two PWM voltage source inverter and decoupled by field-oriented control (FOC) is presented in [13].They describe the effectiveness of Fuzzy Logic Controllers in respect of parameter variations. Multilevel inverter with PWM technique control is proposed and analyzed in [14]. The double star induction motor is controlled by multi carrier PWM technique. They also studied the effects of offsets on harmonics considering gap between two star windings. Simulation studies are provided in the paper. Construction of a six phase induction motor based on the optimized parametric information obtained from GA method has been shown in [15]. The authors have selected the quality parameters such as efficiency, power losses and power factor in the evaluation of optimized parameters.

In this paper a comparison of six phase induction motor having phase orientations with different angles are considered. A six phase induction motor is treated as consisting of two sets of three phase windings with phase lagging or leading. In our study we consider 60o, 40o and 20o displacement between the two sets of three phase windings. A comparison of these windings based motors are presented. The drives are controlled in voltage fed mode with inner current feedback loop. The drive with sinusoidal current fed is controlled with PWM technique. The input voltage is sinusoidal in nature and its peak value is adjusted to limit the current. Both symmetrical and asymmetrical operation of the drive with indirect field orientation technique for healthy and faulty conditions are analyzed and compared with simulation of the drive system in C++ environment.

II. MATHEMATICAL MODEL OF GENERAL MULTIPHASE INDUCTION MOTOR

A six phase induction motor has six stator phase windings and its rotor is normally squirrel cage type. The six phase stator windings may be grouped as double three phase connections. There may be displacement angles between the two three phases or not. We consider zero displacement between the two sets of windings but with phase displacement for one set of winding with respect to the other set. The windings are symmetrical and two axis theory of machine analysis is applicable in this case. Using mutually perpendicular stationary two phase variables we can write the stator circuit voltage equations in $\alpha\beta$ stator frame are written as:

$$v_{\alpha s} = R_{\alpha s} i_{\alpha s} + p\psi_{\alpha s} \quad (1)$$

$$v_{\beta s} = R_s i_{\beta s} + p\psi_{\beta s} \quad (2)$$

Where, the flux linkages $\psi_{\alpha s}$ and $\psi_{\beta s}$ are defined by:

$$\psi_{\alpha s} = (L_{ls}+L_m) i_{\alpha s} + L_m i_{\alpha r} \quad (3)$$

$$\psi_{\beta s} = (L_{ls}+L_m) i_{\beta s} + L_m i_{\beta r} \quad (4)$$

The windings of six phase induction motor are grouped in abc and xyz dual three phases as shown in Fig.1.The perpendicular reference frame (α β) is aligned with a-phase as shown in this figure.

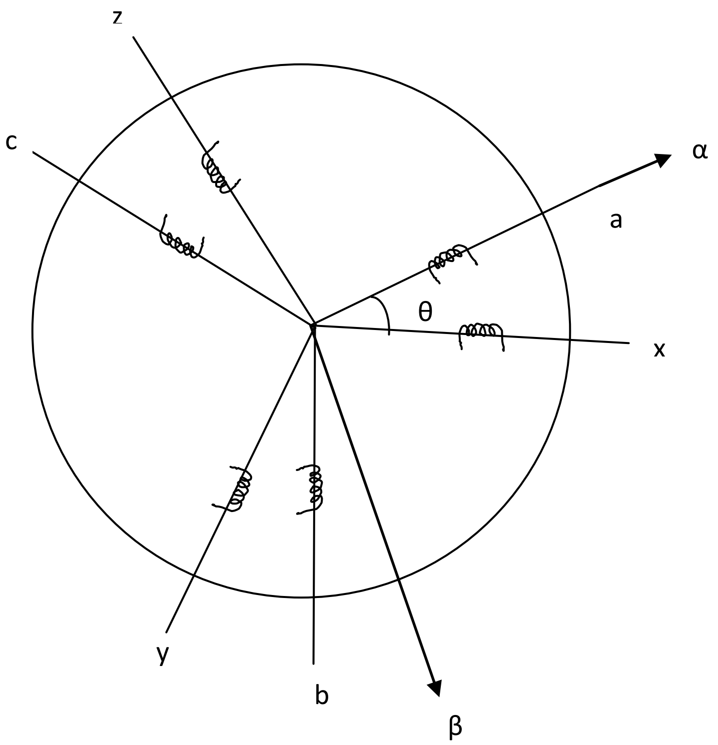


Fig.1 Winding coils of six phase induction motor and reference axes

The rotor circuit voltage equations are written as:

$$v_{\alpha r} = R_r i_{\alpha r} + \omega_r \psi_{\beta r} + p\psi_{\alpha r} \quad (5)$$

$$v_{\beta r} = R_r i_{\beta r} - \omega_r \lambda_{\alpha r} + p\psi_{\beta r} \quad (6)$$

In the above two equations the rotor flux linkages λ αr and λ βr are defined as:

$$\psi_{\alpha r} = (L_{lr}+L_m) i_{\alpha r} + L_m i_{\alpha s} \quad (7)$$

$$\psi_{\beta r} = (L_{ls}+L_m) i_{\beta r} + L_m i_{\beta s} \quad (8)$$

The state space representation of the system is described below in matrix form with two stator currents and two rotor flux linkages as state variables.

$$\frac{d}{dt}\begin{bmatrix} i_{\alpha s} \\ i_{\beta s} \\ \lambda_{\alpha r} \\ \lambda_{\beta r} \end{bmatrix} = \begin{bmatrix} \frac{-R_s}{\sigma L_s} + \frac{R_r(1-\sigma)}{\sigma L_r} & 0 & \frac{L_m}{\sigma L_s L_r}\frac{R_r}{L_r} & \frac{L_m}{\sigma L_s L_r}\omega_r \\ 0 & \frac{-R_s}{\sigma L_s} + \frac{R_r(1-\sigma)}{\sigma L_r} & \frac{L_m}{\sigma L_s L_r}\omega_r & \frac{L_m}{\sigma L_s L_r}\frac{R_r}{L_r} \\ L_m\frac{R_r}{L_r} & 0 & \frac{R_r}{L_r} & -\omega_r \\ 0 & L_m\frac{R_r}{L_r} & \omega_r & \frac{R_r}{L_r} \end{bmatrix} \begin{bmatrix} i_{\alpha s} \\ i_{\beta s} \\ \lambda_{\alpha r} \\ \lambda_{\beta r} \end{bmatrix} + \frac{1}{\sigma L_s}\begin{bmatrix} v_{\alpha s} \\ v_{\beta s} \\ 0 \\ 0 \end{bmatrix} \quad (9)$$

Where, $\sigma = \frac{1-L_m^2}{L_s L_r}$ and $v_{\alpha s}$ and $v_{\beta s}$ are the equivalent two phase voltages. Using power invariant transformation these voltage components are generated from actual phase voltages using the following relation:

$$\begin{bmatrix} v_{\alpha s} \\ v_{\beta s} \end{bmatrix} = \sqrt{\frac{2}{n}}\begin{bmatrix} 1 & cos\alpha & cos2\alpha & \cdot\cdot & cosn\alpha \\ 0 & sin\alpha & sin2\alpha & \cdot\cdot & sinn\alpha \end{bmatrix} \begin{bmatrix} v_1 \\ v_2 \\ v_3 \\ v_4 \\ \vdots \\ v_n \end{bmatrix} \quad (10)$$

The electromagnetic torque developed is written as:

$$T_d = \sqrt{\frac{n}{2}} P_p \left(\lambda_{\beta r}(\lambda_{\alpha r} - L_m i_{\alpha s}/L_r) - \lambda_{\alpha r}(\lambda_{\beta r} - L_m i_{\beta s}/L_r)\right) \quad (11)$$

With Tl as load torque, J as inertia coefficient and B as friction coefficient at motor mechanical speed ω_m, the torque balance equation is given by

$$Td = Tl + J\frac{d\omega_m}{dt} + B\omega_m \quad (12)$$

For indirect rotor flux FOC the slip speed is given by

$$\omega_{sl} = \frac{R_r I_{qs,ref}}{\lambda_r^*} \quad (13)$$

The inner current control loop is implemented by actual current feedback and generating the () axes currents through Clarkes transformation and then generating the maximum value of motor current. This maximum current is compared with the controller generated maximum current to produce the error in maximum current used by a PI controller to produce the controlled maximum value of inverter by a controlled converter. The control action is illustrated in Fig.2. Two synchronized inverters generate the va,vb,vc and vx,vy,vz produce the six phase voltages as shown in the figure. The current controlled drive system block diagram is similar to that shown for a five phase induction motor drive in [16].

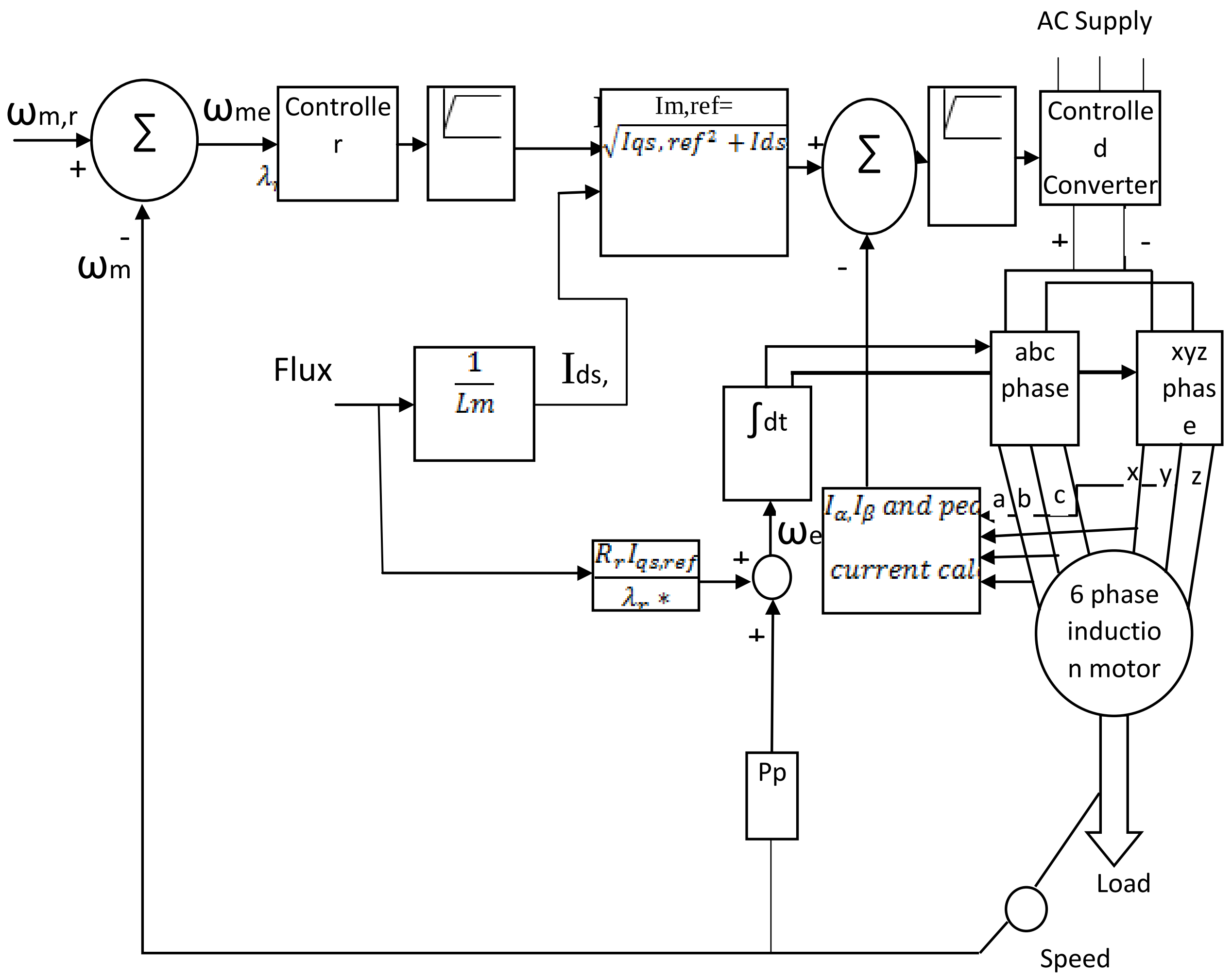


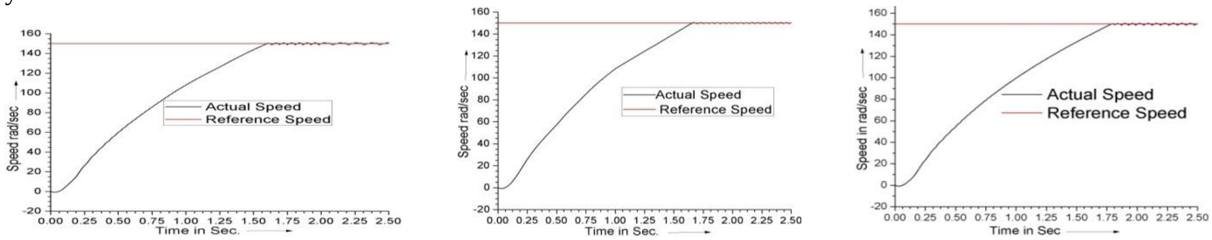
Fig.2 Control Circuit Block Diagram of Dual three phase (six phase) Voltage fed Induction Motor Drive.

III. SIMULATION RESULTS

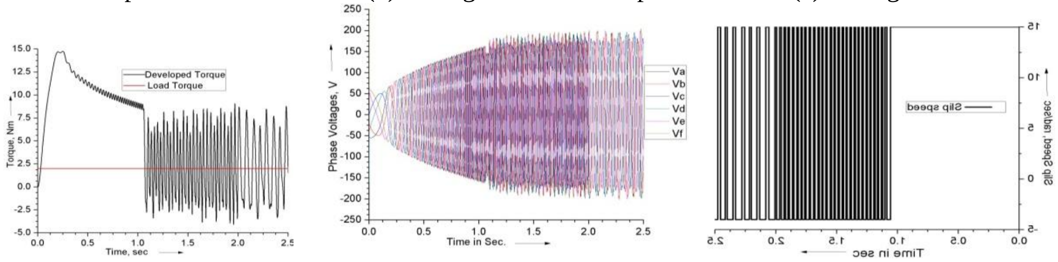
The drive system shown in Fig.2 was simulated in C++ environment using machine model described above. Different angles between the dual three phase windings such as 20o, 30o and 40o are considered for voltage fed induction motor drive and 40o for current fed induction motor drive. The PI controller are adaptive and speed error dependent. Time step is 2µsec.

IV. STARTING TRANSIENT

Six phase voltage fed induction motor performance was tested from rest condition with a set speed of 150 rad/sec. The load torque for the motors were 2.0 Nm. The starting characteristics are shown in Fig.3. Speed characteristic for voltage fed machine with 20o phase displacement is shown in Fig3 (a). This motor requires 1.65 sec to reach the set speed. The motor having 40o phase displacement with same load torque reaches the set speed in 1.656 sec. The starting speed transient of the motor is shown in Fig.3 (b). With same load torque and set speed the motor with 60o phase displacement takes 1.77 sec as shown in Fig.3 (c). For the three configurations the starting speed transient indicates that increasing the phase displacement reduces the starting time and produces faster response. After the motor reaches the set value speed the motor developed torque decrease and oscillates around the load torque. Variation of motor input voltage due to inner current feedback loop is shown in Fig.3 (e). Similarly, the slip speed is set to its limiting value at initial starting condition and oscillates at quasi steady state condition



Voltage fed with 20o phase shift (b) Voltage fed with 40o phase shift (c) Voltage fed with 60o phase shift

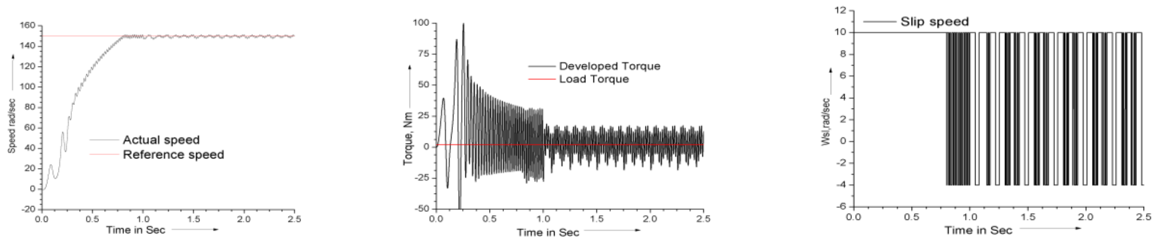


(d)Td and Tl for Voltage fed with 40o phase shift (e) Phase Voltages for 40o phase shift (f) Slip speed for 40o phase shift

Fig.3 Starting performance of six phase voltage fed induction motor drive

V. EFFECT OF VOLTAGE CONTROL AND CURRENT FEEDBACK

Improvement of the drive performance due to voltage control by current feedback is demonstrated by comparing the starting characteristics shown in Fig.4 with the corresponding characteristics given in Fig.3. It can be visualized that the speed response with fixed voltage is faster but full of disturbances. Since control over the motor current is relaxed with fixed voltage initial developed torque is very high and is responsible for fast speed response. However, slip speed varies between zero and limiting values.

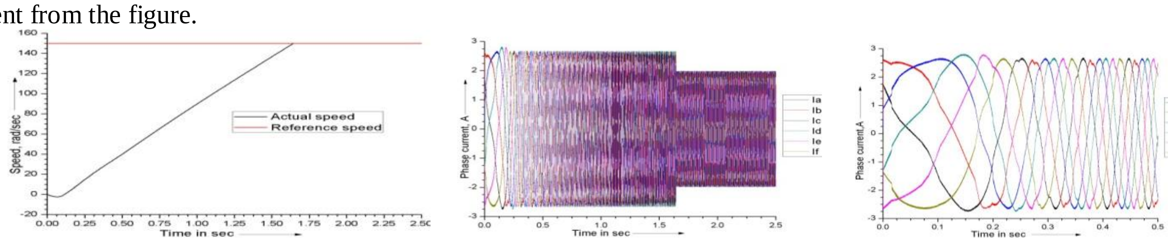


Speed response with fixed voltage (b) Torque characteristic (c) Slip speed

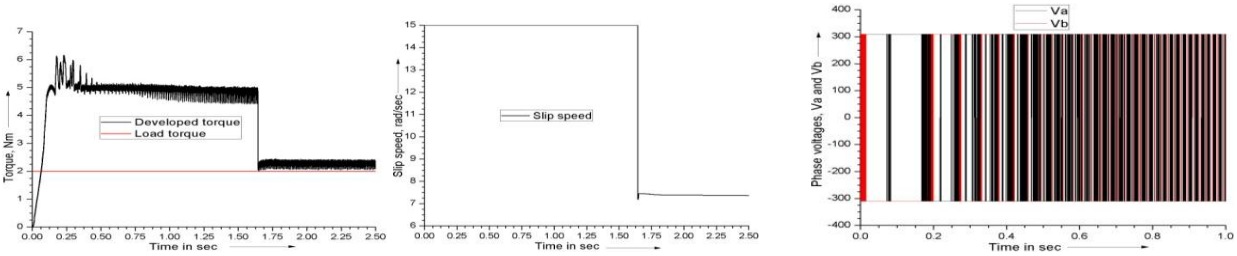
Fig.4 Characteristics of Six Phase Fixed Voltage fed Induction Motor at Starting

VI. SIX PHASE CURRENT FED INDUCTION MOTOR DRIVE STARTING PERFORMANCE

We modelled the dual three (six) phase induction motor drive with 40o displacement angle between the two winding sets. The current was controlled by hysteresis controllers for each phase as described in [16]. The starting performance of the drive system was evaluated for the drive with a load torque of 2.0 Nm. The characteristics are presented in Fig. 5. The motor speed during starting transient condition is shown in Fig.5 (a) indicating that the motor reaches the set speed in about 1.67 sec without any oscillation. The motor phase currents and their initial zoomed values are shown in Fig. 5(b) and (c) respectively. The motor phase currents are reduced as the motor speed reaches to reference speed as can be seen from Fig.5(b) and Fig.5 (c) indicates the nature of settling the initial phase currents. The motor torque characteristics are shown in Fig.5 (d) indicates that during acceleration the developed torque in much higher than the load torque. At starting the slip speed variation is shown in Fig. 5(e). The slip speed remains to its maximum set value during the motor acceleration period and settles to a lower value to generate the load torque only. PWM phase voltages Va and Vb are shown in Fig. 5(f) to illustrate the variation of their widths during starting condition. The width decrease as the motor speed is increased and is evident from the figure.



Reference and Motor Speeds (b) Input phase currents (c) Zoomed phase currents

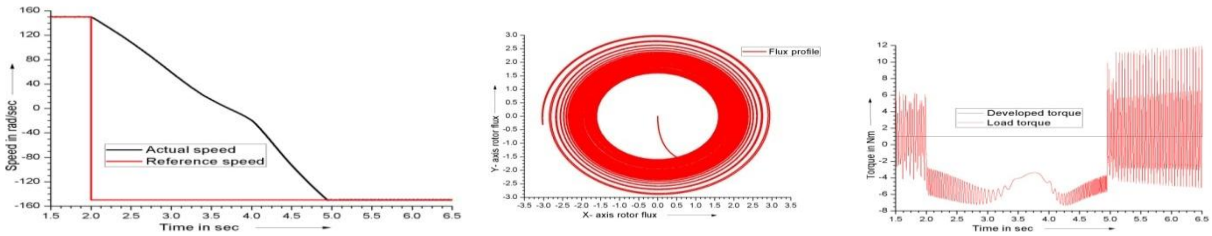


(d) Developed and load torque char. (e) Slip speed characteristic (f) PWM phase voltages Va and Vb

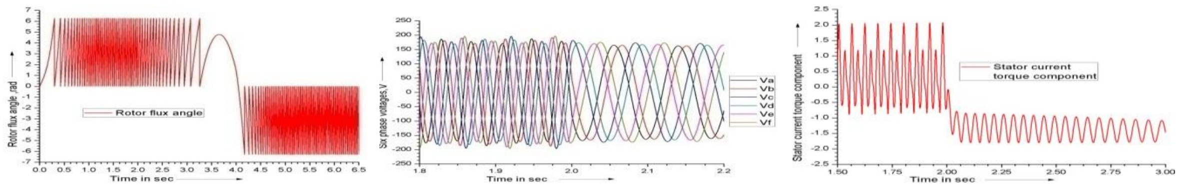
Fig. 5 Starting Performance of the dual three phase induction Motor

VII. SPEED REVERSAL

Performances of the drives were tested for speed reversal from +150 rad/sec to -150 rad per sec. The characteristics are shown in Figs 6 and 7 for voltage fed and current fed drives respectively. The motor were operating at 150 rad/sec and at 2 sec the reference speed was changed to -150 rad per sec. Both the motors were with 40o phase displacement between the two sets of windings. The speed change characteristics are presented in (a) of Fig.6 and 7. The current fed machine operates better during speed reversal as can be visualized from the figures. The circular field patterns of rotor flux reverse their direction that can be visualized from Figs 6(b) and 7(b) for voltage and current fed machines respectively. The variation of developed torques can be observed from Figs 6(c) and 7(c) respectively for voltage and current fed machines. Rotor field angle variation from 0 to 2π for speed in positive direction to 0 to -2π for negative speed can be visualized from Figs 6(d) and 7(d) for voltage and current fed machines respectively. Phase current profiles for voltage and current fed machines are demonstrated in Figs 6(e) and 7(e) respectively. Variation of torque component of stator current for the voltage fed machine can be observed from Fig. 6(f). The phase voltage profile foe the CRPWM condition is demonstrated in Fig.7(f).

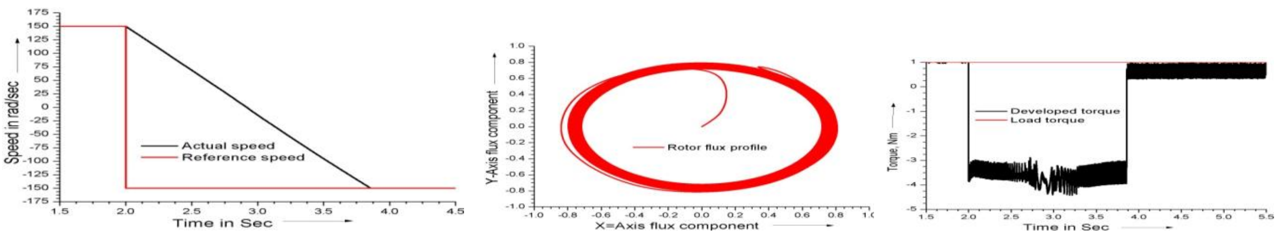


. (a) speed characteristics (b) rotor flux profile (c) torque characteristics

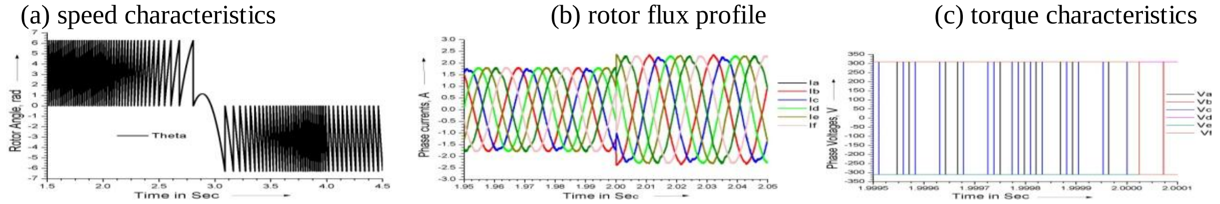


(d) Rotor field angle (e) six phase current profile (zoomed) (f) Stator current torque component

Fig. 6. Speed reversal characteristics of six phase voltage fed induction machine with 40o phase displacement



(a) speed characteristics (b) rotor flux profile (c) torque characteristics

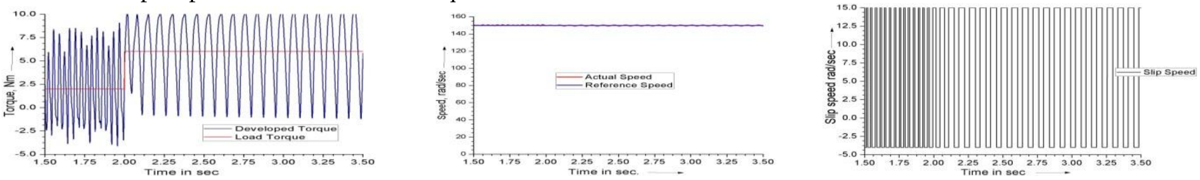


(d) Rotor field angle (e) Six phase current profile (zoomed) (f) Six phase voltage profile(zoomed)

Fig. 7 Speed reversal characteristics of six phase induction machine with current regulated PWM and indirect field orientation

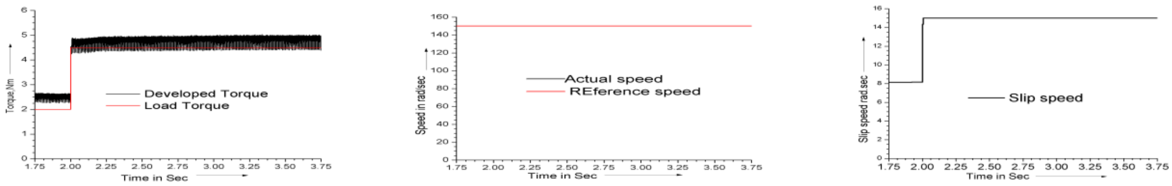
VIII. SUDDEN LOAD TORQUE DISTURBANCE

The machines were running under steady state condition. At 2.0 sec the load torque was suddenly enhanced from 2.0 Nm to 6.0 Nm for the voltage fed induction motor with 40o phase displacement between the two sets of three phase windings as indicated in Fig. 8(a). The developed torque increases but no effect on speed characteristic as shown in Fig.8(b). The slip speed response for this condition is shown in Fig.8(c). For the six phase current fed machine with same displacement the load torque was enhanced from 2.0 Nm to 4.5 Nm as given in Fig.9(a). This motor can develop torque upto a maximum of 4.5 Nm. No effect on motor speed is observed from Fig. 9(b). The slip speed response in Fig.9(c) indicates enhancement of slip to produce more motor torque.



Sudden enhancement of Load Torque (b) Effect on Motor Speed (c) Slip speed response

Fig. 8 Effect of Sudden Load Torque Disturbance for 40o Phase Shifted Voltage fed Induction Motor Drive

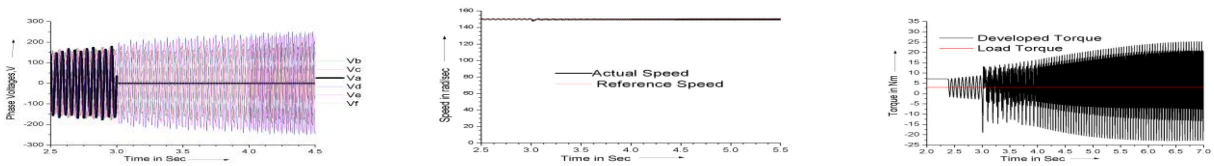


Sudden enhancement of Load Torque (b) Effect on Motor Speed (c) Slip speed response

Fig. 9 Effect of Sudden Load Torque Disturbance for 40o Phase Shifted Current fed Induction Motor Drive

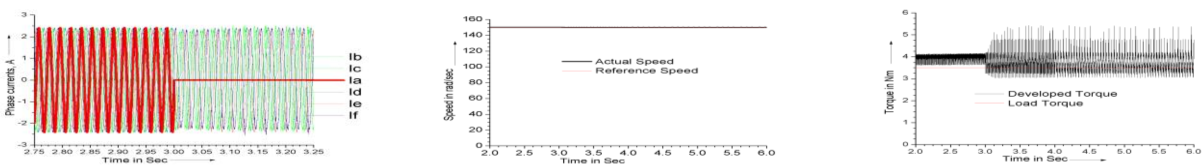
IX. PERFORMANCE WITH ASYMMETRICAL OPERATION (ONE PHASE OPEN)

The motor drives were tested under fault condition where one of six phases open at 3.0 second for both the voltage fed and current fed drives. The voltage fed drive runs stably with 3.0 Nm load torque under sudden open circuit of a phase winding. However, the motor with phase fault can start with higher amount of load torque. The current fed motor can run stably with a maximum of 3.5 Nm load torque. The fault condition (Va=0 and Ia=0) are created at time t=3.0 sec for both the 40o phase displaced voltage fed and current fed drive systems respectively. The phase voltages and phase currents with fault condition are shown in Fig.10(a) and Fig.11(a) respectively. Effects of the faults on speed are indicated in Fig.10(b) and Fig.11(b) respectively indicating stability of the drive systems. Effects on developed torque can be visualized from Fig.10(c) and Fig.11(c) respectively, indicate enhanced torque oscillation under this abnormal conditions.



Phase Voltage (b) Motor Speed (c) Torque Characteristic

Fig. 10 Test result with one of six phases open Voltage Fed Drive



Phase Currents (b) Motor Speed (c) Torque response

Fig. 11 Test result with one of six phases open Current Fed Drive

X. CONCLUSION

The study conducted on dual three phase (six phase) induction machine through mathematical modeling and simulation indicates that the drives operate conveniently for transient conditions, speed reversal, load torque disturbances and single phase faulty conditions. It was observed that voltage fed drives provide faster dynamic response than current fed drives. However, in a voltage fed drive there are two controllers that affect stability of the drive system, which can be visualised by torque capability reduction during phase fault condition. The current fed drive is more stabilised as can be seen from the torque and slip speed characteristic. The control system proposed in this paper is simple and easy to implement.

XI. REFERENCES

[1] P. Venter, A. A. Jimoh and J. L. Munda," Realization of a "3 & 6 Phase" Induction Machine",Conference Paper · January 2012, pp.447-453.

[2] Dr. Archana Nanoty and A. R. Chudasama,"Design, Development of Six Phase Squirrel Cage Induction Motor and its Comparitive Analysis with Equivalent Three Phase Squirrel Cage Induction Motor Using Circle Diagram,"International Journal of Emerging Technology and Advanced Engineering,Vol.3,Issue 8, August 2013, pp.731-737.

[3] S.N. Vukosavic, M. Jones, E. Levi, J. Varga," Rotor flux oriented control of a symmetrical six-phase induction machine," Electric Power Systems Research, Elsivier, 75 (2005),pp.142–152

[4] Hamidreza Pairodin Nabi, Pooya Dadashi and Abbas Shoulaie," A Novel Structure for Vector Control of Symmetrical Six-Phase Induction Machines with Three Current Sensors," ETASR - Engineering, Technology & Applied Science Research Vol. 1, _o. 2, 2011, pp. 23-29.

[5] Wang Bu-lai Gong Zhe-song Gu wei Zhu Jian-xin Guo Yi," Modeling for A Dual Three-Phase Induction Motor Based On A Winding Transformation" Conference: 2008 IEEE Conference on Robotics, Automation and Mechatronics, RAM 2008, 21-24 September 2008, Chengdu, China, pp. 555-559.

[6] I. Gonzalez, M. J. Duran, H. S. Che, E. Levi, M. Bermudez and F. Barrero," Fault-tolerant Operation of Six-phase Energy Conversion Systems with Parallel Machine-side Converters," IEEE Transactions on Power Electronics,2015.

[7] R. Gregor1, F. Barrero1, S. Toral1 and M.J. Durán," Realization of an Asynchronous Six-Phase Induction Motor Drive Test-Rig," RE&PQJ, Vol. 1, No.6, March 2008, pp.101-105.

[8] Radu Bojoi, Francesco Faria, Francesco Profumo, Alberto Tenconi,'' Dual-Three Phase Induction Machine Drives Control," pp.420-429.

[9] K. A. Chinmaya Girish Kumar Singh," Experimental analysis of various space vector pulse width modulation (SVPWM) techniques for dual three-phase induction motor drive", Int Trans Electr Energ Syst. 2019;29:e2678 June 2018, pp.1-15.

[10] Radhwane Sadouni, Abdelkader Meroufel and Salim Djriou, "Study and Simulation of Direct Torque Control (DTC) for a Six Phase Induction Machine (SPIM)," International Journal of Energy, Issue 2, Vol. 7, 2013, pp.31-37.

[11] Hamidreza Heidari, Anton Rassõlkin, Toomas Vaimann, Ants Kallaste, Asghar Taheri, Mohammad Hosein Holakooie and Anouar Belahcen." A Novel Vector Control Strategy for a Six-Phase Induction Motor with Low Torque Ripples and Harmonic Currents," MDPI Journal of Energies, March 2019, pp.1-14.

[12] Renato O. C. Lyra Thomas A. Lipo," Torque Density Improvement in a Six-Phase Induction Motor With Third Harmonic Current Injection,"IEEE 2001, pp.1779-1786.

[13] Radhwane Sadouni, Abdelkader Meroufel," Indirect Rotor Field-oriented Control (IRFOC) of a Dual Star Induction Machine (DSIM) Using a Fuzzy Controller," Acta Polytechnica Hungarica Vol. 9, No. 4, 2012, pp.177-192.

[14] Mohamed Arbi Khlifi," Behavior of a Dual Stator Induction Machine Fed by Neutral Point Clamped Multilevel Inverter," Hindawi Journal of Energy Volume October 2018, pp.1-10.

[15] Z. Fazlipour, R. Kianinezhad and M. Razaz," Genetic Algorithm Based Design Optimization of a Six PhaseInduction Motor," J Electr Eng Technol.2015; vol.10, pp. 30-40.

[16] Bashudeb Chandra Ghosh and Md. Ershad Ali, "Performance Analysis of a PWM Current Controlled Five Phase Induction Motor Drive for Disturbances and Faulty Condition" in Journal entitled "Journal of Power Electronics and Devices" Volume 5, Issue 3, 2019,pp. 32-41.