ISSN 2320-6802

INTERNATIONAL JOURNAL FOR ADVANCE RESEARCH IN ENGINEERING AND TECHNOLOGY

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ANALYSIS - FOR DIFFERENT LEVELS OF CASCADE MULTI-LEVEL STATCOM FOR DTC INDUCTION MOTOR DRIVE

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Abstract: *This paper presents a direct torque control (DTC) of induction motor drive (IMD) using Different levels of Cascade Multilevel STATCOM. The DTC is one of the most excellent strategies of flux ripples control and torque of IMD. The main drawback of the DTC of IMD using conventional PI controller based SR is high torque, stator flux ripples and speed of IMD is decreasing under transient and steady state operating conditions. This drawback was eliminated using In front of DTC IM drive connected Different levels of Cascade Multilevel STATCOM. The main objective of this paper is to present an approach capable of performing fast torque response and harmonics reduction in DTC drive. Because of that, an efficient control strategy is applied,is needed to reduce the voltage fluctuations like sag and swell conditions and also to reduce current and voltage harmonics in the DTC drive system. In this paper, the work proposed is aimed at obtaining results exhibiting improved THD contents of 5, 7 and 9 level cascade multilevel inverters at the ac mains and reduced the Torque ripples of the DTC IMD Drive .*

Key Words *—Direct torque control (DTC), induction motor, Voltage Source Converter (VSC), STATCOM, SHEM, Cascade Multilevel Inverter, THD.*

1. INTRODUCTION

The electric drives are used for motion control. The IMD control methods can be divided into two methods such as, scalar and vector control. The general classification of the variable frequency controls is presented in Fig.l. The scalar control is operating in steady state and controls the angular speed of current, voltage, and flux linkage in the space vectors. Thus, the scalar control does not operating in the space vector position during transient state. The vector control, which is based on relations valid for dynamic states, not only angular speed and magnitude but also instantaneous position of current, voltage, and flux linkage space vector are controlled. In the vector control, the most popular method for induction motor drives, known as Field Oriented Control (FOC) presented by F.Blaschke (Direct FOC) and Hasse (Indirect FOC) in early 1970's, gives high performance, and high efficiency for industrial applications [1]. In the FOC, the motor equations are transformed into a coordinate system that rotates in synchronism with the rotor flux vector control [2]. This drawback was eliminated using the new strategies for torque and flux ripple control of IMD using DTC was proposed by Isao Takahashi and Toshihiko Noguchi, in the mid 1980's [3]. The main feature of DTC is simple structure and good dynamic behavior and high performance and efficiency [4]. The new control strategies proposed to replace motor linearization and decoupling via coordinate transformation, by torque and flux hysteresis controllers [5].

Since past decade, multilevel inverters have drawn increasing attention because of their promising applications in power systems and industrial drives. They can be efficiently used in the distributed energy systems in which, output ac voltage is obtained by connecting dc sources such as batteries, fuel cells, solar cells, rectified wind turbines etc at input side of the inverters. The ac output voltage obtained from the inverters can be fed to a load directly or interconnect to the ac grid without voltage balancing problems. In addition, the multilevel inverters are used as Voltage source inverters (VSIs) in the static synchronous compensator (STATCOM), a reactive power compensating device used for voltage regulation in power systems [1].

For switching the semiconductor devices, proper selection of switching angles is must. The switching angles at fundamental frequency, in general, are obtained from the solution of non linear transcendental equations characterizing harmonics contents in the output ac voltage; these equations are known as selective harmonic elimination (SHE) equations. As the SHE equations are non linear transcendental in nature, their solutions may have simple, multiple and even no roots for a particular value of modulation index (m), moreover, it is difficult to solve these equations. A big challenge is how to get all possible solution sets where they exist using simple and less computationally complex method. Once these solution sets are

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obtained, the switching angles producing minimum total harmonic distortion (THD) in the output ac voltage are selected for switching of the power electronics devices. In [6]-[7], iterative numerical techniques have been implemented to solve the SHE equations producing only one solution set, and even for this, a proper initial guess and starting value of *m* for which the solutions exist are required, in general, it is difficult to guess the initial solution and the value of *m* for which solution exist.

Early STATCOM generally used the zigzag transformer in the main circuit topology as voltage source inverter. However, the zigzag transformer has some difficulties, which is hard to overcome in terms of cost, transformer loss as well as the control. When the cascaded multilevel inverter is used as the main circuit topology, STATCOM has a little floor space, easy to split-phase control, high reliability, and easy expansion of capacity, etc. In addition, because it has no use for the zigzag transformer, it makes the existing STATCOM free of the most serious problems such as device over-voltage caused by the magnetic saturation and nonlinearity in the transformer excitation circuit .So the cascaded multilevel inverter structure for large capacity STATCOM is concerned by a large number of engineering designers more and more.

In the present paper discussed, 5-level, 7-level and 9-level Cascade Multilevel STATCOM is connected in front of the DTC Based Induction Motor are employed to generate ac input voltage of DTC IM Drive producing different magnitudes of THD, rotor speed, stator current and Electro Magnetic Torque at different values of modulation indices for comparison purpose.

2. MATHEMATICAL MODEL OF INDUCTION MOTOR DRIVE

The mathematical model of induction motor drives when the motor is operating in both the steady state and transient states. The standard IMD equivalent model can be used to calculate motor variables such as developed torque, flux, stator voltage, stator current, and rotor current, etc. The induction motor can be modeled with stator current and flux in reference (d^S-q^S) as state variable expressed as follows.

$$x(t) = A\,x(t) + Bu_s(t)$$
$$y(t) = Cx(t)$$

Where A is System matrix, B is the control and C is the observation, and X(t) is the state variable, u(t) is input vector and y(t) is output vector. An improved method of speed estimation that operates on the principle of a speed adaptive flux observer. An observer is basically an estimator that uses a plant model and a feedback loop with measured plant variables. The machine model in d^S -q^S frame, where the state flux variables are ψ_{ds}^{s} and ψ_{qs}^{s} and stator currents $i_{ds}^{s}$and i_{qs}^{s}[8].

$$Y(t) = [i_{ds}\ \ i_{qs}]^T$$
$$X(t) = [i_{ds}{}^{s}\ \ i_{qs}{}^{s}\ \ \psi_{ds}{}^{s}\ \ \psi_{qs}{}^{s}]^T$$
$$U_s(t) = [U_{ds}{}^{s}\ U_{qs}{}^{s}\ 0\ \ 0\ ]^T$$

$$A = \begin{bmatrix} -\lambda & 0 & \frac{\gamma}{tr} & \gamma\omega r \\ 0 & -\lambda & -\gamma\omega r & \frac{\gamma}{tr} \\ \frac{Lm}{tr} & 0 & -\frac{1}{tr} & -\omega r \\ 0 & \frac{Lm}{tr} & \omega r & -\frac{1}{tr} \end{bmatrix}$$

Where $\lambda = \left[\frac{Rs}{\sigma Ls} + \frac{L_m^2}{\sigma Ls Lr Tr}\right]$ $\gamma = \frac{Lm}{\sigma Ls Lr}$

$t_t = \frac{Lt}{Rt}$, $t_s = \frac{Ls}{Rs}$ $\sigma = 1 - \frac{L_m^2}{L_m L_s}$

The above all equations are used for the simulations model of induction motor drive.

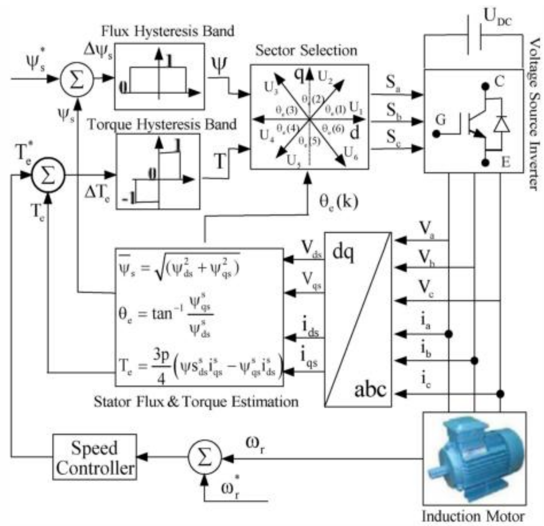

Figure 1: Schematic diagram of direct torque control of induction motor drive.

3. CASCADE MULTILEVEL INVERTER

The cascade multilevel inverter consists of a number of H-bridge inverter units with separate dc source for each unit and is connected in cascade or series as shown in Fig. 1. Each H-bridge can produce three different voltage levels: +Vdc,0 and –V_{dc} by connecting the dc source to ac output side by different combinations of the four switches S1, S2, S3, and S4. The ac output of each H-bridge is connected in series such that the synthesized output voltage waveform is the sum of all of the individual H-bridge outputs. By connecting sufficient number of H-bridges in cascade and using proper modulation scheme, a nearly sinusoidal output voltage waveform can be synthesized.

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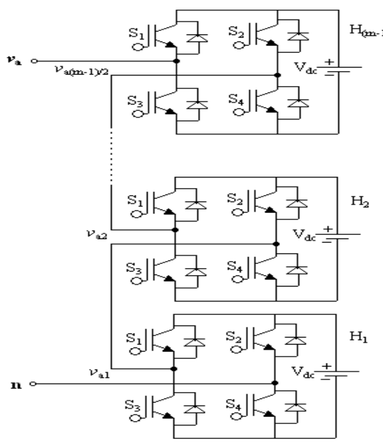

Figure 2: Single-phase cascade multilevel inverter topology.

The number of levels in the output phase voltage and line voltage are 2*s*+1 and 4*s*+1 respectively, where *s* is the number of H-bridges used per phase. For example, Three H Bridges, five H-bridges and seven H-bridges per phase are required for 7-level, 11-level and 15-level multilevel inverter respectively. Fig. 2 shows a typical waveform produced by 7-level CMLI.

4. FUNDAMENTALS OF STATCOM

Static compensators based on inverter circuit (STATCOM) are mostly designed for voltage support of three-phase balanced systems. On transmission level, systems are normally balanced, but it is not a case during the fault conditions or in distribution system. In three phase balanced system STATCOM produce a set of balanced reactive currents so that instantaneous power flow in STATCOM or from STATCOM is always zero. It means that, at each moment, instantaneous power brought to the STATCOM by one phase is equal to the instantaneous power taken away from the STATCOM by other two phases and vice versa. The zero instantaneous power flow permits the use of small capacitors on the DC side of inverter. The role of those capacitors is to keep DC voltage on a suitable level that satisfies reactive needs of the load and not to store large amount of energy. Physically, compensator based on a three phase inverter circuit interconnects all three phases of three phase AC system, providing path for exchange of reactive power between them [9]. This type of exchange is disturbed during unbalance operation of the AC system. In this case each phase of inverter must provide unequal voltage. If PWM strategy of control is used, it is possible to change phase voltages by changing control signals and keeping DC voltage constant[9]. The value of DC reference voltage will determine the rating of the inverter and the inverter will always draw some active power from AC system to cover for its losses and to keep the DC bus voltage constant. If hysteresis current control is applied, harmonics can be compensated and the inverter will act as an active filter [10]. But both command strategies mentioned above impose high switching frequency and hence high switching losses. To avoid high switching losses, fundamental frequency modulation strategy (FFM) for control of multilevel inverter has been suggested where the control of reactive power is achieved by controlling power angle which permits charging and discharging of DC side capacitors of inverter resulting in the control of the fundamental component of inverter output voltage. When more reactive power is needed, the inverter output voltage is made to lag the phase voltage of the AC system allowing power to flow from the AC system into the inverter, boosting voltage in its DC bus capacitors. With boost in DC bus voltage, output voltage waveform of all three phases of inverter is affected. To get three unequal output voltages, one solution is to shift switching angles (there are many switching angles because commercially applied STATCOM must be made of many six pulses inverter or some other multilevel topology are to be used), but it means online computation and introduction of additional distortion in to the system. Moreover, shifting switching angels will introduce distortion that is variable so it can be difficult to clear.

5. SIMULATION RESULTS

In This paper, The proposed model of multilevel STATCOM connected in shunt configuration to a three phase source feeding dynamic motor loads is developed using Simulink of MATLAB software. Simulated results demonstrate that multi level STATCOM can be considered as a variable solution for solving such voltage dip problems. This thesis work aims at developing a multilevel STATCOM for induction machines with voltage dip and Comparison of Electromagnetic Torque of DTC Induction motor with different levels of STATCOM and without STATCOM.

This paper deals with the design and implementation of a multilevel voltage source converter based static synchronous compensator (STATCOM) at Different levels 5,7 and 9 level employing an effective modulation based on three-phase induction motor (IM) under direct torque control (DTC) technique in a MATLAB/Simulink. So large starting currents and objectionable voltage drop during the starting of an induction motor could be critical for the entire system. Circuit diagram as shown in fig 3.

This large voltage sag is encountered at the starting of induction motor However, the voltage sag is now within limits as the motor is already started and is drawing normal full rated current, shows the stator current, rotor current, load voltage, speed, electromagnetic torque with respect to time. The multi level STATCOM helps to eliminate the Total Harmonics Distortion (THD).

www.ijaret.org Vol. 1, Issue VI, July 2013
ISSN 2320-6802
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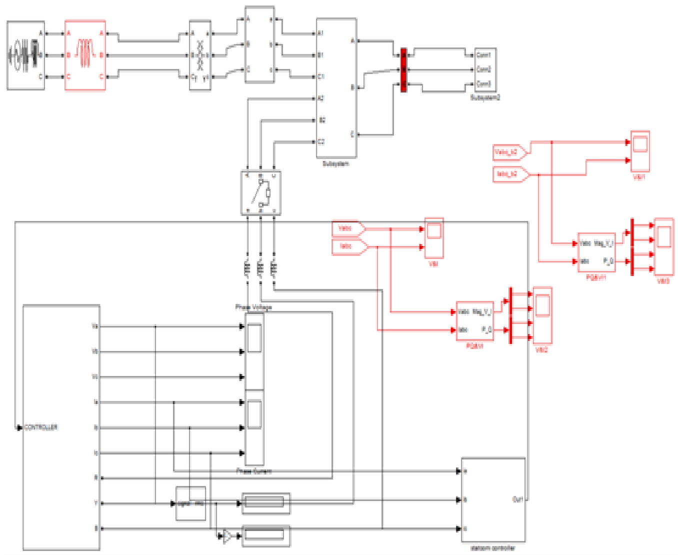

Figure 3: MATLAB Simulink model of DTC based IMD with Multi level STATCOM.

6. RESULTS AND DISCUSSIONS

Performance of the DTC based IMD is studied for both the configurations namely, a six-pulse diode bridge rectifier and multi level STATCOM at the front end. Fig. 6 shows the dynamic performance of the drive fed from a six-pulse diode bridge rectifier for load conditions. Waveforms consist of source phase voltage (*vas*), source line current (*ias*), rotor speed (*Nr*), electromagnetic torque (Te) for the rating of. Pn =1.1 kW, *Un* =415 V, *f*=50 Hz, Ω*n* =1415 r/min, Rs =6.03 Ω, Rr = 6.085Ω, Lls = 29.9 mH, Llr = 29.9 mH, Lm =489.3 mH, J = 0.011787 Kg.m2.

The ac mains current waveform and its harmonic spectra at load is shown in Figs. 5 and 6 which show that THD at full load. From these results it can be concluded that it is necessary to use improved power quality converters at front end of the DTC based IMD. The electromagnetic torque developed and reference torque at the DTC induction motor as shown in Fig.4.

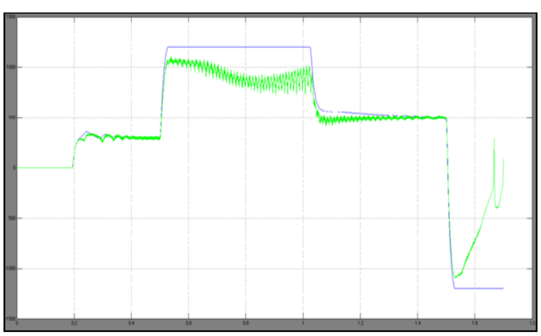

Figure 4: Comparison of simulation results of the DTC of IMD using both Electromagnetic
Torque developed and reference torque given to the Torque control IM

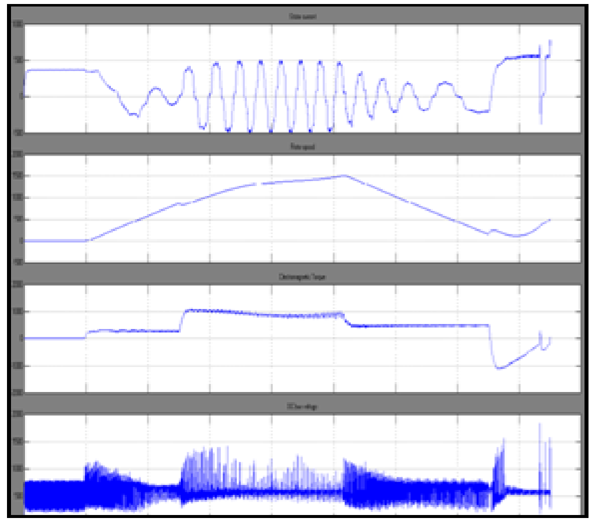

Figure 5: Dynamics of a DTC based IMD with a simple diode bridge rectifier

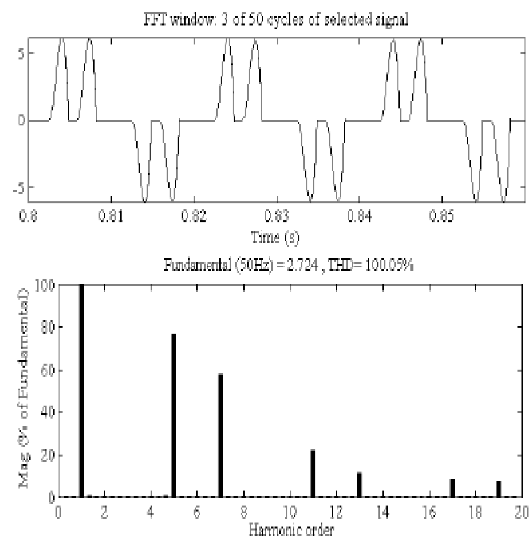

Figure 6: AC mains current and harmonic spectrum for DTC based

A. 5level STATCOM

A 5 level Cascade Multi level STATCOM is employed in place of the uncontrolled 6-pulse converter. The waveforms of a DTC based IMD for load conditions fed from a Multi level STATCOM at the front end are shown in Fig. 3. The ac mains current and its harmonic spectra for load as shown in Figs.9. It can be noted that the THD of ac mains current at load is 17.31%. A significant improvement as compared to the case fed from a simple diode bridge rectifier. The comparison of THD with load for DTC based. And the electromagnetic torque developed and reference torque at the DTC induction motor as shown in Fig.7.

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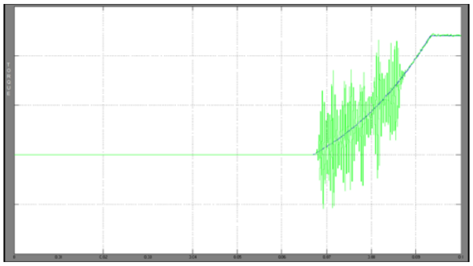

Figure 7: Comparison of simulation results of the DTC of IMD using both Electromagnetic Torque developed and reference torque given to the Torque control IM

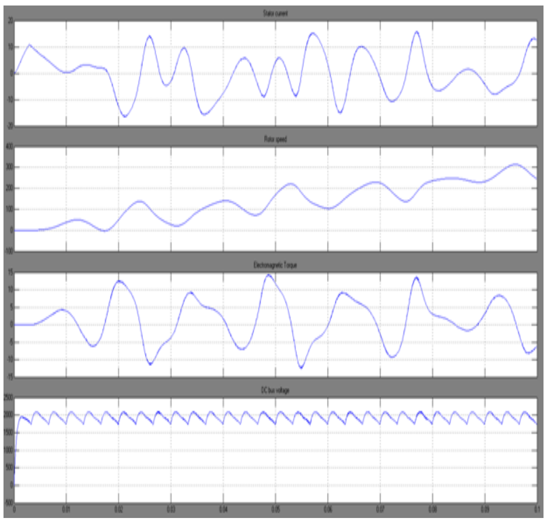

Figure 8: Dynamics of a DTC based IMD with a simple diode bridge rectifier and Multi-Level STATCOM at the front end

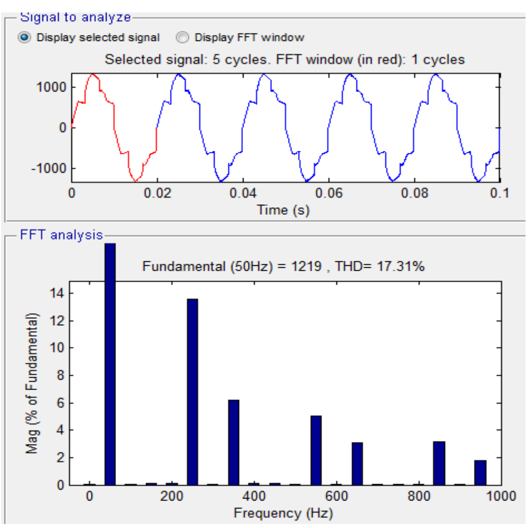

Figure 9: AC mains current and harmonic spectrum for DTC based IMD with Multi Level STATCOM at the front of DTC

B. 7level STATCOM

A 7 level Cascade Multi level STATCOM is employed in place of the uncontrolled 6-pulse converter. The waveforms of a DTC based IMD for load conditions fed from a Multi level STATCOM at the front end are shown in Fig. 3. The ac mains current and its harmonic spectra for load as shown in Figs.12. It can be noted that the THD of ac mains current at load is 10.38%. A significant improvement as compared to the case fed from a simple diode bridge rectifier. The comparison of THD with load for DTC based. And the electromagnetic torque developed and reference torque at the DTC induction motor as shown in Fig.10.

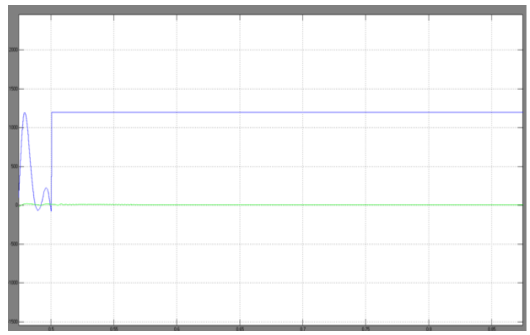

Figure 10: Comparison of simulation results of the DTC of IMD using both Electromagnetic Torque developed and reference torque given to the Torque control IM

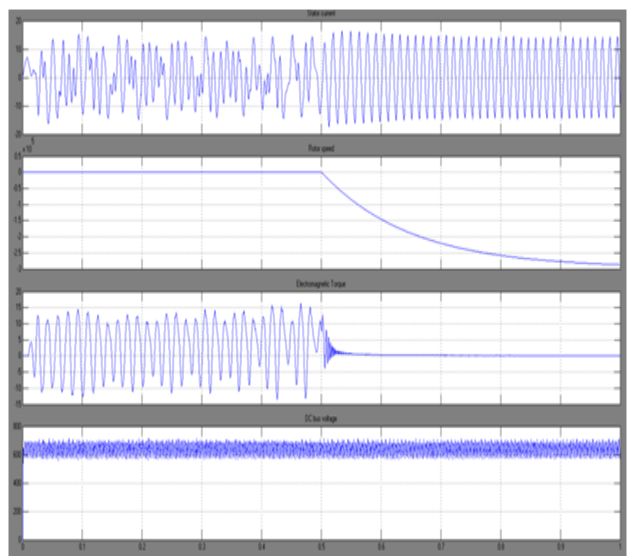

Figure 11: Dynamics of a DTC based IMD with a simple diode bridge rectifier and Multi-Level STATCOM at the front end

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ISSN 2320-6802
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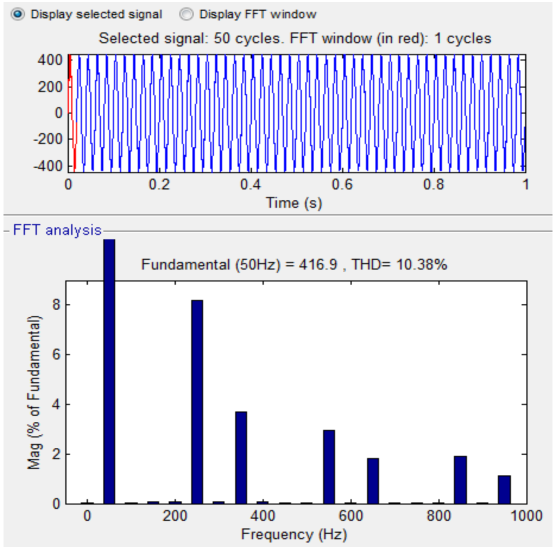

Figure 12: AC mains current and harmonic spectrum for DTC based IMD with Multi Level STATCOM at the front of DTC

C. 9 level STATCOM

A 9 level Cascade Multi level STATCOM is employed in place of the uncontrolled 6-pulse converter. The waveforms of a DTC based IMD for load conditions fed from a Multi level STATCOM at the front end are shown in Fig. 3. The ac mains current and its harmonic spectra for load as shown in Figs.15. It can be noted that the THD of ac mains current at load is 4.60%. A significant improvement as compared to the case fed from a simple diode bridge rectifier. The comparison of THD with load for DTC based. And the electromagnetic torque developed and reference torque at the DTC induction motor as shown in Fig.13.

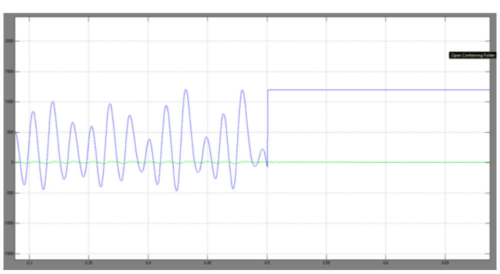

Figure 13: Comparison of simulation results of the DTC of IMD using both Electromagnetic Torque developed and reference torque given to the Torque control IM

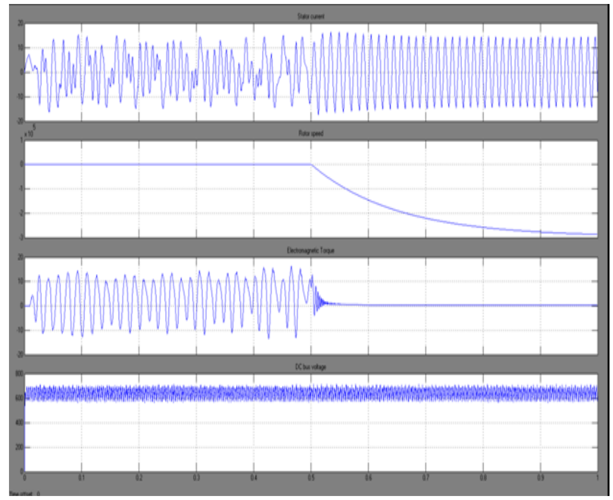

Figure 14: Dynamics of a DTC based IMD with a simple diode bridge rectifier and Multi-Level STATCOM at the front end

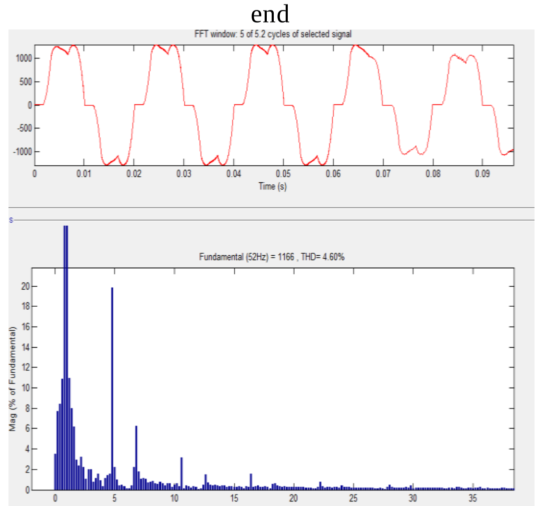

Figure 15: AC mains current and harmonic spectrum for DTC based IMD with Multi Level STATCOM at the front of DTC

7. CONCLUSION

The switching angles for cascade multilevel inverters of 5, 7 and 9-level have been computed for analysis of total Harmonic distortions produced in output voltage and complexity in computation of these angles. It has been found that complexity in computation of switching angles increases with increase in number of levels as more sets of solution are produced but the operating range of modulation index goes down. On other part, the THD in output voltage decrease and output voltage increase with increase in number of levels. Analytical results are validated with simulation results for all level of Multi level STATCOM for 9-level Multi level STATCOM of the results also validated with experiment.

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