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SCOTT TRANSFORMER AND DIODE CLAMPED INVERTER FED INDUCTION MOTOR BASED ON FOC

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ABSTRACT :
This paper presents a Scott transformer based three phase, two-switch PFC (Power Factor Correction) boost rectifier for improving the power quality in a three-level diode clamped inverter (DCI) feeding indirect rotor field oriented control (FOC) based induction motor drive (IMD). The sinusoidal improved power factor source current and dc-link voltage regulation are achieved in the proposed rectifier only with two-switches. The three-level DCI is supplied by a split dc-link obtained from a Scott connected transformer feeding a rectifier. It is shown that a three-level DCI achieves reduced stator current with lower voltage harmonic content even at a lower switching frequency as compared to a two-level inverter. This results in reduction of voltage stress on motor windings for the same amount of torque ripple when indirect rotor FOC algorithm is implemented for the IMD.

Keywords :*Scott transformer, PFC Rectifier controlling, Induction motor drive, power factor corrector (PFC) converters,, split dc-bus voltage, three-phase rectifier, Diode Clamper Inverter(DCI),Rotor Field Oriented Control(FOC)*

I. INTRODUCTION

One of the improved power quality AC-DC converters for low or medium powered drives is a three-phase, two-switch power factor correction (PFC) boost rectifier based on a Scott transformer. It is used to provide improved PF at AC mains, reduced AC current harmonics, nearly sinusoidal AC current, and constant DC voltage even under varying input AC voltage and loads. Besides, it also provides low frequency isolation for safety[2]-[3]. Multi-level VSIs are used for medium and high-voltage/ power ac motor drives. In this a Scott transformer based three-phase, two-switch boost PFC rectifier for improving the power quality. The proposed PFC rectifier provides nearly improved PF at AC mains along with sinusoidal supply current and effective dc link voltage regulation in wide operating range of load on the drive.The Scott transformer provides galvanic isolation and sine and cosine secondary voltage waveforms to the high power factor rectifiers, resulting in a perfectly regulated dc output voltage[4]. Those converters connected to the

mains have the potential of injecting current harmonics that may cause voltage distortion. These harmonics can be significantly reduced if the input power factor is corrected by shaping the input current in each of the three phases so that it is sinusoidal and in phase with the phase voltage. Due to this fact, switch-mode rectifiers for power-factor correction (PFC) have gained considerable attention. Further advantages for the use of PFC rectifiers are their adaptability to different line voltages and the fact that they preregulate the dc output voltage Rotor field orientated control (FOC) of an induction motor drive (IMD) can achieve such performance levels similar to that of a dc motor drive. The coupling between the flux and torque producing components of stator current is a major deterring factor in achieving high dynamic performance in an IMD. This is overcome successfully in FOC making it the standard control adopted by industries. Indirect rotor FOC estimates the rotor flux position in an indirect manner by adding the instantaneous slip speed with the rotor speed and integrating the result. The voltage of dc link is shown in fig. 2 and voltage across capacitors shown in fig.3. The Scott connection is one alternative to convert the three phase to two-phase transformation that uses two single-phase transformers.

II. LITERATURE SURVEY

1 A. A. Badin and I. Barbi, "Unity Power Factor Isolated Three-Phase Rectifier With Split DC-Bus on the Scott Transformer," *IEEE Tran.* Power Electronics, vol.23, no.3 ,pp.1278-1287 ,May 2008.

-have proposed the instantaneous average current control PWM technique for three-phase rectifier PFC based on Scott transformer. The use of the Scott transformer makes a split DC-bus voltage possible and the rectifier operates with unity power factor

2. G. A. Varsamis, E.D. Mitronikas and A. N. Safacas,"Field oriented control with space vector modulation for induction machine fed by diode clamed three level inverter," *IEEE Tran.* in Proc. Conference on Electrical Machines, ICEM, Sept.2008, pp.1-6.

- have presented FOC method for an IM drive by a three-level DCI using SVM. Also, the use of the control system to eliminate the impact of the DC link voltage unbalance on the torque of the induction machine is examine.

3 S.K.T. Miller and I. Barbi, "Practical aspects of the unity power factor isolated three-phase rectifier based on the Scott transformer," in Proc. *IEEE Tran.* Applied Power Electronics Conference and Exposition, March 2005, vol.1, pp. 621-627

- presents a Scott transformer for isolation and uses instantaneous average current control. Models for proper design of the current and voltage loops are obtained by two methods. Using these models, reference current phase-shifting is analyzed and implemented. A design procedure for the boost inductors and the Scott transformer, based on switching functions

III. SYSTEM CONFIGURATION AND PRINCIPAL OF OPERATION

This rectifier has a split dc-bus and the voltages across the switches are VO/2. The control method employed to control the currents of the two boost inductors, Each PFC boost rectifier has two loops one is voltage outer loop and the other inner current loop. Voltage loop of boost rectifier-1 guarantees the voltage regulation and the other guarantees the balanced voltage across two split capacitors[6]. The controller block diagram for generating two PWM pulses is shown in Fig. 1.

The voltage across each switch is equal to half of total dc link voltage and two boost rectifiers form a split dc-link which is suitable for supplying input to a three-level DCI. The diode clamped multilevel inverter uses capacitors in series to divide up the dc bus voltage into a set of voltage levels. To produce m levels of the phase voltage, an m level diode clamp inverter needs (m-1) capacitors on the dc bus. Each leg in three-level DCI is composed of four switches with anti-parallel diodes as shown in Fig.

III. CONTROL SCHEME

The scheme is divided into two parts:
PWM Controller for controlling PFC rectifier and
FOC Controller for controlling DCI.

i)PWM Controller for controlling PFC rectifier.

The PFC boost rectifier controller for generating PWM pulses to its switches. Voltage loop of boost rectifier-1 guarantees the voltage regulation and other guarantees the balance voltage across two split capacitors. Modeling of the controller is explained as follows.
The sensed dc link voltage Vdc is compared with reference V_{dc}^* to generate I_d^* through a limiter using a PI controller.

$$I_{d(n)} = I_{d(n-1)} + K_p\left(V_{dc\_e(n)} - V_{dc\_e(n-1)}\right) + K_i V_{dc_{e(n)}} \quad -(1)$$

Where, $I_{d(n)}$, $I_{d(n-1)}$ are the output of the PI controller and $V_{dc\_e(n)}$, $V_{dc\_e(n-1)}$ are the errors of the dc link voltage at the n^{th} , $(n-1)^{th}$ instants . K_p and K_i are PI controller constant.

Improved power factor is achieved by controlling the boost inductor current to follow the shape of the rectified secondary voltage. I_d is multiplied with unit template (u_{sT1}) of tertiary transformer(T1) secondary voltage (V_{sT2}) to generate reference dc current (i_{dc1}) .

$$i_{dc1}^* = |u_{sT1}| \times I_d \quad -(2)$$

Where $u_{sT1} = V_{sT1} / V_{sT1m}$, V_{sT1m} is the peak voltage of transformer T1 secondary voltage.

The reference dc current of boost converter1 (i_{dc1}^*) and the sensed dc current (i_{dc1}) are compared and the current error (Δi_{dc1}) is amplified by multiplying it by a constant gain (K).

Then the amplified error ($K\Delta i_{dc1}$) is compared with modulating triangular waveform m_{tria} to generate PWM pulses S_1 .

$K\Delta i_{dc1} \geq m_{tria}; S_1 = 1, else\ S_1 = 0$

The difference in two capacitors voltage ($V_{c1}\ and\ V_{c2}$) are passed through another PI controller to generate the reference current I_c^* to make equal voltage across dc bus capacitors.

$$I_{c(n)} = I_{c(n-1)} + K_{p1}(V_{c\_e(n)} - V_{c\_e(n-1)}) + K_{i1}V_{c\_e(n)} \quad -(3)$$

Where, $I_{c(n)}$, $I_{c(n-1)}$ are the output of the PI controller and $V_{c\_e(n)}$, $V_{c\_e(n-1)}$ are the errors between half of dc link voltage and V_{c2} ($V_{c\_e(n)} = V_{dc/2} - V_{c2}$) at the n^{th} and $(n-1)^{th}$ instant. K_{p1} and K_{i1} are PI controller constant.

Two voltage loops are added together to guarantees the balanced voltage across split capacitors.

The I_c is multiplied with unit template (u_{sT2}) of the main transformer (T2) secondary voltage (V_{sT2}) and added with I_d to generate reference dc current (i_{dc2}^*).

$$i_{dc2}^* = |u_{sT2}| \times (I_c + I_d) \quad -(4)$$

Where, $u_{sT2} = V_{sT2}/V_{sT2m}$, V_{sT2m} is the peak voltage of transformer T2 secondary voltage.

The reference dc current of boost converter-2 (i_{dc2}^*) and sensed dc current (i_{dc2}) are compared and the current error (Δi_{dc2}) is amplified by multiplying it by a constant gain (K) and then the amplified error ($K\Delta i_{dc2}$) is compared with modulating triangular waveform m_{tria} to generate PWM pulse S_2 .

$$If \;\; K\Delta i_{dc2} \geq m_{tria}; S_2 = 1, else\; S_2 = 0 \quad [5]$$

ii) FOC Controller for controlling DCI.

Indirect rotor FOC algorithm [9] gives a high level of motor control performance by decoupling the torque and flux components. The controller block diagram is shown in Fig. 1. The modeling of rotor FOC technique is explained as follows. Reference speed (wr*) and sensed speed (wr) are compared and the speed error generated (we) is given to the speed PI regulator to generate torque (Te*) reference as,

$$T^*_{e(n)} = T^*_{e(n-1)} + K_{pw}(w_{e(n)} - w_{e(n-1)}) + K_{iw}w_{e(n)} \quad (6)$$

where, Kpw, Kiw are the PI Controller gains.

Torque component of stator current ($i^e_{qs}{}^*$) calculated using reference torque (Te*) as,

$$i^e_{qs}{}^* = \frac{2}{3} \times \frac{2}{P} \times \frac{L_r}{L_m} \times \frac{T^*_e}{\hat{\Psi}_r} \quad (7)$$

For decoupling control where Ψdr = 0 and Ψqr is aligned along with total rotor flux $\hat{\Psi}_r$ = Ψqr. Rotor flux is calculated as,

$$\frac{L_r}{R_r}\frac{d\hat{\Psi}_r}{dt} + \hat{\Psi}_r = L_m i_{ds} \quad (8)$$

Stator flux component of current ($i^e_{ds}{}^*$) is calculated using constant reference rated flux $\hat{\Psi}^*_r$ induction motor as,

$$i^e_{ds}{}^* = \frac{\hat{\Psi}^*_r}{L_m} \quad (9)$$

Synchronously rotating stator reference currents ($i^e_{ds}{}^*, i^e_{qs}{}^*$) are transformed into stationary two phase stator reference current ($i^s_{ds}{}^*, i^s_{qs}{}^*$) using inverse Parks transformation as

$$i^s_{ds}{}^* = -\sin\theta_e \times i^e_{qs}{}^* + \cos\theta_e \times i^e_{ds}{}^* \quad (10)$$

$$i^s_{qs}{}^* = \cos\theta_e \times i^e_{qs}{}^* + \sin\theta_e \times i^e_{ds}{}^* \quad (11)$$

where θe is the rotor flux angle which is rotating at synchronous speed. In indirect vector control scheme the rotor flux position is obtained in fed forward manner by integrating the addition of slip speed (wsl) and rotor speed (wr) as,

$$\theta_e = \int w_e dt = \int (w_r + w_{sl})dt = \theta_r + \theta_{sl} \quad (12)$$

Two phase stator reference currents ($i^s_{ds}{}^*, i^s_{qs}{}^*$) are transformed into three phase stator reference currents (ias*, ibs*, ics*) using inverse Carks formation as,

$$i_{as}^* = i^s_{qs}{}^* \quad (13)$$

$$i_{bs}^* = -\frac{1}{2}i^s_{qs}{}^* - \frac{\sqrt{3}}{2}i^s_{ds}{}^* \quad (14)$$

$$i_{cs}^* = -\frac{1}{2}i^s_{qs}{}^* + \frac{\sqrt{3}}{2}i^s_{ds}{}^* \quad (15)$$

The sensed stator current ias is subtracted from reference current ias* and the current error (Δias) is amplified by multiplying it by a constant gain (Kv) and then the amplified error (KvΔias) is compared with upper modulating triangular waveform mtria_u to generate PWM pulse to IGBT Ta1 and the complement is given to Ta3. For generating PWM pulse to IGBT Ta2 the same amplified current error (KvΔias) is compared with lower modulating triangular waveform mtria_land the complement is given to the IGBT Ta4. Similarly, the PWM pulses to the switches of leg ‘b’ and ‘c’ are generated using above procedure.

IV. FFIGURES

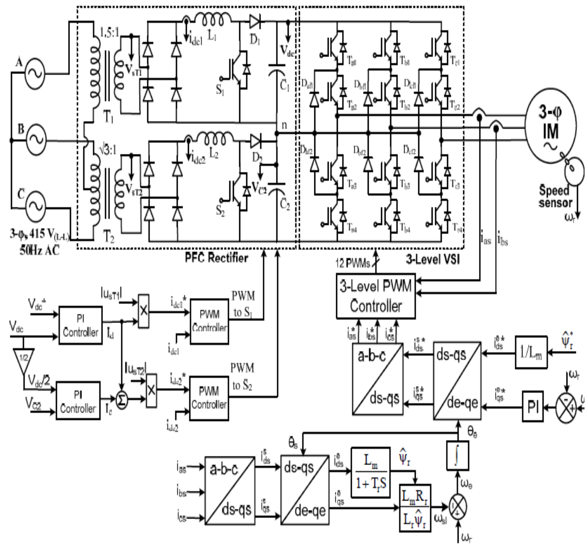

Fig.1 Scott transformer based PFC with three-level DCI fed rotor FOC based IMD

VI. RESULT

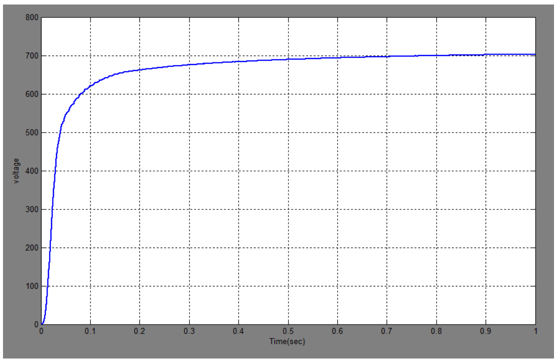

Fig.2 Waveform of Vdc

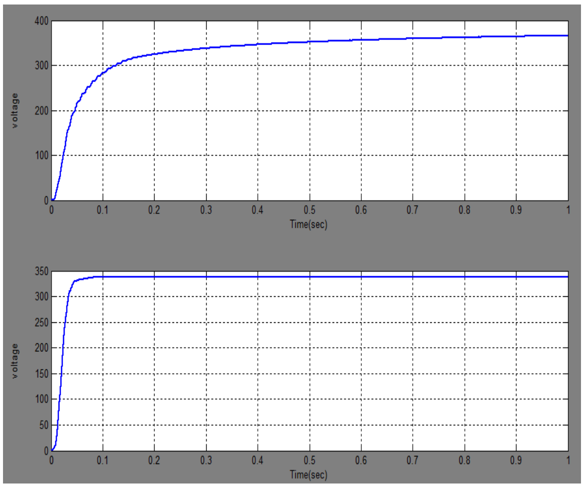

Fig.3 Waveform of VC1 and VC2

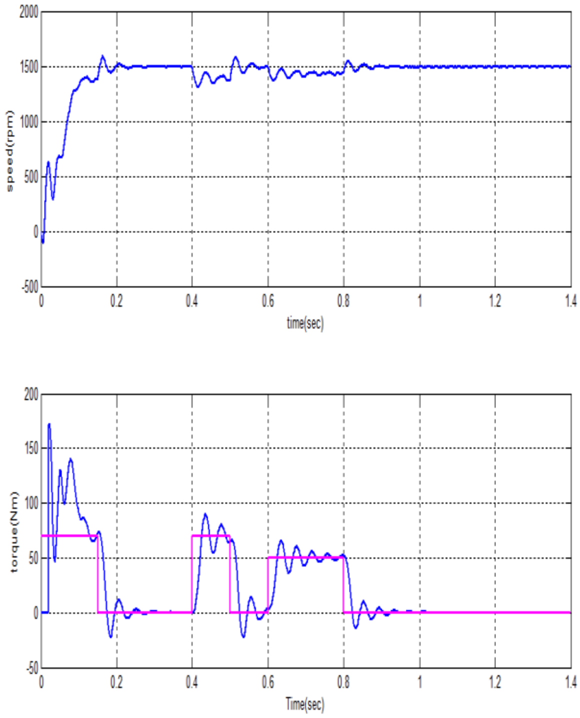

Fig. 4 Waveform of speed and torque

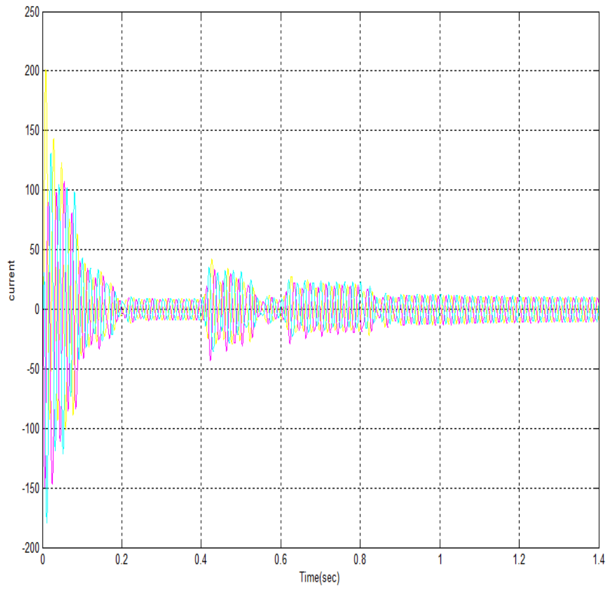

Fig.5 Waveform of Iabcs

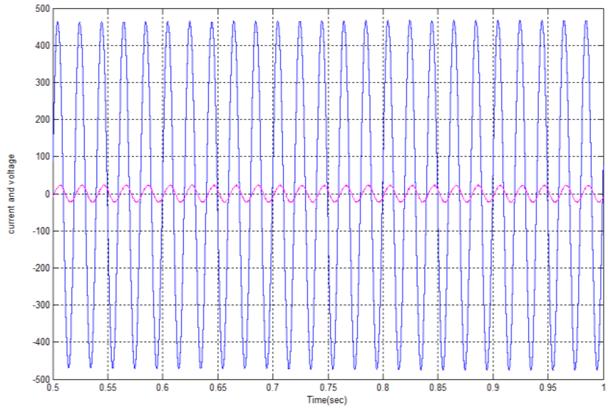

Fig.5 Waveform of Va and Ia

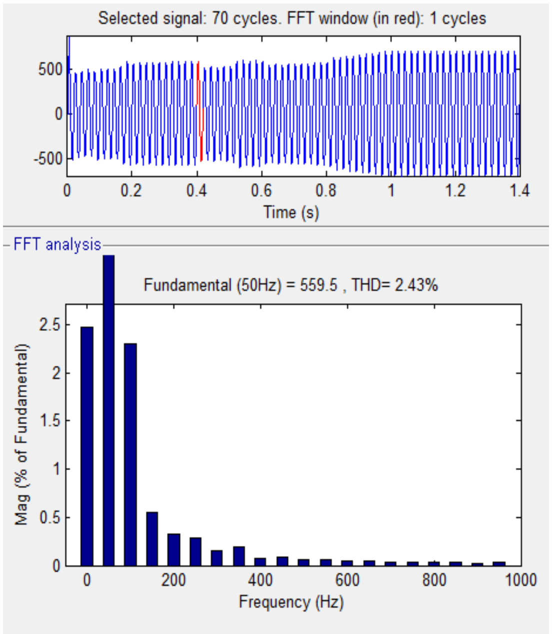

Fig.6 FFT Analysis for Va

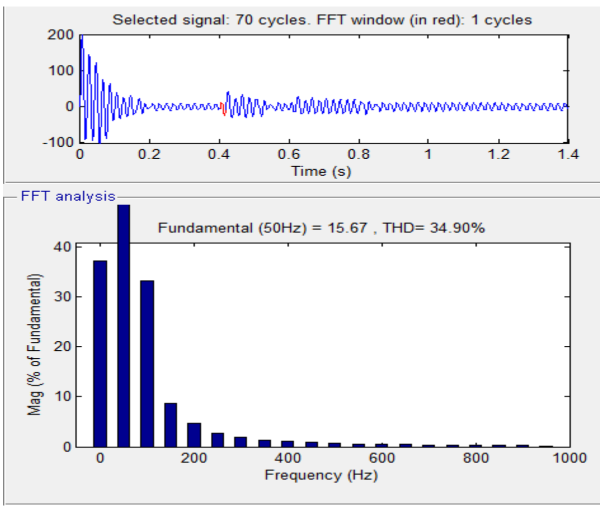

Fig.6 FFT Analysis for Va

VII. CONCLUSION

The design, modeling and simulation of an isolated PFC boost AC-DC converter are presented for mitigate the power quality problems. With the use of only two active switches it is shown that PFC rectifier provides sinusoidal input currents with improved power factor and dc link voltage regulation. In this. Mitigation poer quality problems in FOC controlled IMD fed by three level VSI.

1. Advantages.

i) It is used to provide constant DC voltage even under varying input AC voltage and loads.
ii) It provides low frequency isolation for safety.

2. Applications.

Isolated rectifier are widely used for medium or high power drive application which are employed in subways, electrochemical and petrochemical industries

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