ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 1, January 2017

Three-Phase Four-Switch Inverter-Fed Induction Motor Drives with DC-Link Voltages Offset Suppression by Using Fuzzy Logic Controller

G.Rakesh Kumar[1], Dr.V.Usha Reddy[2]

PG Student, Dept. of Electrical & Electronics Engineering, S.V. University College of Engineering, A.P. India[1]

Assistant Professor, Dept. of Electrical & Electronics Engineering, S.V. University College of Engineering, A.P. India[2]

ABSTRACT: The induction motor drives with B4 inverter is used to balance the three phase currents in order to maintain low dc link voltages offset suppression. The three phase B4 inverter controls both stator flux and torque. Whereas in B6 inverter stator flux and torque are not controlled and three phase currents are collapsed due to fluctuations. In B4 inverter Stator flux will controls the three phase currents and it forces the three phase currents to stay in balance condition and on the other side torque will control voltage, amplitude and magnitude. Induction motor with three phase B4 inverter fed uses predictive torque control scheme for voltage vectors of B4 inverter to minimize open and short circuit fluctuations in two dc link capacitor voltages .In fault tolerant conditions of induction motor with three phase B4 inverter in open and short circuits it derives precise predictions by controlling its pi controller and fuzzy logic controller. Three phase induction motor drives operate under four switches in order to maintain low cost function.

KEYWORDS: Cost function, current unbalance, four-switch inverter, induction motor (IM) drives, model predictive control (MPC).

I. INTRODUCTION

In many streams six switches B6 inverter with three phase voltage sources are being used and mostly they are referred in active filters and motor drives. Induction motor with three phase currents B6 inverter is more cost affecting factor. It is overcome by three phase inverter with four switches was introduced by van der broeck and van wyk [1]. In such a way to reduce the cost of the segment and the circuit diagram of B4 inverter are given below in fig.1.

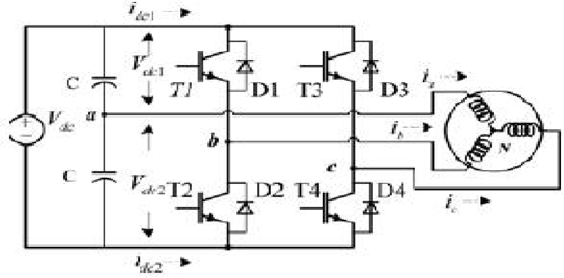

Fig.1. Circuit diagrams of a B4 inverter-fed induction motor drive.

When this B4 inverter was proposed an adaptive space vector modulation scheme was innovated in order to overcome the dc link voltage ripple and effects of capacitor center tap voltages are minimized. Later on modern predictive torque control was introduced to B4 inverter with three phase voltage sources of induction motor and executed the precise

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Vol. 6, Issue 1, January 2017

prediction in dc link capacitor voltages offset suppression and it is profitable that the three phase currents are forced to stay in balanced state by controlling the stator flux and torque.

Where as in B6 inverter three phase current voltage sources in fault tolerant conditions in open and short circuits. Here three phase currents are collapsed due to capacitor center tap fluctuations and dc link voltage ripple.

At an inspecting period constant usage time taken a toll for the PTC plot in B4 inverter is reduced when it compares with the B6 inverter. The B4 inverter in fault tolerant control is having extremely profitable in many cases such as pulled in light of a legitimate concern of rail traction. The MPC technique is a new control technique therefore it is more reliable.   B4 inverter and induction motor (IM) are observed in section II.

PARAMETERS OF THE INDUCTION MACHINE:

$\boldsymbol{\varphi_r}$ ⟶ Rotor flux.
$\boldsymbol{\varphi_s}$ ⟶ Stator flux.
$\boldsymbol{\tau_r}$ ⟶ Rotor Torque Constant.
L_m ⟶ Magnetizing Inductance.
L_s ⟶ Stator Leakage Inductance.
L_r ⟶ Rotor Leakage Inductance.
k_r ⟶ Rotor coupling element.
σ ⟶ Total Leakage Factor.
$\boldsymbol{\lambda_{dc}}$ ⟶ Weight factor of the dc-link capacitor.
$\boldsymbol{\lambda_0}$ ⟶ Weight factor.
T_e ⟶ Electromagnetic Torque.
T_{enom} ⟶ Rated Torque.
i_s ⟶ Stator current.
i_r ⟶ Rotor current.

TABLE I
SWITCHING FUNCTION AND THE OUTPUT VOLTAGES OF THE B4 INVERTER

States		Switch On		output Voltages VaN	VbN	Vc N
S_b	S_c					
0	0	T_2	T_4	$\frac{2Vdc_2}{3}$	$-\frac{Vdc_2}{3}$	$-\frac{Vdc_2}{3}$
0	1	T_2	T_3	$\frac{V_{dc2} - V_{dc}}{3}$	$-\frac{2V_{dc2} + V_{dc}}{3}$	$\frac{2V_{dc1} + V_{dc2}}{3}$
1	0	T_1	T_4	$\frac{V_{dc2} - V_{dc}}{3}$	$\frac{2V_{dc1} + V_{dc2}}{3}$	$-\frac{2V_{dc2} + V_{dc}}{3}$
1	1	T_1	T_3	$-\frac{2Vdc_1}{3}$	$\frac{Vdc_1}{3}$	$\frac{Vdc_1}{3}$

The proposed PTC control plot with capacitor voltage suppression is clarified in Section III. The weight figures the fetched capacity are dissected and talked about in Section IV. In Section V, exploratory outcomes are appeared. The conclusions are introduced in Section VI.

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II. DEMONSTRATING OF THE B4 INVERTER AND IM

A. INBORN VOLTAGE VECTOR OF A B4 INVERTER

TheB4 topology comprises of a two-leg inverter, as outlined in Fig. 1. The dc-link is part into two voltage sources, to the center of which one load phase is associated. For advantageous examination, the inverter is considered for execution by perfect switches (T1–T4) (i.e., with no dead time and no immersion voltage drop).

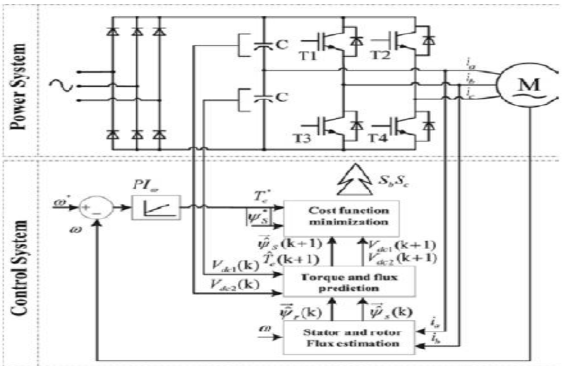

Fig.2. Structure of the B4 inverter-fed IM drive based on the PTC scheme.

III. PI CONTROLLER BASED SCHEME FOR THE B4 INVERTER-FED IM DRIVE

In the proposed conspire; the internal loop is a stator flux and electromagnetic torque controller in view of PTC, while the external speed loop is a customary PI controller. The structure of the B4 inverter-sustained IM drive-based PTC scheme is appeared in Fig.2.

A. FLUX ESTIMATION

It is advantageous to note that the voltage-demonstrate based flux estimator utilizing the order voltages can around gauge the stator flux in the B6 case.

Here, a present model-based flux estimator utilizing moment streams what's more, speed signs are embraced in the proposed plot and the estimations of the stator flux $\vec{\psi_s}$ and the rotor flux $\vec{\psi_r}$ at the present testing step k are required.

Utilizing Euler-based discretization as discrete conditions of the rotor and stator flux estimation are as per the following:

$$\vec{\varphi_r}(K) = \frac{\tau_r}{T_s(1-j\omega*\tau_r)} * \vec{\varphi_r}(K-1) + \frac{L_m}{1-j\omega*\tau_r} \quad (1)$$

$$\vec{\varphi_s}(K) = k_r * \vec{\varphi_r}(k) + \sigma L_s * \vec{i_s}(k) \quad (2)$$

Where Ts relates to the testing time, kr = Lm/Lr is the rotor coupling element and σ = 1− (L2 m/LsLr) is the aggregate spillage consider. As it is clear to find in (1), the rotor flux estimation is gotten without utilizing the order voltages.

B.STATOR FLUX AND ELECTROMAGNETIC TORQUE PREDICTION

Since the control factors are stator flux is estimated above in equation (2) and electromagnetic torque is derived below as,

$$\widetilde{T_e}(K+1) = \frac{3}{2} p * I'm \left\{ \vec{\varphi_s}(k+1) * \vec{i_s}(k+1) \right\} \quad (3)$$

The forecast articulation of the stator current is (k + 1) is acquired utilizing the proportional condition of the stator progression of an induction machine

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The forecast condition of the stator current is at the moment k + 1 is acquired.

$$\underset{\hat{i}_s}{\rightarrow}(K+1) = \left(1+\frac{T_s}{\tau_\sigma}\right) * \underset{i_s}{\rightarrow}(k) + \frac{T_s}{\tau_\sigma + T_s} * \left\{\frac{1}{R_\sigma} * \left(\left(\frac{k_r}{\tau_r} - j * k_r * \omega\right) * \underset{\hat{\varphi}_r}{\rightarrow}(K) + v_s(k)\right)\right\} \quad (4)$$

Once the forecasts of the stator flux (2) and the stator current (4) are acquired, the forecast of the electromagnetic torque can be ascertained in (3).

C. COST FUNCTION OPTIMIZATION

The following stride in predictive control is the optimization of an fitting control law that is characterized as a cost work. The structure type of the cost function is given as takes after:

$$g_i = \left|\frac{T_e^* - \dot{T}_e(k+2)_i}{T_{e_{nom}}}\right| + \boldsymbol{\lambda_0}\left|\frac{\left\|\underset{\dot{\varphi}^*_s}{\rightarrow}\right\| - \left\|\underset{\dot{\varphi}_s}{\rightarrow}(k+2)_i\right\|}{\left\|\underset{\dot{\varphi}^*_s}{\rightarrow}\right\|_{nom}}\right|,$$

$$i \in \{1,2,3,4\}. \quad (5)$$

Where i indicates the index of the stator voltage vector utilized to figure the expectations Te (k + 1) and $\underset{\psi_S}{\rightarrow}$ (k + 1), respectively. The component λ0 signifies a weight figure. At long last, the improvement step is completed, and the inverter voltage vector that minimizes the cost capacity is chosen as the ideal exchanging state for the following testing time frame k + 1, hence the ideal torque and flux control is accomplished.

D. TIME-DELAY COMPENSATION

It is outstanding that there is one-phase delay in advanced usage. In other word, the voltage vector chose at the moment time k won't be connected until the moment time k + 1. To wipe out this deferral, the value at the moment time k + 2 ought to be utilized as a part of (18) as opposed to the moment time k + 1.

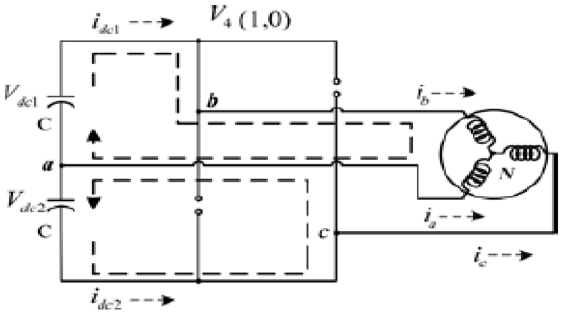

Fig.3. Current paths in the switching state *V*4.

E.DC-LINK VOLTAGE OFFSET SUPPRESSION

The improper starting phase angle of phase "a" current or the irregularity current flowing in the two capacitors will bring about voltage deviation.

The cost work, including the voltage balance concealment, is given by adding a third term to the cost work (19)

$$g_i = \left|\frac{T_e^* - \dot{T}_e(k+2)_i}{T_{e_{nom}}}\right| + \boldsymbol{\lambda_0}\left|\frac{\left\|\underset{\dot{\varphi}^*_s}{\rightarrow}\right\| - \left\|\underset{\dot{\varphi}_s}{\rightarrow}(k+2)_i\right\|}{\left\|\underset{\dot{\varphi}^*_s}{\rightarrow}\right\|_{nom}}\right| + \boldsymbol{\lambda_{dc}}\left|\frac{\dot{V}_{dc1}(k+2)_i - \dot{V}_{dc2}(k+2)_i}{V_{dc}}\right|,$$

$$i \in \{1,2,3,4\}. \quad (6)$$

 DOI:10.15662/IJAREEIE.2017.0601020

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Vol. 6, Issue 1, January 2017

Where V_{dc} is dc-link voltage, which can be gotten by V_{dc} = Vdc1 + Vdc2, λ_{dc} is the weight variable of the dc-link capacitor voltage offset suppression. The minimization is finished by a comprehensive inquiry for all achievable voltage vectors. The proposed control plot can be executed in the accompanying grouping (see Fig. 5). The superscript k, k + 1, and k + 2 mean the factors' value at testing time k, k + 1, and k + 2, separately.

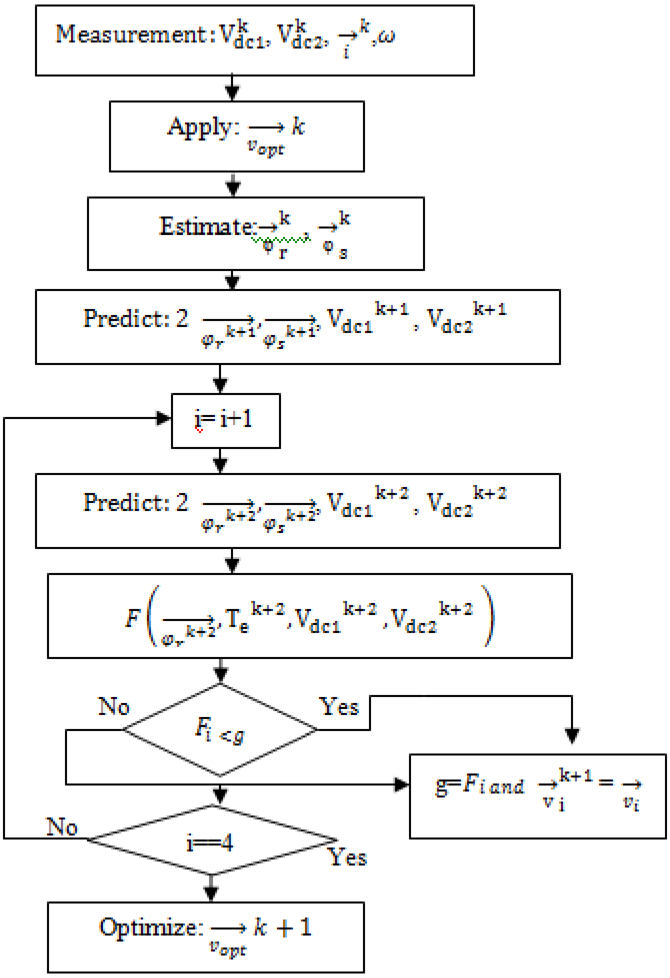

Fig.4. Implementation flowchart of the proposed scheme.

IV. FUZZY LOGIC CONTROLLER

Basically fuzzy logic controller is a numerical controlling system which is nothing but a rule based controlling system. In this controller the rules should be taken as either 1 or 0 by using “AND & OR” conditions.
Fuzzy controller is broadly used as a part of machine control. The expression "fuzzy" alludes to the way that the rationale included can manage ideas that cannot be communicated as the "real" or "imaginary" but instead as "partly real". The author Albeit elective methodologies, give some examples like, hereditary calculations and neural systems can perform generally and additionally fuzzy logic as a rule, fuzzy controller has the point of interest that the answer for the issue can be thrown in wording that human administrators can see, so that their experience can be used as a part of the outline of the controller. This makes it less asking for to robotize tries that are beginning at now effectively performed by individuals.

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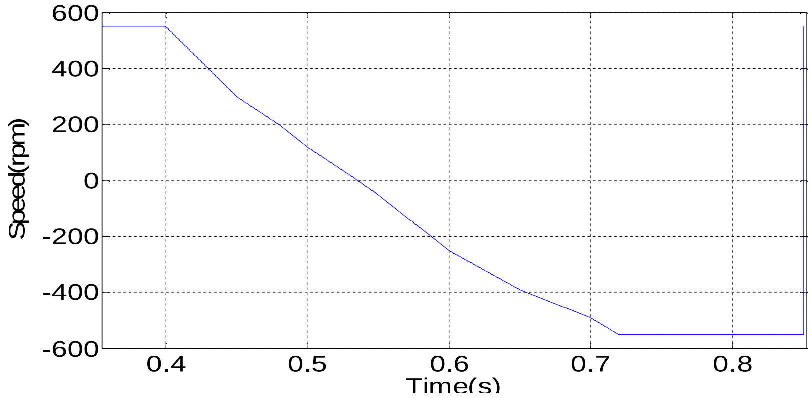
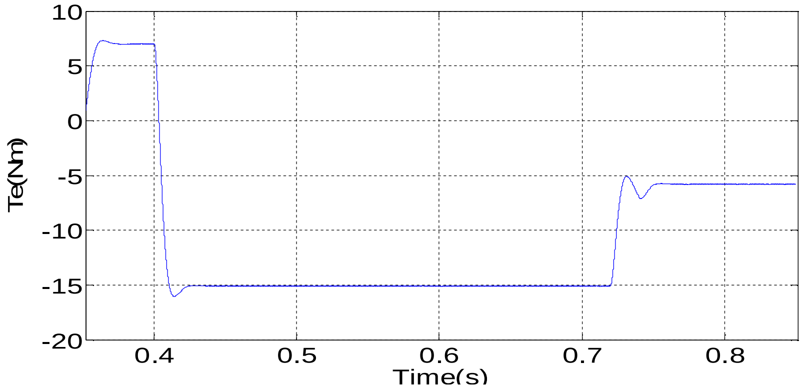
V. SIMULATION RESULTS

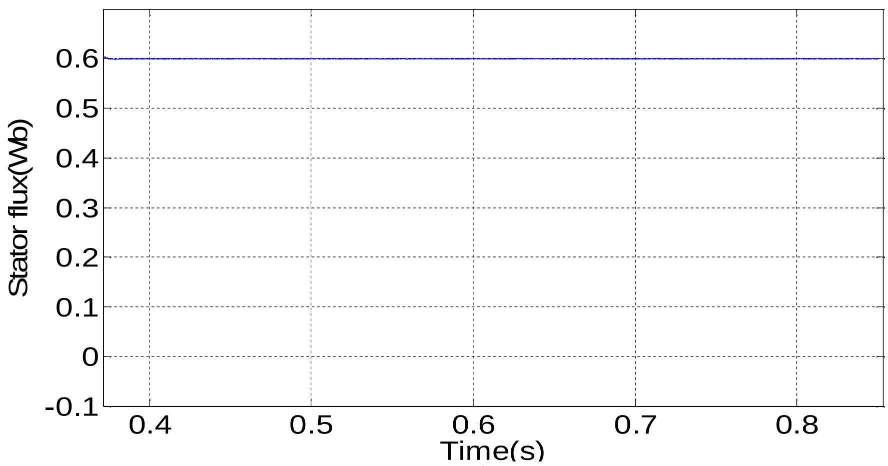
FUZZY LOGIC CONTROLLER:



(a) Speed



(b) Developed torque



(c) Stator flux

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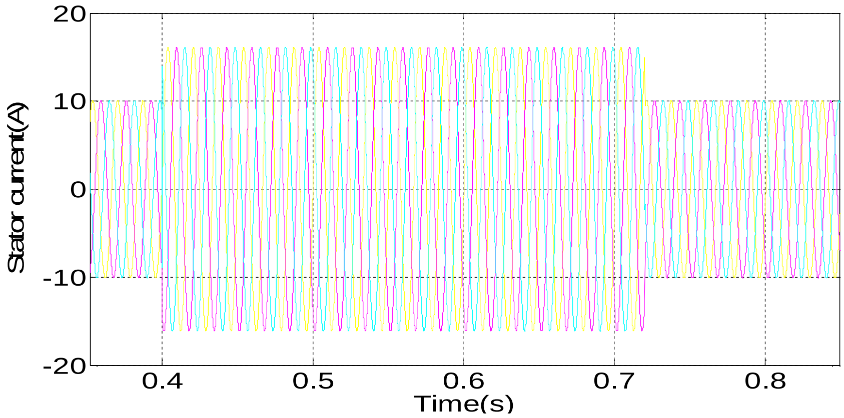
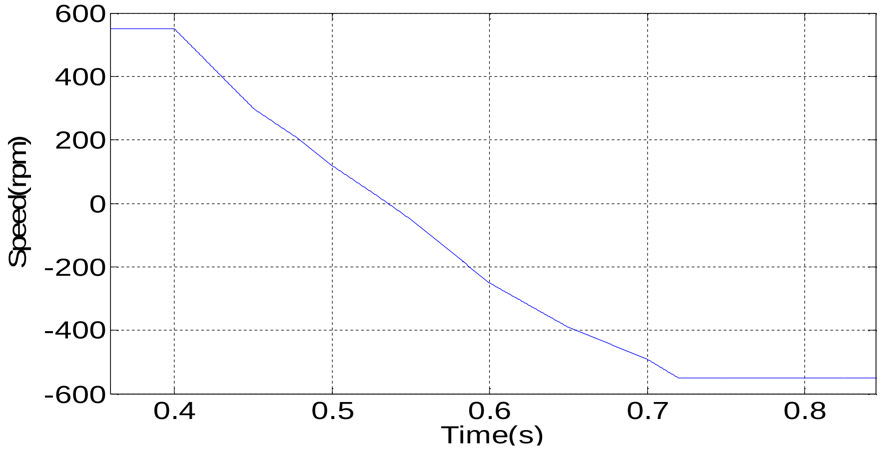
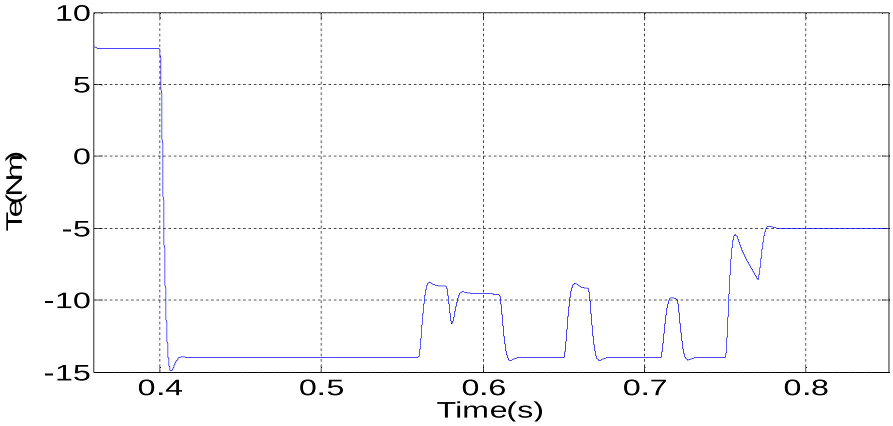


(d) Stator current

Fig.5. Simulated waveforms using the proposed scheme in a B4 inverter fed IM behaviors during a speed-reversal maneuver at 50% rated load torque ($\lambda 0 = 3$).



(a) Speed



(b) Developed torque

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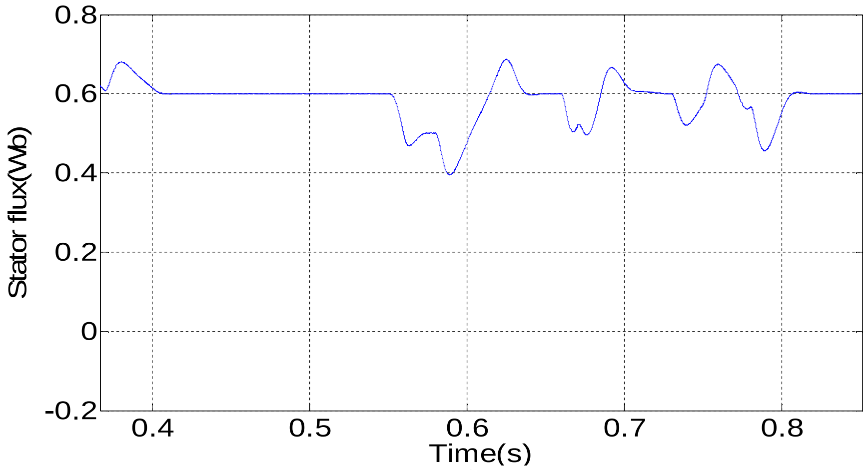
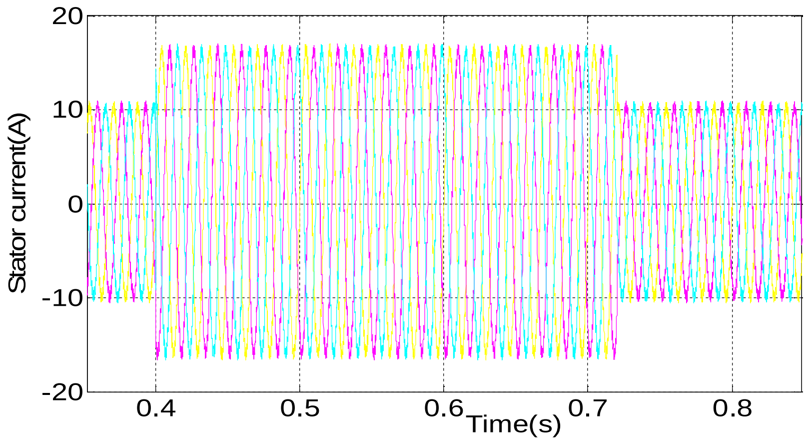


(c) Stator flux



(d) Stator current

Fig.6. Simulated waveforms using the proposed scheme in a B4 inverter fed behaviors during a speed-reversal maneuver at 50% rated load torque ($\lambda 0 = 1$).IM.

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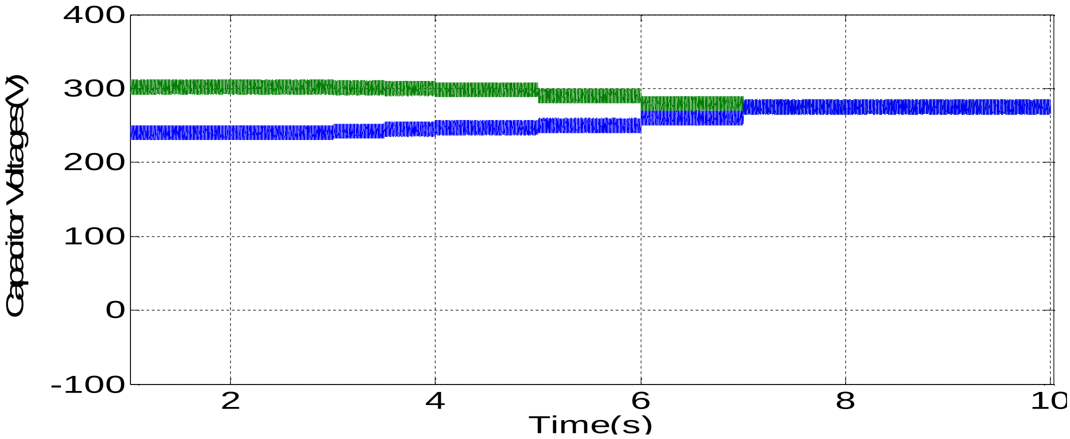
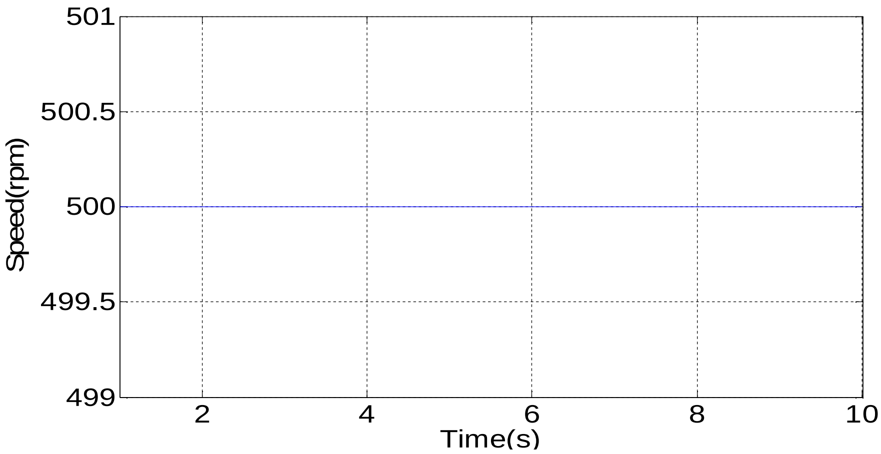
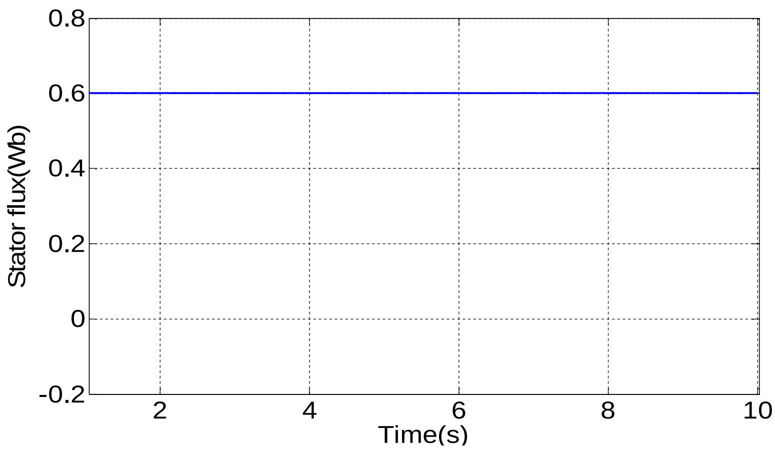


(a) Capacitor voltages



(a) Speed



(a) Stator flux

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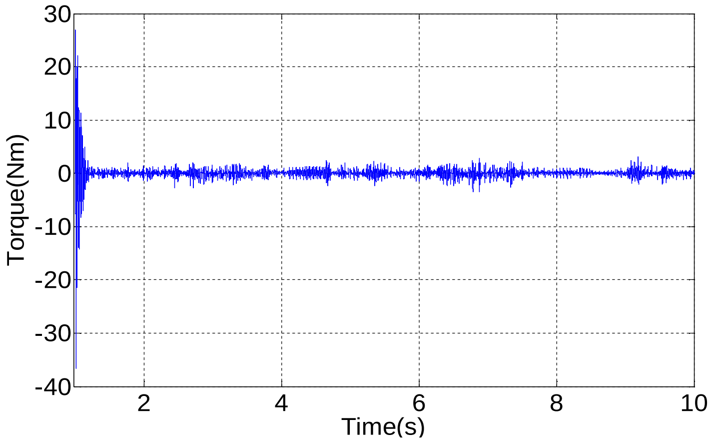
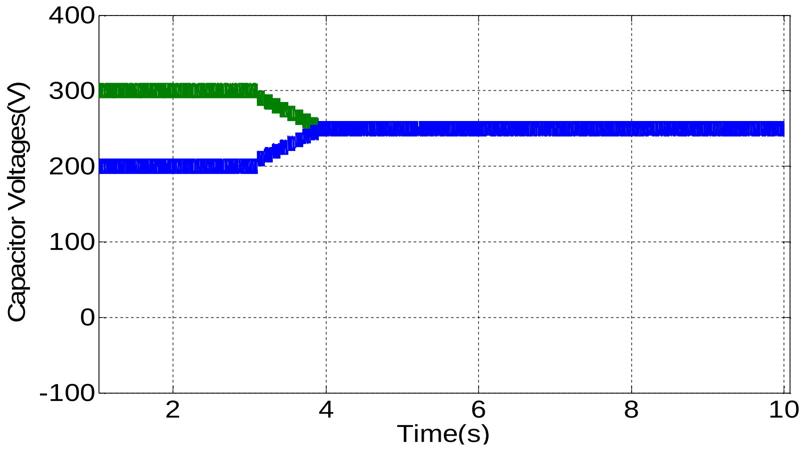
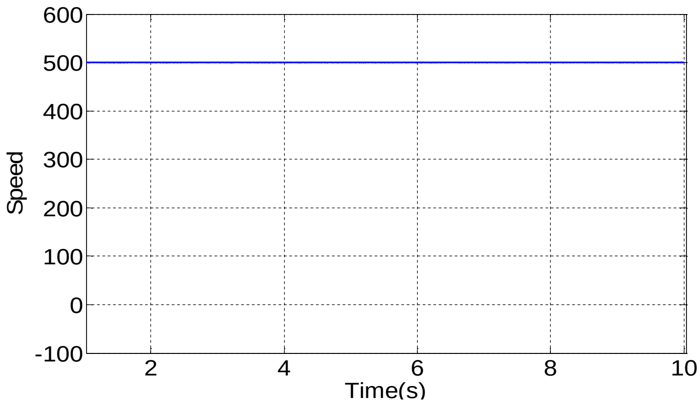


(a) Developed torque

Fig.7. simulated two capacitor voltages with offset suppression method. Behaviors during a voltage suppression method applied ($\lambda dc = 1000$).



(a) Capacitor voltages



(a) speed

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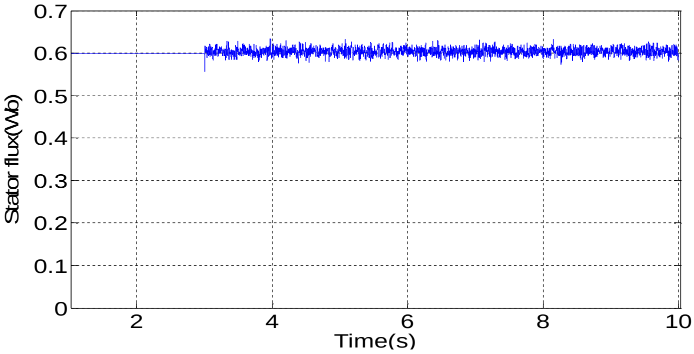
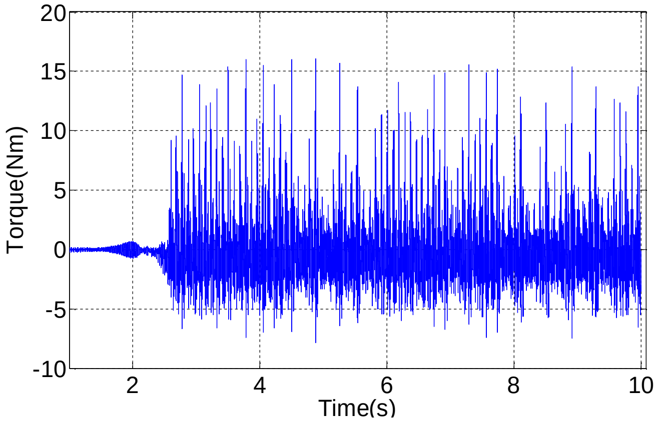


(a) stator flux



(a) developed torque

Fig.8. Simulated two capacitor voltages with offset suppression method behaviors during a voltage suppression method applied ($\lambda dc = 2000$).

Results comparison table:

S.No.	Output Name	THD for Fuzzy Logic Controller
1.	Stator current when $\lambda 0 = 3$	0.19
2.	Stator current when $\lambda 0 = 1$	4.68
3.	Torque when $\lambda dc = 1000$	35.13
4.	Torque when $\lambda dc = 2000$	746.69

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Vol. 6, Issue 1, January 2017

VI. CONCLUSION

In the field of high performance industrial variable speed drive streams the proposed B4 inverter fed induction motor IM drives was more advantageous and less cost efficient. B4 inverter fed induction motor IM drives through modern predictive control had made good factor in establishing the balanced three phase currents and suppressing the capacitor voltage offset.

Still more accurate methods should be accomplished to rectify the problems based on parameters readings fluctuations in motor drives and complications in extracting the accurate values of the parameters. Modern predictive control adapted to B4 inverter fed induction motor drives advancing techniques is examined.

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