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An Optimal Four-Switch Inverter-Fed Induction Motor Operation Using Bacterial Foraging Algorithm DTC Scheme Parameter Estimation

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Abstract : The induction motor drives are habitually used for the speed controlling strategies in a lot of the manufacturing speed based applications. The speed limit is greatly affects the output of the industrial speed based application in the performance of induction motor. There are different types of research methodologies are used to focus on reaching the higher performance. In this case the direct torque control is commonly used to control the speed and stator flux variation resourcefully. In the previous existing system, the six-switch three phase inverter in the direct torque control scheme is mainly used to control the speed and stator flux variation in well-organized manner. On the other hand it reduce the performance due to the fluctuation of the stator current values it leads to performance deprivation like unbalanced capacitor voltage, torque ripples, stator current etc., To overcome this problem the optimization methodology called the Bacterial Foraging Algorithm (BFA) is introduced in proposed DTC scheme. By using the proposed BFA algorithm the previous negative aspects are eliminated. It is mainly used for estimate the parameter values such as torque and flux values optimally. This proposed approach achieves the good optimization consequence where the optimal values of stator resistance and inductance are selected. It can be used to get rid of the stator current oscillation trouble, in the torque controlled systems. By giving the phase current values in the BFA approach, it reduces the stator current oscillation and it also produces the optimal values of the torque and stator flux. In the vector selection table also it steers clear of the needless dimensionalities and it also consider as the section of the Clarke plane into six sectors. In the four switch three-phase inverter (FSTPI), the planned method is used in the induction motor (IM) drives. The simulation results that are obtained have been proved that the proposed research methodology can provide better performance than the existing research methodologies.
Keywords : Four switch, DTC scheme, bacterial foraging algorithm, optimal parameter estimation.

1. INTRODUCTION

These days, in the asynchronous motor control the two predictable methods namely scalar and vector control grouped together. In the motor the first one is based on steady-state motor control and the second one is based on dynamic model [1]. Takahashi introduced a fresh vector control method namely Direct Torque Control (DTC) in 1980's. It is mostly paying attention on variable load and speed asynchronous

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motor drives. In the various types of induction motors the vector control is a better substitute method instead of field oriented control (FOC). It is having the several advantages like simple control structure. And there is no need of motor parameters so the parameter changes don't affect the fast dynamic response. Additionally, the high torque, current ripples and variable switching frequency performance are the disadvantages of the DTC system. And it is also having the involvedness of execution method owing to stipulation of stumpy sampling time.

Habitually, the voltage source inverter (VSI) driven by IM beneath DTC system in the six-switch three-phase inverter (SSTPI). In this scheme the electric and hybrid impulsion systems applications are consistently feasible. By using this obligation, the four switch three phase inverter (FSTPI) is reconfigured from SSTPI. This reconfiguration process is presently gives the rising consideration in case of a switch/leg failure [3]. In the proposed scheme [4] the DTC approach is devoted to FSTPI-fed IM drives. This type of scheme is used to reduce the low dynamic and the high ripple of the torque. This types of disadvantages are owing to the DTC strategy dedicated to FSTPI-fed IM drives has been proposed in [4]. Even though this method is simpler but will cause the motor performance due to its dynamic and high ripple nature. These drawbacks are due to the unhinged voltage vectors to the control flux and torque in the section of the Clarke plane inadequate to four sectors. In the industrial application generally using the Proportional-Integral (PI) controller which is mainly used to simplify structure and robust performance in a variety of operation. Lots of schemes as introduced for alteration the PI controller and it also produce a Ziegler-Nichols, root-locus and pole assignment [5]. These kind of schemes requires a precise model of the system and extremely reliant on the actual operating conditions.

Currently, lots of evolutionary algorithms (EA's) like Genetic Algorithm (GA), particle Swarm Optimization (PSO) and the Ant colony optimization (ACO) have been introduced. These algorithms are less or more victorious for managing the various types of non-linear optimization trouble. These algorithms are mainly used to search in complex, bulky and multimodal landscapes and it also gives near-optimal solutions for the intention or appropriateness function of an optimization troubles. The evolutionary algorithms are used to tuning the various controller parameters in three phase drives is sensible owing to their high speed convergence and logical precision. In the searching optimal solutions the bacterial foraging optimization (BFO) is used.

In this proposed work the BFO algorithm is mainly used to tune the PI speed controller parameters of a four switch induction motor inverter drive systems fed by a three phase MC. Untill the every turbulence and constant convergence distinguishing requiring a better speed and torque responses. And it also shows BFO is an influential optimization scheme for solving the PI controller parameters problems.

Considering this overall research work if follows: to achieve a good motor optimization result by using the different types of associated research work in section 2. In the third section the research methodologies is make clear details. By using simulation environment the results are obtained in section 4. At last in section 5, the research of the work is completed with their consequences.

2. RELATED WORKS

The researchers have implemented a various types of distinct control techniques and various speed control strategies of AC drives to obtain speed control of induction motors (IM) and permanent magnet synchronous motors (PMSM) by this work.

A predictive torque control (PTC) strategy for the B4 inverter-fed induction motor(IM) in the dc-link voltage equalize inhibition to balance among the phase currents collapses due to the fluctuations of the two dc-link capacitor voltages is proposed in Dehong Zhou et al., The B4 inverter voltage vectors beneath the fluctuation of the two dc-link capacitor voltages are derivative for accurate calculation and manage the torque and stator flux. The capacitor voltage offset is inhibited results to achieve it by using balanced three-phase currents. In this work, some disadvantages are available. So some more process are used to implement a well resourceful PTC strategy, and give a answer for the left over questions like parameter deviation from robustness, parameter sensitivity and the parameter values are differ in motor drives. At the same time to obtain a accurate values of the parameters are complicated.

A new strategy for balanced IM drive as name as fuzzy logic controller based on FSTHI introduced by Mohamed S. Zaky & Mohamed K. Metwaly [7]. It increases a dynamic response and decreases a computation trouble in the proposed FLC. This work has been evaluated in cooperation with simulation and testing at different speed reference tracking and torque disturbances, mostly at little speeds. The most helpfulness of the FLC is the elevated dynamic speed response without go beyond and undershoot, and with zero steady-state error, and less THD of stator currents. This shows the good capability of FLC controller during speed tracking performance, disturbance rejection, and parameters variation. It is also appropriate for money-spinning low power industrial applications. The production of the THD of the stator current is the important problem of this work.

Mourad Masmoudi et al [8] planned a novel DTC approach which exhibits a competence of decreasing the torque ripple for the duration of sector to sector commutations. In this proposed work the active voltage vectors following to the three phase conduction mode is done, at first each sectors are compel the current in the turned-off phase to flow through a convenient IGBT instead of an unmanageable IGBT non-interventionist diode. DTC-1 which is enthused from the one proposed to the control of B6-inverter-fed BLDC motor drives. The drawback that is found in this method is substantial deviation stage current which might affect the electromagnetic torque values.

The comparative analysis of field oriented control (IFOC) and Direct Torque control (DTC) of the induction motors with the help of adaptive flux observer is presented in the abdesselam chichi et al [9]. The two types of control strategies performance are explained in terms of torque, current ripples and transient response to load to queue variations. On the other hand to concentrate a progress of DTC strategy compared to FOC scheme concerning the dynamic flux control presentation and the accomplishment complication. Finally, the use of anti-windup PI controller outperforms the classical PI controller in speed control of high performance induction motor drive. The disadvantages was found in this research work is more oscillation of starting stator current values.

A novel Direct Torque Control (DTC) scheme is mainly focused on the bus-clamping technique devoted to induction motor drives by Bassem El Badsi et al [10] was proposed. In this scheme consists a two vector selection tables correctly arranged in view of the bus-clamping technique. The proposed BCDTC strategy has been intended to consider both anticlockwise and clockwise rotations of the induction motor. The two vector selection tables are synthesized depending on the motor rotation direction. The BCDTC scheme yields the clamping of each motor phase during two 60◦ intervals per cycle. The main problem found in this work is the demagnetization problem which would affect the performance of DR strategy.

3. OVERVIEW OF EXISTING SYSTEMS

The AC electric motor is one of the types of asynchronous motor of and induction motor. In this AC electric motor having the part of stator winding and it has the magnetic field. From the stator winding the torque ripples are produced by using the electromagnetic induction. Either wound or squirrel cage type can be an asynchronous motor rotor type.

In the past various industries utilize the induction motors to run their applications with high mobility, robustness and so on. 6-switch 3-phase inverters are most preferred technique in the variable speed IM drives. In this work conventional six switch three phase inverter fed motors are utilized for the static current variation. Later the performance of the SSTPI performance is enhanced by introducing the four switch three phase inverter by integrating the voltage which can lead to increased accurate result.

3.1. Six Switch Three Phase Inverter Fed Induction Motor

The induction motor power circuit from the six switch three phase (SSTP) voltage- source inverter is shown in Figure 1. Consider this circuit this circuit having two parts. One is front-end rectifier and the second one is six switches power circuit and six diodes. From the DC supply the front end rectifier get an electric charge. The input dc voltage is coiled during a two sequence associated capacitors. And the second part is used to function the two line to line voltages V_{cb} and V_{ac}. And also from the split capacitor bank by using a Kirchhoff's law the Vba is created. In this analysis stage the inverter switch motors are taken as ideal switches.

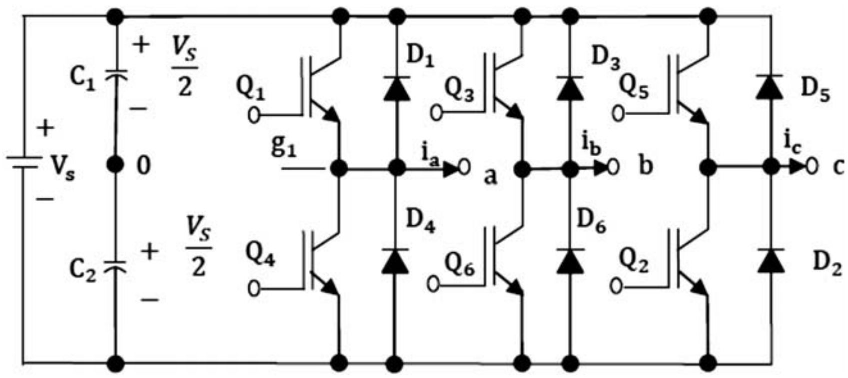

Figure 1: Illustrate 6 switch 3 phase inverter Circuit diagram

In the above circuit diagram, there are three phases namely '*a*', '*b*' and 'c' and these phases are mainly used to follow the instructions. This process is supported by two independent sinusoidal band current [11]. The vector and speed control loops are used to produce the above instruction followed by the phase '*a*', '*b*' and '*c*'. The outcome is generated by using six logics form. In the inverter power switches the six logic form methods is used and the process of this logics is switch on and off in the inverter power switches.

Basic DTC With Unbalanced Vector of FSTPI

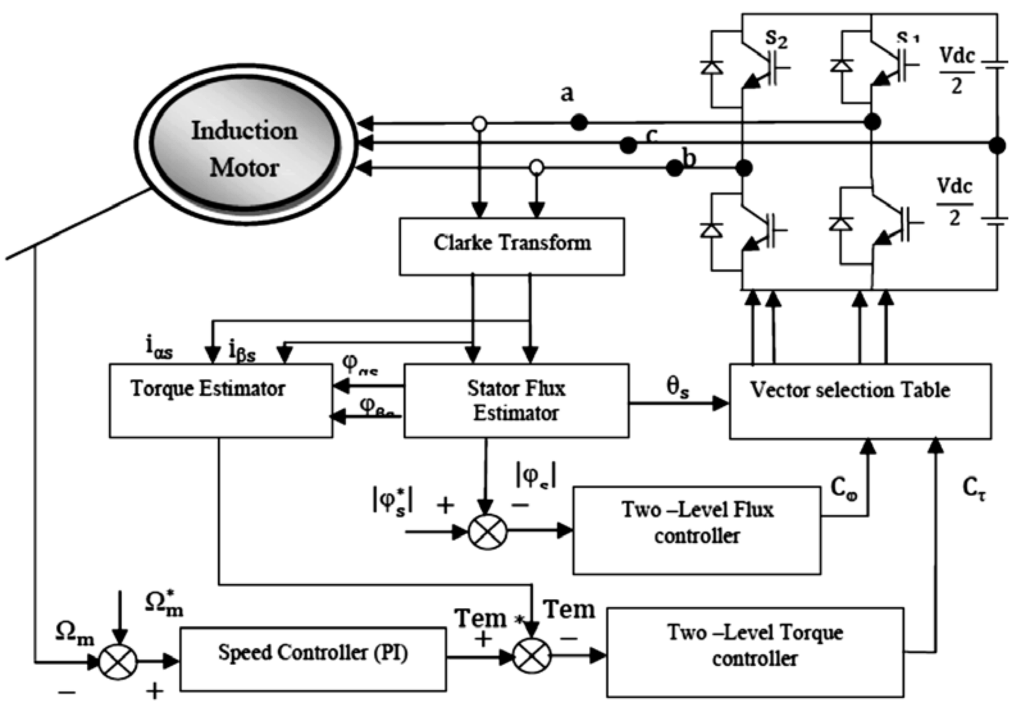

Figure 2: Implementation scheme of the DTC strategy dedicated to FSTPI-fed IM drives

To control the torque speed by using the Direct torque Control (DTC) which is mainly used in frequency drives of the three-phase AC electric motors. It is used to evaluate the motor's magnetic flux and torque based on the calculated voltage and current of the motor. The four switches S1, S2, S3 and S4 and a split capacitor are available in power inverter. In the inverter the two phases '*a*' and '*b*' are connected and in the dc link capacitors C1 and C2 the third phase '*c*' is connected. The capacitance values of C1 and C2 values are equal. In the DC link capacitor the voltage Vc1 and Vc2 are across (Vc1 = Vc2). 'V_{dc}' is the voltage transversely the capacitor C1 and C2 (V_{dc} = Vc1 + Vc2). DTC method allow a instantly control of the motor variables during a suitable choice of the inverter control signals, in order to accomplish the necessities as whether the stator flux, stator current and torque necessitate to be improved, decreased, or maintained. These conditions are generated according to the output c_φ of the flux hysteresis controller, the output c_τ of the torque hysteresis controller, and the angular displacement θ_s of the stator flux vector Φ_s in the Clarke (αβ) plane. The success scheme of the DTC strategy devoted to a FSTPI-fed IM, shown in Figure 2.

The DTC strategy execution scheme in FSTPI-fed IM is shown in Figure 2, and it has the same design as the one of the basic DTC scheme initially proposed apart from that

1. The FSTPI is generated by using the SSTPI inverter. Those specifications is done out by adding to the former three extra TRIACs with three fast acting fuses.
2. The three-level hysteresis controller in the torque loop is substituted by a two-level hysteresis controller.

Let's consider that the states of the four insulated-gate bipolar transistors (IGBTs) of the FSTPI are denoted by the binary variables S1 to S4, where the binary "1" corresponds to an ON state and the binary "0" indicates an OFF state. The IM stator voltages are denoted in terms of the states (S1 and S2) of the upper IGBTs, as follows:

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \frac{V_{dc}}{6}\begin{bmatrix} 4 & -2 & -1 \\ -2 & 4 & -1 \\ -2 & -2 & 2 \end{bmatrix}\begin{bmatrix} S_1 \\ S_2 \\ 1 \end{bmatrix}$$

The Clarke transform substituted to the stator voltages retrieves:

$$\begin{bmatrix} V_{\alpha S} \\ V_{\beta S} \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix}$$

The voltage vectors (V1 to V4) are differentiated by using IGBTs in the β $p$lane, and this information's are mentioned in Table 1. Switching states, stator phase voltages, their clarke components And equivalent voltage vectors of FSTPI are given in the table 1 and the voltage vectors that are produced are depicted in the figure 3.

Table 1
Values observed from FSTPI

$(S_1\, S_2)$	V_{as}	V_{bs}	V_{cs}	$V_{\alpha s}$	$V_{\beta s}$	V_I
(0 0)	$-\frac{V_{dc}}{6}$	$-\frac{V_{dc}}{6}$	$\frac{V_{dc}}{3}$	$-\frac{V_{dc}}{2\sqrt{6}}$	$-\frac{V_{dc}}{2\sqrt{2}}$	V_1
(1 0)	$\frac{V_{dc}}{2}$	$-\frac{V_{dc}}{2}$	0	$\frac{3V_{dc}}{2\sqrt{6}}$	$-\frac{V_{dc}}{2\sqrt{2}}$	V_2
(1 1)	$\frac{V_{dc}}{6}$	$\frac{V_{dc}}{6}$	$-\frac{V_{dc}}{3}$	$\frac{V_{dc}}{2\sqrt{6}}$	$\frac{V_{dc}}{2\sqrt{2}}$	V_3
(0 1)	$-\frac{V_{dc}}{2}$	$\frac{V_{dc}}{2}$	0	$-\frac{3V_{dc}}{2\sqrt{6}}$	$\frac{V_{dc}}{2\sqrt{2}}$	V_4

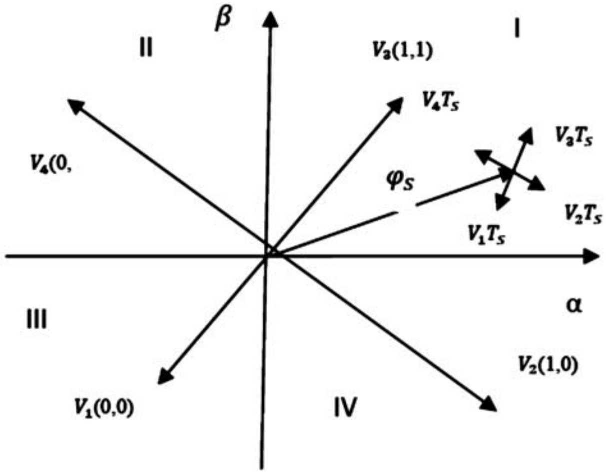

Figure 3: Unbalanced active voltage vectors generated by the FSTPI

3.2. Limitations Found in Unbalanced Voltage Vector Based DTC

The disadvantages of unbalanced voltage vector based DTC found are :

1. The voltage vectors V1 or V3 usages in induction motor running causes low torque dynamic if:
2. Φs1 is nearer to vector V2 due to the low amplitude of V1 and V3
3. Φs1 is nearer to vector V3 because of low angular shift of the flux vector
4. The usage of voltage vectors V2 or V4 would cause a low torque dynamic if Φs1 is nearer to vector V2 because of low angular shift of the flux vector
5. The usage of voltage vectors V2 or V4 would cause a high torque dynamic if Φs1 is present near vectorV3

2. GENERAL FUNCTIONING OF DTC SCHEME WITH BALANCED VOLTAGE VECTORS

The stator voltage vector is used to control the torque. To achieve this process the suitable stator voltage vector is chooses to control the torque value and it is known as direct torque control. The main plan of the DTC is to decide the best vector of the voltage it makes the flux rotate and generate the preferred torque. The amplitude of the stator flux keeps constants value for the particular period of rotation. All calculated electrical values of the motor are converted into a stationary α-β reference frame on the DTC scheme and conversation matrix as given in (1 to 3).

$$i_{\alpha\beta0} = [T]\, i_{abc} \tag{1}$$

$$V_{\alpha\beta0} = [T]\, V_{abc} \tag{2}$$

i_{abc}, v_{abc} calculated and $i_{\alpha\beta0}$, $v_{\alpha\beta0}$ deliberate phase currents and voltages correspondingly. T is transformation matrix as given in (3).

$$T = \frac{2}{3}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \tag{3}$$

Stator flux vector is measured by utilizing the current and voltage vectors of the induction motors at current time as given in (4-6).

$$\lambda_\alpha = \int (V_\alpha - R_s i_\alpha)dt \tag{4}$$

$$\lambda_\beta = \int (V_\beta - R_s i_\beta)dt \tag{5}$$

$$\lambda = \sqrt{\lambda_\alpha^2 + \lambda_\beta^2} \tag{6}$$

Where the stator flux space vector (λ), stator voltage is V_{ds} and V_{qs}, line currents i_{ds} and i_{qs} in α-β reference frame and stator resistance R_s. The equation (7) is used to estimate the electromagnetic torque of an asynchronous machine (7).

$$\theta_\lambda = \frac{3}{2} p(\lambda_\alpha i_\beta - \lambda_\beta i_\alpha) \tag{7}$$

In the above equation *p* is represented by the number of pole pairs. A significant control parameter for DTC is stator flux vector sector. Stator flux rotate trajectory is alienated six sectors and evaluation of stator flux vector sector as given in (8).

$$\theta_\lambda = \tan^{-1}\left(\frac{\lambda_\beta}{\lambda_\alpha}\right) \tag{8}$$

In DTC scheme, hysteresis comparators create two control parameter values namely stator flux which is represented as two level types and torque which represented as tree level type. These hysteresis comparators use flux and torque immediate error values as input and generates control signals as output.

4.1. Limitations Found

The DTC strategy is not only used a torque reference value, but also a stator flux reference values as control parameters. Usually, motors are intended to work their utmost effectiveness in their insignificant working point. But in the various industrial control applications (*i.e.* cranes, elevators) motor loading situations can differ from time to time. For that reason, the motor flux values are readjusted when the load is less than the rated value. This can be achieved by introducing optimization algorithm explicitly bacterial foraging algorithm which is used to optimally find the torque and flux estimator values. Some of the restrictions are

- Unbalanced capacitor voltage affecting experimental results at high speed
- More oscillating at starting stator and torque current voltage level

5. OPTIMIZED DTC CONTROL SCHEME USING BFA APPROACH

In real time the performance of a 4-switch, 3-phase inverter fed cost effective induction motor in the FSTPI for IM drives, it has been implemented by vector control. The bacterial foraging optimization approach is used to improve the four switch three phase inverter fed induction motor. In this scheme it combines the evolutionary algorithm like BFO with the usual DTC approach to tune the parameter values. These output values of BFA is given as input to the torque estimators and the stator flex estimators. The values of torque and stator flux estimator are used to select the suitable voltage vector. The proposed scheme is illustrated in the figure 5.

The above figure gives details of the overall view of four switch three phase inverter fed induction motor system. It optimizes the overall performance by integrating the bacterial foraging algorithm with the traditional DTC strategy.

5.1. Procedure of Bacterial Foraging Algorithm in DTC Scheme

The Bacterial Foraging Optimization Algorithm is enthused by the crowd food searching performance of bacteria such as E.coli and M.xanthus. Particularly, the BFOA is enthused by the chemotaxis performance of bacteria that will distinguish chemical gradients in the environment (such as nutrients) and move toward or left from precise signals. To achieve the optimal induction motor running performance, the parameter values are chosen by using the bacterial foraging algorithm in the proposed research work. In this work the parameters that are considered for the optimal selection are stator current, stator flux and torque values.

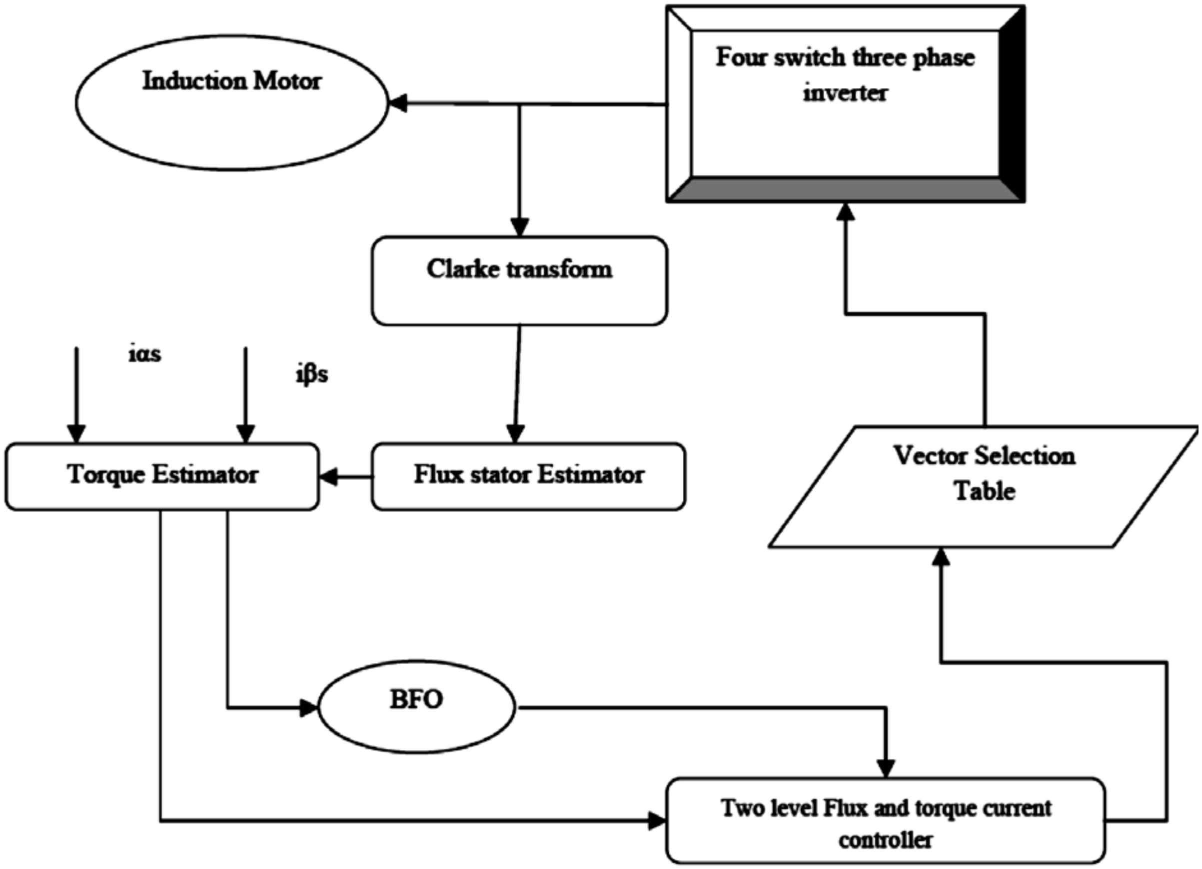

Figure 4: Overall view of Four Switch three phase inverter fed Induction motor System

The selection of speed control parameters are done based on the phase current values. The information processing strategy of the algorithm allows cells to stochastically and cooperatively group toward optima. This work performs three processes on a inhabitants of simulated cells: 1) 'Chemotaxis' where the cost of cells is rerated by the proximity to other cells and cells move along the manipulated cost surface one at a time 2) 'Reproduction' where only those cells with good performance for the long period of time may alive in the next generation, and 3) 'Elimination-dispersal' where cells are eliminated and random new samples are taken with a low probability.

This BFO usage in the induction motor running proves to provide the efficient motor running without failure than the existing approaches which selects the stator flux and torque values randomly. This random value selection would lead to more stator current oscillation in the existing research work, thus the induction motor running performance would be degraded. But in the proposed research, instead of using the random stator flux and torque values, BFO algorithm provide optimal values of stator flux and torque which is selected based on the phase current values.

5.1.1. Procedure

The pseudo code of BFOA algorithm which is used to select the optimal values of speed control parameters is illustrated below. This pseudo code shown as picture of chemotaxis and swing characteristics of bacteria's. In this algorithm cost of bacteria would be derated in each iteration based on their foraging performance. The interaction behavior function between bacteria g () is calculated as follows:

$$g(\text{cell}_k) = \sum_{i=1}^{S}\left[-d_{attr} \times \exp\left(-W_{attr} \times \sum_{m=1}^{p} \text{cell}_m^k - \text{other}_m^i\right)^2\right]$$
$$+\sum_{i=1}^{S}\left[h_{repel} \times \exp\left(-W_{repel} \times \left(\sum_{m=1}^{p} \text{cell}_m^k - \text{other}_m^i\right)^2\right)\right]$$

In the above mentioned equation cell_k is represented a given cell, the attraction coefficients are represented by d_{attr} and w_{attr} and repulsion coefficients are represented by h_{repel} and w_{repel}. In the inhabitants S is represented by the number of cells and in the cells position vector P is represented by the number of dimensions. In this algorithm the extra parameters are represented as Cells_{num} and it is used to maintaining the number of cells. N_{ed} is represented the number of elimination-dispersal steps, the number of reproduction steps are represented by N_{re} , N_c is represented as the number of chemotaxis steps, N_s is represented as the number of swim steps, the random direction vector is represented by $\text{Step}_{\text{size}}$ and each value $\in[-1, 1]$, and the probability of a cell is represented as P_{ed} and this focused to eradication and diffusion. The flow chart of the proposed BFA algorithm is shown in the following figure 6.

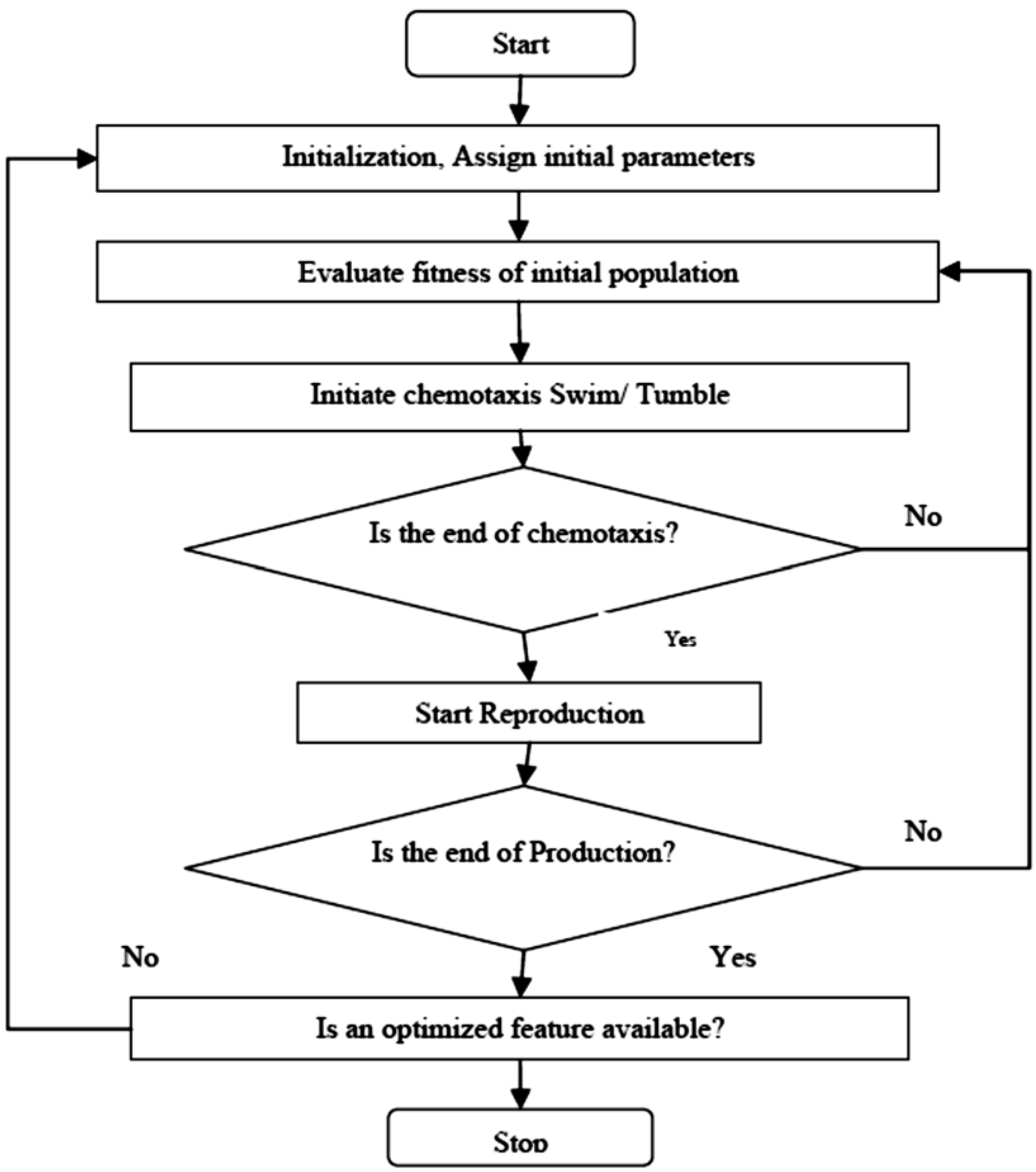

Figure 5: BFA flow diagram.

PSEUDOCODE

Input : $Problem_{size}$,$Cells_{num}$, N_{ed}, N_{re}, N_c, $Step_{size}$, $d_{attract}$, $w_{attract}$, $h_{repellant}$, $w_{repellant}$, P_{ed},

Output : $Cell_{best}$

Population ← Initialize Population ($Cells_{num}$, $Problem_{size}$)

For ($l = 0$ to N_{ed})

For ($k = 0$ to N_{re})

For ($j = 0$ to N_c)

Chemotaxis And Swim (Population, $Problem_{size}$, $Cells_{num}$, N_s, $Step_{size}$, $d_{attract}$, $w_{attract}$, $h_{repellant}$, $w_{repellant}$)

For (cell ∈ Population)

If (Cost (cell) ≤ cost ($Cell_{best}$))

$Cell_{best}$ ← cell

End

End

End

Sort By Cell Health (Population)

Selected ← Select By Cell Health (Population, $\frac{Cells_{num}}{2}$)

Population ← Selected

Population ← Selected

End

For (Cell ∈ Population)

If (Rand() ≤ P_{ed})

Cell ← CreateCellAtRandomLocation ()

End

End

End

Return ($Cell_{best}$)

The above algorithm is used to optimally select the torque and stator flux parameters which is used in the vector selection process for the controlling the speed of induction motors. In the induction motors, initial values of stator flux and torques would be fluctuated more which might lead to uncontrolled speed of the induction motors which needs to be controlled for the improved performance of induction motor. The vectors play a vital role in the speed control. The better stator flux and torque values can lead to optimal selection of vectors from the vector selection table, thus the induction motor performance can be increased. Thus the BFA algorithm introduced in this proposed research work for the optimal selection of stator flux, stator current and torque values with the concern of avoiding the initial fluctuation present in those values. Finally this optimal value of stator flux, stator current and the torque is given as input to the vector selection table to control the speed of the induction motors which is described in detail in the following sub section.

The improvement attained and the optimal values of stator flux, torque and the stator current values found using BFO approach is illustrated in the simulation result section under the figures 6, 7 and 8. With these figures, the simulation results of the existing research methodology is also given from which it is proved that the proposed research leads to provide the better improvement than the existing research work.

5.2. Balanced Voltage Vector Based FSTPI

The balanced voltage vector based DTC strategy is based on the cloning of SSTPI operation by the FSTPI. It is done by generating the six balanced voltage vectors by utilizing the intrinsic of FSTPI. At the time of generation, concern should be taken on amplitude and angular shift values which should remain as same as SSTPI which is inspired Takahashi [12]. The torque ripples can be reduced considerably by avoiding the control parameter combination that are generated by two level hysteresis controllers and make use of BFOA approach for the selection of control parameter values. The equations of output phase voltage of inverter which is controlled by space vector modulation are given in the following equations.

$$V_{ao} = V_{an} + V_{no}$$
$$V_{bo} = V_{bn} + V_{no}$$
$$V_{co} = V_{cn} + V_{no}$$
$$V_{no} = \frac{1}{2}\text{median}\,(V_{an}, V_{bn}, V_{cn})$$
$$V_{an} = |\vec{V}_{sref}|\cos(\theta_s)$$
$$V_{bn} = |\vec{V}_{sref}|\cos\left(\theta_s - \frac{2\pi}{3}\right)$$

And

$$V_{cn} = |\vec{V}_{sref}|\cos\left(\theta_s + \frac{2\pi}{3}\right)$$

The above equations are used to achieve the balanced voltage vectors which can be used to run the induction motors smoothly. This work ensures the reduction of stator current oscillation, thus the performance the induction motor is guaranteed. Generally, performance of the induction motors might be degraded due to supplying uneven current distribution that is unbalanced voltage vectors to the induction motors. This is resolved in this research work by selecting the balanced voltage vectors using the optimal values of stator flux and torque obtained from the BFO approach. Thus the stator current oscillation problem is reduced considerably that ensures the induction motor running performance improvement. A balanced voltage vector generated by FSTPI is given in the figure 4.

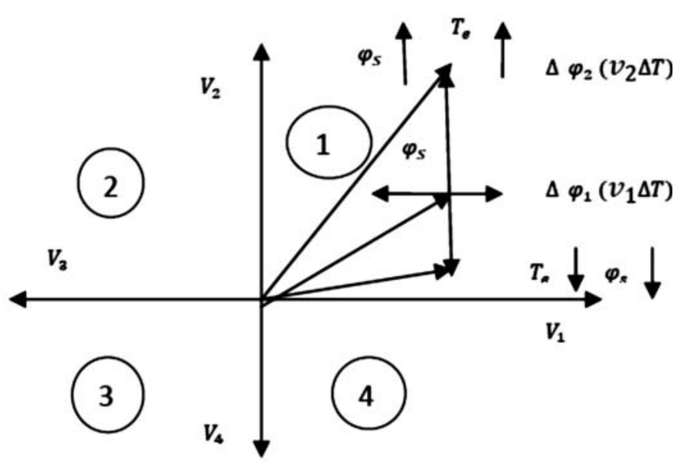

Figure 6: Balanced active voltage vectors generated by the FSTPI

6. SIMULATION RESULTS

The experimental evaluation BFA based DCT FSTPI fed induction motor drive is carried out in the SIMULINK MATLAB environment. The experimental tests has been conducted for the proposed methodology under varying load levels. The performance metrics that are considered in this work for evaluating the effectiveness of the proposed research methodology are,

1. Stator flux
2. Rotor torque
3. Stator current
4. Speed
5. Rotor flux angle
6. Total weighted harmonic distortions

The performance evaluation is conducted in the different level for the existing and proposed scenarios and the difference is made by experimenting with load and without load conditions. The components of FSTPI driven induction motors are 3 phase diode bridge rectifier, 4 switch 3 phase inverter, split capacitor and 3 pahse squirrel cage IM. Input supply voltage: 3-phase, 415 V (rms), 50 Hz; Induction Motor: 5 hp 415 V, 50 Hz, 1430 rpm. The simulation setup of the proposed research work is illustrated in the figure 5. Figure 5 shows the modules and functions involved in the proposed research methodology which leads to optimal induction motor running result.

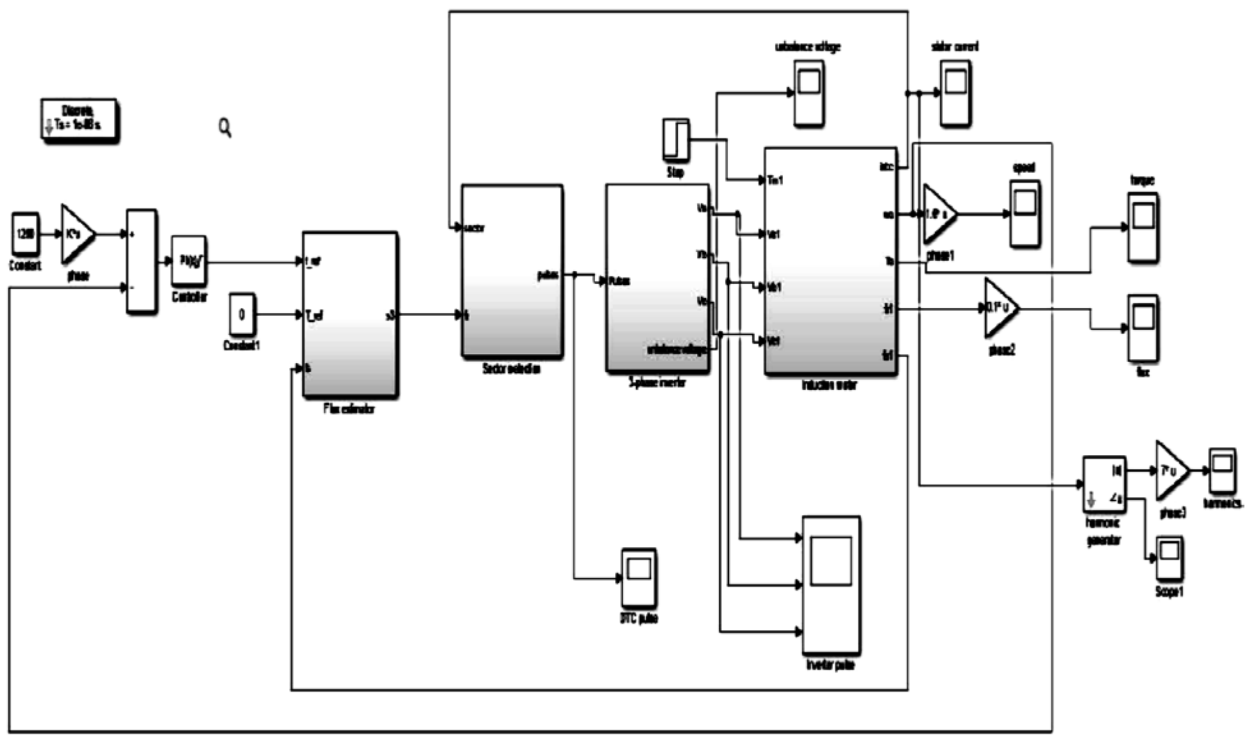

Figure 7: Simulation setup

In the proposed research work, BFOA approach is used for optimal selection speed control parameter values, where the performance of BFOA in terms of optimal selection of control parameter values depends on convergence rate which might affect the accuracy of optimal selection of values. In this research, initially parameters values are chosen based on trial and error method where the multiple attempts would be made for getting possible solutions. Then the execution would be made for varying voltage conversion rations. From the analysis, it is predicted that the proposed algorithm is stable and the objective function continues to converge to the global optimum even with different initial values.

6.1. Stator Current

Stator current only generates torque and the actual rotor magnetic flux field. In an induction motor, there is slip. The slip between the rotating field and the rotor induces a current in the rotor bars. That current generates the rotor's magnetic field, which interacts with the stator field to rotate the motor.

In figure 8a and 8b, stator current values obtained in the existing research and proposed research of induction motor is given. As can be noticed, the stator phase currents are almost balanced. From these figures it is proved that the proposed research methodology tends to provide the optimal current rate to the induction motor for running with reduced fluctuation than the existing research methodology which shows it's more fluctuation in the current rate. In the existing system balanced stator current is obtained after 164 ms whereas proposed research can obtain balanced stator current at 13 ms itself. This is due to optimal selection of the stator flux and torque value selection in the proposed research, thus the balanced stator current is achieved in the minimal iteration and reduced time.

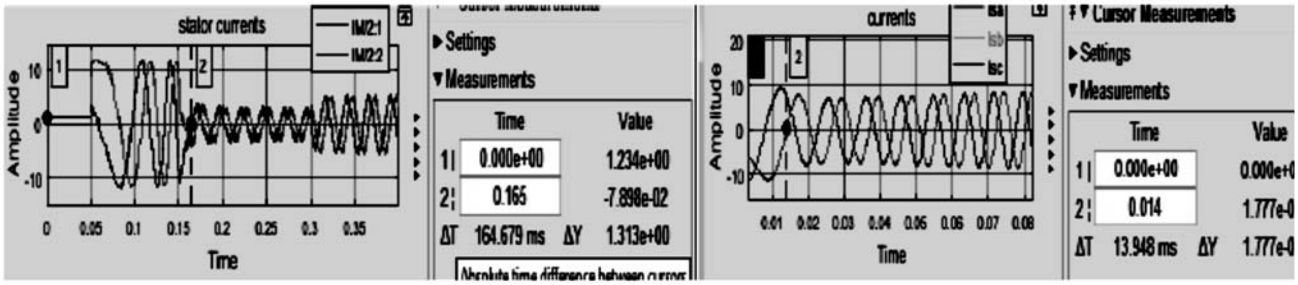

Figure 8: (*a*) Exiting stator current values **Figure 8: (*b*) Proposed Stator current values**

6.2. Speed

AC motors are also known as constant speed motors. For the reason that the synchronous speed of an induction motor is based on the supply frequency and the number of poles in the motor winding. An AC motor's synchronous speed, n_s, is the rotation rate of the stator's magnetic field,

$$n_s = \frac{2f}{p}$$

In the above equation f is represented as the motor supply's frequency, the number of magnetic poles is represented by p and the identical units are represented as n_s and f.

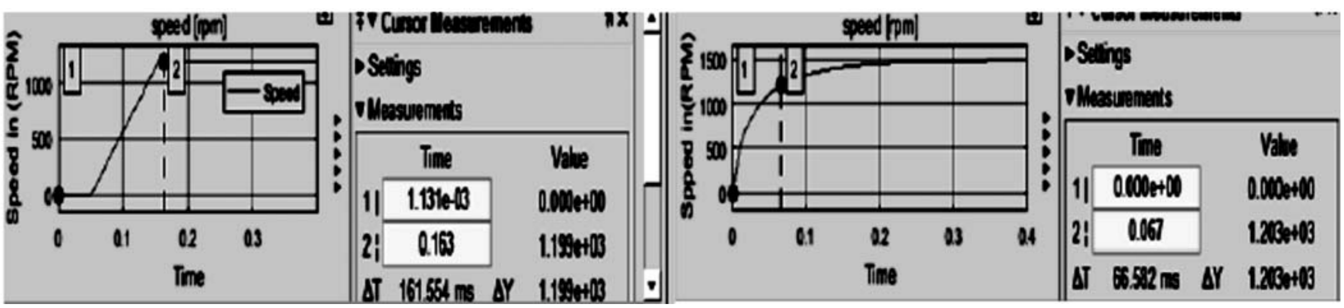

Figure 9: (*a*) Existing speed **Figure 9: (*b*) Proposed Speed**

From this figure 9(*a*) and 9(*b*), it can be predicted that the proposed methodology can lead to provide the better speed performance than the existing research methodologies. Speed is a most important factor for the induction motor running process which should be high and increased in the constant rate. The proposed research speed in the figure 7(*a*) shows its constant speed improvement where the figure 7(*b*) shows the more oscillation in the speed increase. From the figures it can be proved that the proposed research methodology can perform better in the induction motor running process by gradually increasing speed and reaches the maximum speed within less time period whereas in the existing research methodology, speed is increased to high suddenly and takes long time period to reach the maximum speed. The time taken to reach the maximum speed of induction motor in existing method and proposed method are 161 ms and 66 ms respectively.

6.3. Rotor Torque

The induction motor running mainly depends on the current supplied which required torque needs to be produced at the proper level for the optimized motor running performance. Here the torque can be generated from magnetic field of the stator winding. Torque is a measure which decides an force level F which is to be given to motors for the running.

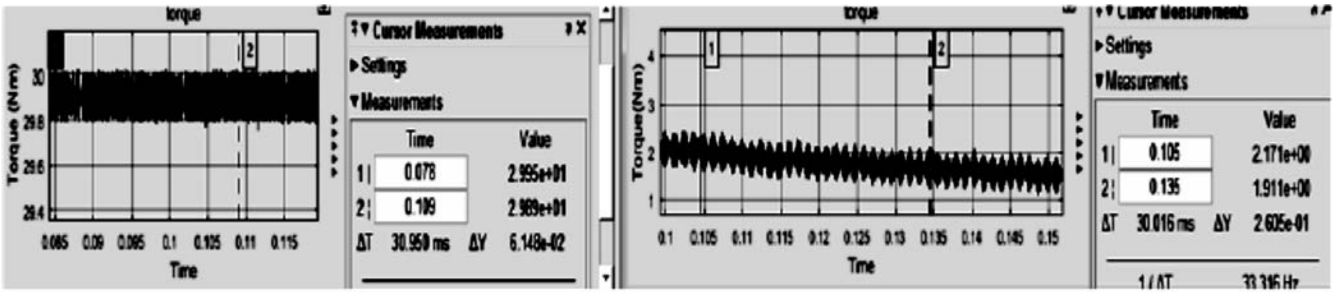

Figure 10: (*a*) Existing torque **Figure 10: (*b*) Proposed Torque**

Figure 10(*a*) and 10(*b*) shows the rotor torque waves. This figure illustrates the existing torque ripples and the proposed torque ripples. From this figure the proposed work are achieved and it is guides to give the variable high and low fluctuation in the torque representation. From these figures it is proved that the proposed current torque values generated are better with reduced fluctuation rate than the existing research methodology which produces more fluctuation in the torque values. Figure 8 indicated torque ripples comparison values of both existing and proposed research methodologies at the same time period. This figure proves that the proposed research method can leads to less torque ripples than the proposed research method at the same time period due to optimal selection of torque estimation values. This comparison is given at the time period of 30 ms.

6.4. Stator Flux

One of the parts of the induction motors is an stator which would generate varying flux linkage values which is an 2D value. Flux linkage is similar to an magnetic flux which is represented in the following equation

$$\lambda = \int \varepsilon dt$$

In the above equation ε is represented as the voltage transversely the device or the possible differentiation flanked by the two terminals.

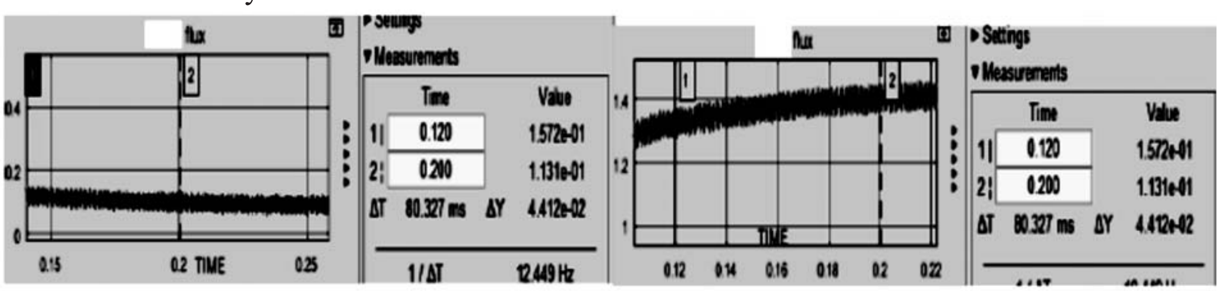

Figure 11: (*a*) Existing Stator flux values **Figure 11: (*b*) Proposed stator flux values**

Figure 11(*a*) and 11(*b*) shows the stator flux waves. It clearly shows that demagnetization happens at the each sector initialization. For example, at the start in sector I, if Φs is located means the equivalent control grouping ($c_\varphi = +1$, $c_\tau = +1$) is proved by the application of the voltage vector V3. This guides to diminish of the stator flux owing to the voltage drop. From this figure it can be proved that the proposed methodology produces an optimal stator flux than the existing research methodology.

6.5. Capacitor Unbalanced Voltage

An unequaled voltage lines of 3 phase circuit is called as voltage unbalance. This voltage unbalance would lead to tremendous cause on the induction motor running process which should be balanced to increase the performance. The voltage unbalance can be calculated as like as follows:

$$\%\text{ voltage unbalance} = \frac{\text{Maximum voltage deviation from average voltage}}{\text{Average voltage}}$$

In figure 12, capacitor unbalanced voltage is represented in the wave form

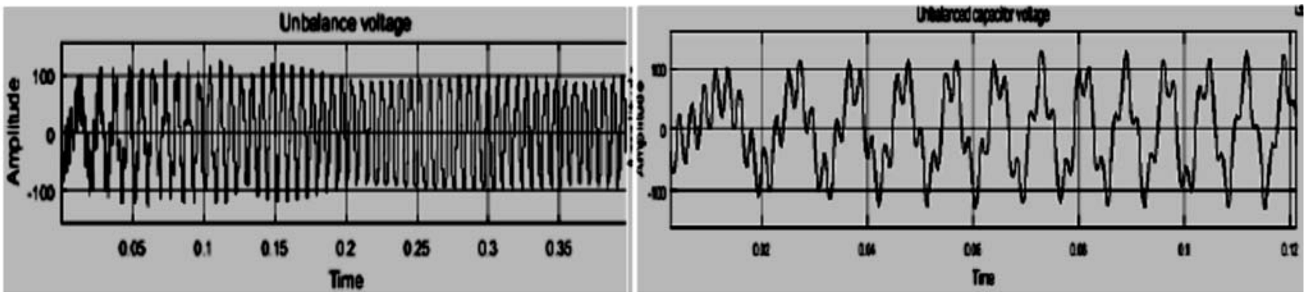

Figure 12: (*a*) Existing Capacitor Unbalanced Voltage

Figure 12: (*b*) Proposed Capacitor Unbalanced Voltage

Figure 12(*a*) and 12(*b*) represents the unbalanced voltage details of both existing and proposed research methodologies. The proposed methodology leads to show that it can reach less fluctuation in the voltage supply within less time period where the existing method couldn't reach less fluctuation even in the long time period. From this figure it is proved that the proposed methods can reach less fluctuated voltage supply at the time period of 0.02 ms – 0.12 ms itself but the existing system cannot reach this even at the time of 0.35 ms.

6.6. Total Harmonic Distortion

In order to highlight the performance gained by the introduced DTC scheme, the resulting steady-state features are compared to the ones obtained following the implementation of the basic DTC strategy. Figure 11 illustrates the waveforms of V_{as}, i_{as}, V_{cs}, and i_{cs} and the harmonic spectra of i_{as} and i_{cs} following the implementation of the proposed DTC strategy (subscript "1") and the basic DTC one (subscript "2") for Ω_m = 50 rad/s and Tl = 1 Nm. The considered comparison criterion is the total harmonic distortion (THD) of currents i_{as} and i_{cs}, which is expressed as:

$$\text{THD} = \frac{\sqrt{\sum_{n \# 1} I_n^2}}{I_1}$$

where I_1 and I_n are the amplitudes of the fundamental and the nth harmonic ranks of i_{as} and i_{cs}, with n = 2, 3, 5, and 7.

7. CONCLUSION AND FUTURE WORK

Induction motor is an ac type motor which is utilized in the many real world applications that is based on speed. DTC control scheme is a most preferred technique in the speed control application which controls the speed of the motor by controlling the torque and flux variation. The stator current oscillation problem that arises in the DTC scheme is resolved in the proposed research work, replacing the random assumption of stator flux and torque estimator values which is used to control the variation. This is done by using the BFO optimization algorithm which will be given with the input values as phase currents, based on which stator flux and torque values would be estimated optimally. This approach can lead to the better optimization result where the optimal values of stator flux and torque values can eliminate the stator current oscillation problem. The simulation results that are obtained have been proved that the proposed research methodology can provide better performance than the existing research methodologies. The proposed research leads to elimination stator current oscillation problem along with reduced current harmonic distortion problem. In further scenario, elimination/reduction fifth order harmonic can be considered to achieve better performance of induction motors.

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