STEADY STATE PERFORMANCE IMPROVEMENT OF DTC IM DRIVE UNDER PARAMETER AND TRANSDUCTION ERRORS

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ABSTRACT
This paper presents steady state behavior of Direct Torque Control (DTC) of Induction motor (IM) drive. As in direct torque and flux control scheme electromagnetic torque and stator flux magnitude of induction motor drive is limited in closed loop without shaft sensors voltage modulator. This values are calculated with the help of dc link voltage of inverter and stator current. As during estimation of stator flux magnitude and torque results in some errors. In addition to this stator resistance mismatch also take place due to continuous operation of motor. As stator resistance is only parameter which considered during flux and hence in stator current estimation. Change in stator resistance also affects the torque linearity, and degrades the drive performance. Thus stator resistance PI compensator is adopted for the estimation and correction of stator resistance. This paper gives the theoretical finding of all errors and simulation results for adopted stator resistance PI compensator for DTC IM drive.

Keywords: Direct Torque Control (DTC), Induction Motor Stator Resistance, Stator Resistance PI Compensator.

I. INTRODUCTION
In IM Drive system DTC control method becomes the most popular control technique due to its easy control and capability to attain quick response. Takahashi and T. Noguchi introduced the DTC scheme as a new high performance control technique for induction motor drives fed by VSI as an substitute to Field Orientation control. DTC scheme of induction motor Drive for the evaluation of stator flux magnitude and electromagnetic torque is controlled in closed-loop manner without in-between any shaft sensors, current loops & voltage modulators [1-3]. Basically this scheme works in order to compute immediate values of flux and torque with the help of stator variables by selecting proper switching configuration. Hence proper voltage vector selection is depending on flux and torque error. The flux and torque controller are of hysteresis type which are not able to differentiate the small and large error [3].

Thus for complete sampling period given voltage vector is applied even for all small errors, large overshooting steady state region occurs. Resulting high torque ripples in steady state operation. Stator resistance is the single factor which is required for Stator flux estimation and further for the calculation of stator current. Mainly variance in stator resistance is because of resistance variation throughout the induction motor operation. Continuous operation of induction motor results in motor heating. Voltage and current transduction are also affected due to gain errors and offsets [1]. As temperature variation and stator frequency variation degrades the drive behaviour by incorporating error in evaluated magnitude and position of stator flux vector.

Resulting effect on the estimation of stator current and torque and degrades the drive performance. In case of FOC IM Drive similar degradation are seen with differences in its processing of transduced variable with different parameter and algorithm. Thus there are different errors and their effect on drive which degrades drive performance. To overcome problem of stator resistance mismatch different schemes are available...
[2]. Among all those techniques adoption of PI estimator for tuning stator resistance. Steady state value of current reference is evaluated using motor parameters and initial values of torque and flux s with presence of errors in current reference and its measured values.

Paper is structured as follows. Second portion states the fundamental idea of DTC of an Induction motor. Next section gives the different errors and there theoretical finding. The fourth and fifth section presents the control technique for avoiding stator resistance variation which is nothing but with PI compensation scheme, and lastly simulation results are presented for both schemes. [2-7].

II. DIRECT TORQUE CONTROL PRINCIPLE

1. Basic DTC Terminology

The basic model of DTC IM drive scheme is shown in fig1 below. It comprises of torque and stator flux estimators, in addition with comparators which works within hysteresis limits, VSI and table for selection of switching sequence of inverter. The DTC technique basically use to is to decide the optimum value of inverter voltage vector in turn to manage both stator flux and electromagnetic torque of machine at the same time [1]. The input signals are stator flux magnitude $\lambda^*$ & torque $T^*$ which are reference values are compared with estimated values obtain from estimator $\lambda$ and T. [1-3]

Thus the magnitude of stator flux component is obtained by considering integrating difference of the stator voltage and product of resistance and stator current, that means voltage drop as,

$$T = \frac{3}{2}P(\bar{f}_{st} \ast j\bar{A}_{st}) = \frac{3}{2}P(\bar{f}_{st} \bar{A}_{st} - j\bar{f}_{st} \bar{A}_{st})$$

Further their difference is given to hysteresis type flux and torque controller with sextant of stationary plane. Sextant n divides the frame into six sextants shown in fig. 2 given below.

![Fig.2. Sextants division of stationary plane & inverter voltage vectors.](image)

In equations 3 and 4 $\lambda_{sd}$ and $\lambda_{sq}$ are the stator flux magnitude values with reference to direct and quadrature axis component Flux and torque controller produces one positive and one negative level voltage demand $v_{as}^*$& $v_{qs}^*$. On the basis of this values inverter voltage vector decides which voltage should be generated by inverter and further given to IM and this is made with aid of switching table given in Table1. In case of stationary frame path vector of stator voltage and currents are calculated with the help of switching states of inverters $S_a$, $S_b$ and $S_c$. Inverter switches of the voltage inverter decide the vectors as if the value of S is zero switch is close and S is equal to 1, switch is open. Hence according to action of switches and dc link voltage, values of voltage and current vectors are given by equations below.

$$v_s^{st} = \frac{2}{3}V_{dc}(S_a + S_b e^{j\frac{2\pi}{3}} + S_c e^{j\frac{4\pi}{3}})$$

$$i_s^{st} = \frac{2}{3}(i_{as} + i_{bs} e^{j\frac{2\pi}{3}} - (i_{as} + i_{bs} e^{j\frac{4\pi}{3}})$$

Magnitude of stator flux $\lambda_s$ and torque $T_s$ is,

$$\lambda_s = \sqrt{(\lambda_{sd}^2 + \lambda_{sq}^2)}$$

Fig.1 Direct Torque and flux Control of IM
III. ERRORS
1. ERROR AND PARAMETER IDENTIFICATION
DTC scheme is one of the most popular control strategy for inverter fed induction motor because of its several advantages. But with this some drawbacks are also there which affect its performance of ripples in torque and change in switching frequency. Errors are only reason to involve this drawback in DTC IM Drive scheme. Various errors causes degradation of DTC IM drives are,
1) Stator Resistance Mismatch;
2) Offsets;
3) Gain error; and
4) Unbalances in gain

Mismatching of stator resistance is effectively because of the change in resistance throughout IM operation because of the machine gets heat up. Offsets are also generates due to temperature variations at input of the op-amp. As op-amp require two voltages at its input and any error in that values resulting in dc offsets. The gain errors are caused by miscalculation in the circuitry used for holding, mounting, and filtering the dc-link voltage and the stator currents.

Mismatching of the stator resistance is caused by an irregular increase in values of the related circuitry. Thus our main focus is on stator resistance mismatch as it is only the parameter which is used in calculation of stator flux magnitude which is in turn stator current and torque [1-8-11]. Thus in order to find above errors, unbalance and offsets are two assumptions is need to be considered,

1) Small bandwidth of controller i, and
2) Control systems works in minimum time in close loop

While evaluating these errors and their individual effect, voltage harmonics which are generated because of inverter switching are not affect drive performance in steady state. Further these harmonics are filtered out with essential process of voltage model. In addition to this steady state operation of DTC IM Drive give the constant torque with small switching frequency with alternate selection of accelerating and zero voltage vectors. Reduction of harmonic losses and noise level of the motor can be achieved [5-6].

2. PROCESS OF ANALYSIS
Error and parameter identification is done with the help of following consideration,

\[ q = q + \Delta q \]  \hspace{1cm} (5)

As, \( q \) be the value considered in evaluation method, and \( \Delta q \) is error \([1-13]\)

3. STATOR RESISTANCE MISMATCH
It is due to resistance variation during induction motor operation. From equation (5)

\[ R_s = R_s + \Delta R_s \]  \hspace{1cm} (6)

Where \( R_s \) the motor stator resistance, \( \Delta R_s \) is error and \( R_s \) is actual value.

Mismatching in the values of stator resistance because of temperature and frequency results in inaccurate evaluation of the stator flux and electromagnetic torque. Drop in voltage of motor depends upon its speed, as when motor is running at is maximum speed \( R_s \) in stator resistance is very small in comparison with stator voltage; but, at minimum motor speeds, any delusion in a stator resistance affects the evaluated stator flux to depart from its imaginary path that degrades DTC performance. In order to obtain the stable control scheme for IM the value of controller stator resistance must be small than its real value.

### Table I; Switching Table for Selection of Switching Sequence of Voltage Vector of Inverter

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<thead>
<tr>
<th>( \gamma_k=+ )</th>
<th>( \gamma_k=- )</th>
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<tr>
<td>( V_{(n+1)6} )</td>
<td>( V_{o} ) ( V_{7} )</td>
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IV. STATOR RESISTANCE PI COMPENSATOR

The schematic diagram of compensation scheme for minimizing the variations of resistance value is given in figure 4. In direct torque and flux control technique of induction motor drive, studies revealed that $\lambda_r$ and $T_e$ of machine must have same value to their reference values, and the magnitude of $i_s$ vector have unvarying value which should be obtained with their reference values and machine parameters [4] as,

$$i_s = \sqrt{(i_{q}^*)^2 + (\lambda_{q}^*)^2}$$  \hspace{1cm} (7)

The variations in stator resistance vary the flux and torque of the machine that in turn results into variations of magnitude of vector $i_s$. As a result, the actual value of stator resistance evaluation for modification in stator flux and torque evaluation is considered as fast acting strategy for obtaining desired reference value of stator resistance. In case of estimation process any changes in magnitude of stator current vector with its value at initial stage are mainly because of stator resistance variations [7].

The control scheme for designing the PI stator resistance compensator is given in figure below.

![Fig.4. Stator Resistance PI Compensator](image)

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V. SIMULATION RESULTS

Thus the simulation results are carried out in MATLAB/ SIMULINK for 3Kw Induction motor drive for conventional DTC and DTC with stator resistance PI compensator. Figure 5 and 6 is represented by electromagnetic torque of induction motor for conventional DTC and DTC with PI compensator. The motor data for obtaining simulation are given in Appendix I.

The values for $K_p$ and $K_i$ are selected on the basis of trial and error in order to get desired results. The minimum and maximum values of limiter for resistance are chosen according to set value if stator resistance given in appendix. As due to resistance variation in induction motor operation due to motor heating may considered upto 200 %, i.e. 3.90 which is maximum value for limiter.

![Fig.5. MATLAB Simulation results of DTC for electromagnetic torque (N-m) without Stator resistance PI compensator](image)

![Fig.6. MATLAB Simulation results of DTC for electromagnetic torque (N-m) with Stator resistance PI compensator](image)

VI. CONCLUSION

The paper presented the basic DTC scheme with its control scheme for selecting voltage vector for inverter and evaluation of voltage and current vectors from estimator in order to find reference values of stator flux and electromagnetic torque. With error effect on its steady state behavior. In which stator resistance mismatch mainly affect its
steady state behavior which affects the stator flux magnitude and resulting ripples in electromagnetic torque.

Stator resistance PI compensator technique is adopted for elimination of mismatch in stator resistance and hence ripples in electromagnetic torque. In case of this method actual values of stator current and resistance are achieved by obtaining difference between calculated stator current and its reference value and compensated stator resistance with $\Delta R_s$ and PI controller. The simulation results show the reduction in torque ripple with stator resistance PI compensator DTC scheme and hence improvement in its steady state performance.

REFERENCES


APPENDIX I

Induction Motor parameters used in simulation:-
P_n=3Kw, V_n=230V, I_n=7.3A, P=2, f=50Hz, R_s=1.95Ω, R_r=1.66Ω, L_s=243mH, L_r=244mH, m=233mH, V_d=530V, J=0.02kg/m²