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DIRECT TORQUE CONTROL OF INDUCTION MOTOR DRIVE BY CURRENT RECONSTRUCTION METHOD THROUGH DC LINK CURRENT

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ABSTRACT

Fundamental to the successful operation of all ac drives is the ability to quickly and accurately control the motor torque, necessitating precise close-loop control of the motor phase currents. Using the switching signals and dc link current, this project presents a new algorithm for the reconstruction of stator currents of an inverter-fed three-phase induction motor drive. The proposed algorithm makes use of simple logic gates and if-else statements and as a result it generates stable three-phase current signals. Unlike, the various estimator algorithms namely model reference adaptive and extended kalman filters, at least requires two current and voltage sensors across the stator side which reduces the robust of the machine. In this current reconstruction method it employs only one current sensor on the dc link which reduces the cost and also increases the robustness of the sensor less induction machine drive.

Keywords- *Torque Control, Induction Motor, DC Link Current etc.*

I. INTRODUCTION

Induction motor drives controlled by Field Oriented control (FOC) have been till now employed in high performance industrial applications, has achieved a quick torque response, and has been applied in various industrial applications instead of dc motors. It permit independent control of the torque and flux by decoupling the stator current into two orthogonal components FOC, however, is very sensitive to flux, which is mainly affected by parameter variations. It depends on accurate parameter identification to achieve the expected performance. During the last decade a new control method called DTC (Direct Torque Control) has been developed for electrical machines. In this method, Stator voltage vectors is selected according to the differences between the reference and actual torque and stator flux linkage. The DTC method is characterized by its simple implementation and a fast dynamic response. Furthermore, the inverter is directly controlled by the algorithm, i.e. a modulation technique for the inverter is not needed. However if the control is implemented on a digital system, the actual values of flux and torque could cross their boundaries too far. Themain advantages of DTC are absence of coordinate transformation and current regulator; absence of separate voltage modulation block, Common disadvantages of conventional DTC are high torque ripple and slow transient response to the step changes in torque during start-up.

The DTC scheme requires information about the stator currents and the dc-link voltage, which is used with the inverter switches states, to estimate the values of stator flux and electromagnetic torque. In this project, the phase currents are reconstructed from the dc link current, and the speed is estimated with phase voltage and reconstructed phase current. The reference speed and the estimated speed is given as an input to the inverter fed induction motor drive and the torque and speed of the machine is controlled under various loading operating conditions.

II. PHASE CURRENT RECONSTRUCTION METHOD

The proposed method for reconstruction of phase currents is an algorithm developed by using simple logic gates and if-else control flow statements. This algorithm needs the instantaneous value of dc link current and the inverter switching signals as inputs. Functionally, it can be divided into three steps. These are illustrated in the form of a flowchart in Figure 4. While carrying out these steps, it is ensured that the true value of current samples obtained from the dc link remains unaltered at all processing stages.

STEP1: Acquiring DC link current and switching signals:

Initially, the dc link current (Id) is obtained through the shunt capacitor. The switching signals are obtained from the gate pulses of VSI. Here the switching pulses are considered as Sa, Sb, Sc. The upper leg of the switching pulses of is alone considered for the phase current construction. The switching state of the bridge is deduced by monitoring gate drive signals. By using a mask with the help of logic gates, the zero voltage vectors are identified to record the freewheeling measurement through dc link current sensor. By employing a zero-order hold, a continuous signal of the dc offset is obtained. The measured dc link current is calibrated by subtracting this dc offset from the measured dc link current during all switching states. The inverter output current is than reconstructed from the calibrated dc link current with no dc-offset error.

STEP 2: Sample the pulses of calibrated dc link current & assign them to appropriate three phase currents:

For a given phase, information is available in the dc link current when the positive group switch of a given leg in conjunction with either of the negative group switches in the other two legs are conducting or when the negative group switch of a given leg in conjunction with either of the positive group switches in the other two legs are conducting. It is analytically defined as follows. The calibrated dc link current is first sampled and then each sample is assigned to one of the three phase currents according to the specific inverter switches being gated at the instant of sampling.

$$i_a = I_{dc}\left[S_A - \frac{S_B}{2} - \frac{S_C}{2}\right]$$

$$i_b = I_{dc}\left[-\frac{S_A}{2} + S_B - \frac{S_C}{2}\right]$$

$$i_c = I_{dc}\left[-\frac{S_A}{2} - \frac{S_B}{2} + S_C\right]$$

STEP3: IF hold stage:

The output of step 2 is in the form of discontinuous, non-uniform and interleaved short-duration pulses. To reconstructcontinuous waveforms from this sampled data, a zero-order-hold (ZOH) or first-order-hold (FOH) could be used. Both, ZOH andFOH can convert sampled signals to continuous-time signals. The ZOH generates a continuous output by holding the input sampleconstant over one sample period while the FOH uses linear interpolation between the input samples to turn them into a continuoussignal. However, both ZOH and FOH operate at specified sampling intervals. The sampled datapulses neither have equal width nor are always equidistant from each other. Therefore, the use of ZOH or FOH which operates atfixed sampling intervals cannot give a continuous waveform of the shape that the actual phase currents possess.In the proposed method, the if- hold logic is used to obtain a continuous output from the sampled input data. This logic holds themagnitude of a sample pulse having non-zero value, till the next non-zero sample arrives, thereafter it holds the magnitude of nextsample and so on. This procedure is separately performed for the positive and negative half cycles of each phase current. Thelimitation of this method is that it introduces an unwanted dc offset in the region between the adjacent positive half cycles in onecaseand in between the adjacent negative half cycles of the another case. As a solution, a lowpass filter (LPF) is used in parallel to decide which portion of the output given by the if-hold logic is acceptable.

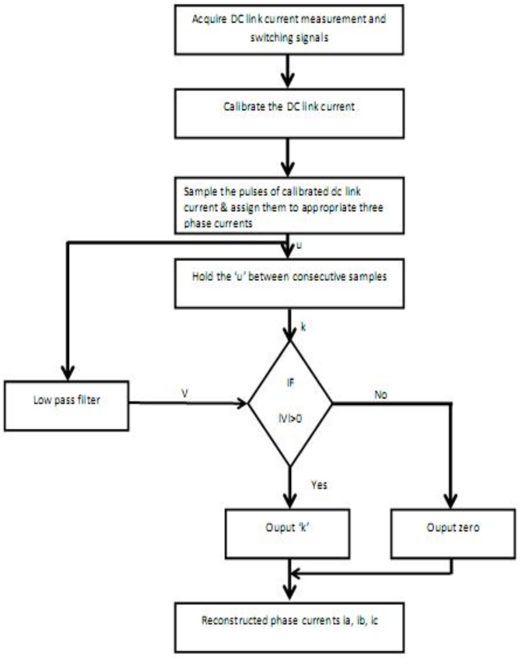


Figure1. Flow Chart of Current Reconstruction Method

III. Direct Torque Control of an Induction Machine

DTC uses a simple switching table to determine the most opportune inverter state to attain a desired output torque. By means of current and voltage measurements, it is possible to compute approximately the instantaneous stator flux and output motor torque. The control algorithm based on flux and torque hysteresis controllers determines the voltage required to drive the flux and torque to the desired values within a fixed time period. The fundamental functional blocks used to implement the DTC scheme are represented

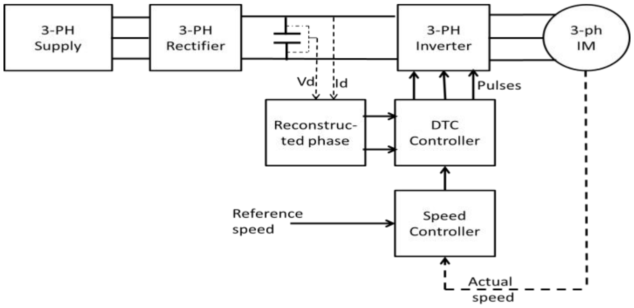


Figure2. Basic Blocks of DTC

- Speed Controller
- Torque And Flux Controller
- Switching Table

Speed Controller

The speed controller is based on a PI regulator, shown below. The output of this regulator is a torque set point applied to theDTC controller block. The speed measurement first-order low-pass filter cut-off frequency (Hz).The sampling time must be a multiple of the simulation time step. Speed Ramps-Acceleration, The maximum change of speed allowed during motor acceleration (rpm/s). An excessively large positive value can cause DC bus under-voltage.

Speed Ramps-Deceleration, The maximum change of speed allowed during motor deceleration (rpm/s). An excessively large negative value can cause DC bus overvoltage.

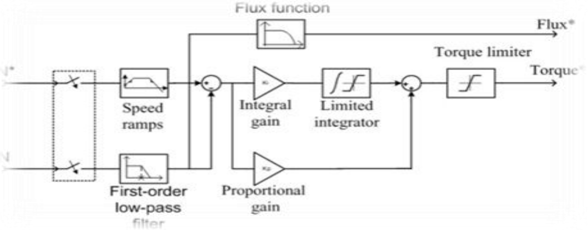


Figure3. Torque and flux controller

The DTC scheme mainly contains the torque and flux controller. In order, to produce the torque and flux for the DTC, it is fed by a three phase voltage and current from the inverter in the basic DTC scheme and according to the project, here the voltage and current waveforms are generated from the dc link and positive pulses of the inverter.

The three-phase voltage and current are equally converted into a two-phase d and q axis voltage and current by the following equations.

$$V_d = (2/3)(V_a - (1/2)V_b - (1/2)V_c)$$

$$V_q = (2/3)(-(\sqrt{3}/2)V_b + (\sqrt{3}/2)V_c)$$

$$I_q = (2/3)(I_a - (1/2)I_c - (1/2)(-I_a - I_b))$$

$$I_d = (2/3)(-\sqrt{3}/2 * I_a + \sqrt{3}/2 * I_b)$$

From, the d and q axis voltage and current the corresponding d and q axis flux are estimated using the following equations

$$\psi_{ds} = \int (V_{ds} - i_{ds} R_{ss}) dt \qquad \psi_s = \sqrt{\psi_{ds}^2 + \psi_{qs}^2}$$
$$\psi_{qs} = \int (V_{qs} - i_{qs} R_{ss}) dt$$

Finally, the torque produced in the DTC controller is given by the following equation

$T_e = (3/2)(P/2)(\psi_{ds} i_{qs} - \psi_{qs} i_{ds})$ The produced torque and flux is compared with the reference torque and flux and it is fed into the hysteresis bandwidth of torque and flux to produce a output within a specified interval.

Hysteresis bandwidth — Torque

This value is the total bandwidth distributed symmetrically around the torque set point (N.m). The following figure 4 illustrates a case where the torque set point is Te* and the torque hysteresis bandwidth is set to dTe.

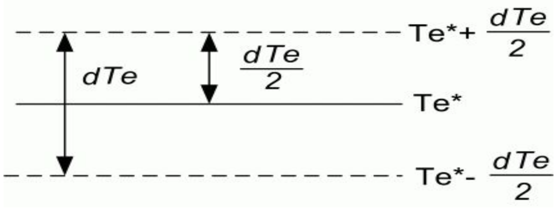


Figure4.Hysteresis bandwidth — Flux

The stator flux hysteresis bandwidth. This value is the total bandwidth distributed symmetrically around the flux set point (Wb). The following figure 5 illustrates a case where the flux set point is ψ* and the torque hysteresis bandwidth is set to dψ.

V.SWITCHING TABLE

DTC uses a simple switching table to determine the most opportune inverter state to attain a desired output torque. Here eight equally spaced voltage vectors are considered. The switching table for the inverter is given below in table 1.

H(phi)	H(te)	S(1)	S(2)	S(3)	S(4)	S(5)	S(6)
1	1	V2	V3	V4	V5	V6	V1
	0	V7	V8	V7	V8	V7	V8
	-1	V6	V1	V2	V3	V4	V5
-1	1	V3	V4	V5	V6	V1	V2
	0	V8	V7	V8	V7	V8	V7
	-1	V5	V6	V1	V2	V3	V4

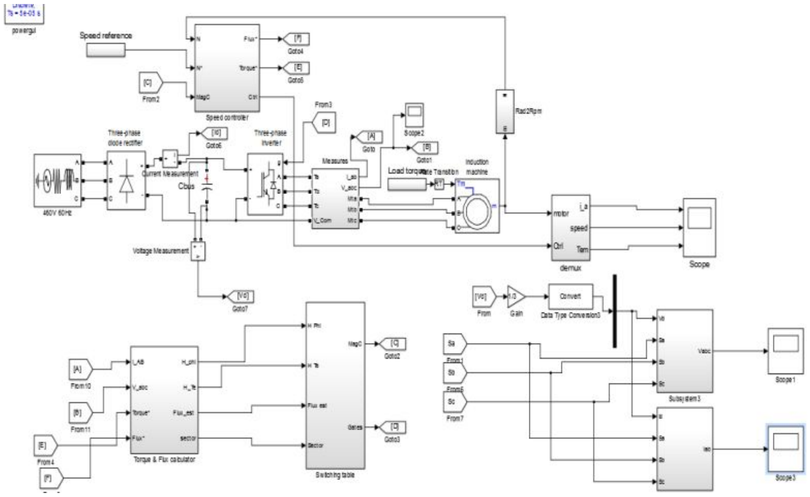
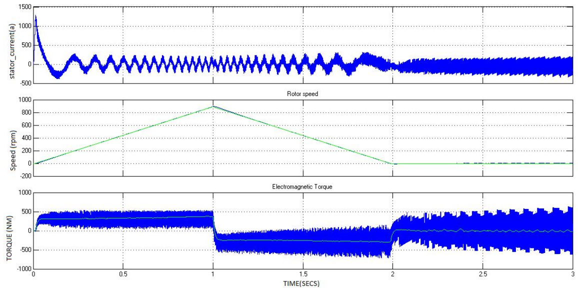


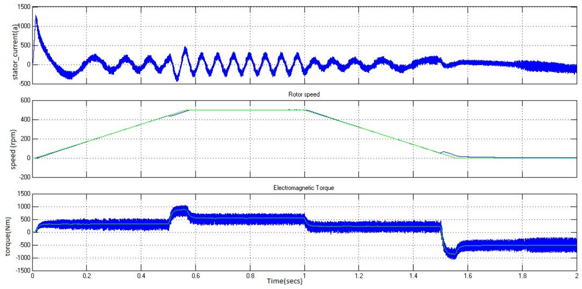
Figure5.SIMULATION CIRCUIT

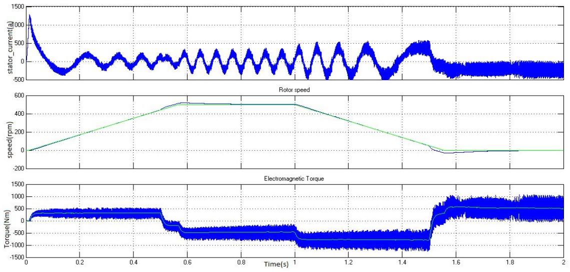
IV. SIMULATION RESULTS

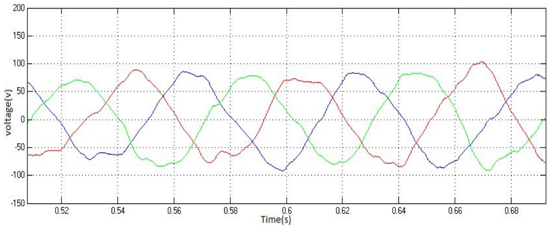
The result of the Direct Torque control of induction machine under various torque and speed condition is observed and the results are justified.

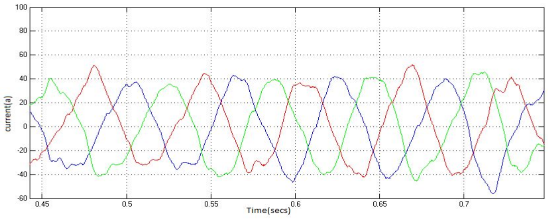
Initially under no load condition at rated speed the simulation results is obtained for torque, speed and dc bus voltage is obtained.











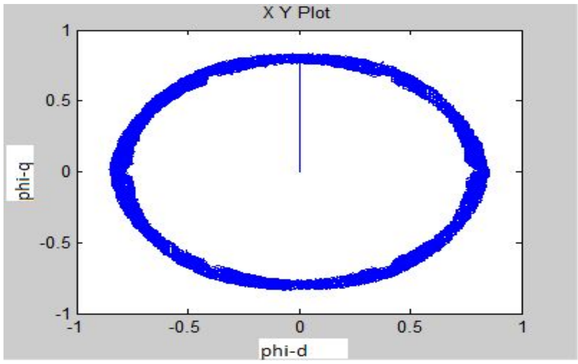


Figure. 6 Simulation outputs

V. COMMENTS ON RESULTS

The phase current and the phase voltage are reconstructed from the dc link current,voltage and the positive leg switches through the equation (1), (2) & (3) which was shown above. The reconstructed phase current are shown in the simulation results at Figure 10 & 11. These reconstructed phase currents and voltages are sinusoidal in nature. These currents and voltages are fed to a DTC controller of induction machine drive and the appropriate switching sequences are produced for the inverter fed induction motor drive. The reuslts which are shown in Figure 8 represents the change in load torque at 0.5 secs to 1.5 secs and the response of the stator current is also shown. In Figure 9, a load torque reversal is applied at 0.5 secs to 1.5 secs and the corresponding stator current change at 0.5 secs to 1.5 secs is obtained.

VI. CONCLUSION

A new method for stator current reconstruction from the dc link current for a current regulated, inverter fed induction motor drive is proposed in this paper. The basic principle of the proposed method is discussed step-wise. This technique eliminates the limitations associated with the use of two or three physical current sensors on the stator side. The dc link current signal can be obtained from the current sensor that is already available in the dc link of any drive for protection purpose. Thus additional current sensor is not needed. This makes the scheme cost effective. Unlike existing methods of current reconstruction available in literature, the proposed method is independent of machine parameters and therefore is robust against any variation in their magnitudes. From the simulation results, the reference speed is initially set at 500 rad/secs which is a low speed operation and constant load torque is applied at 1Nm, the respective output waveforms has been obtained and shown in the results. Now, a change in load torque is applied at 1 sec, the respective change in speed and stator current is also obtained at 1 sec which is also shown in the simulation results. Hence, through the use of single dc link current sensor the same output is obtained as same as using three current sensors at the stator side.

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