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LOW-COST DIRECT TORQUE CONTROL ALGORITHM FOR INDUCTION MOTOR WITHOUT AC PHASE CURRENT SENSORS FOR WIND POWER PLANT

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ABSTRACT

The conventional DTC scheme uses a stator flux vector for the sector identification and then the switching vector to control stator flux and torque. The fundamental stator voltage estimation is based on the steady-state model of IM and the synchronous frequency of operation is derived from the computed stator flux using a low-pass filter technique. The novel method is superior to the existing methods in terms of simplicity and robustness. By appropriately arranging the sequence of the vectors, the commutation frequency is reduced effectively without performance degradation. So the proposed model presents a low cost and simple phase current reconstruction algorithm for three-phase IM under direct torque control DTC using the information obtained from only one shunt resistor. The main aim is to develop low-cost high performance IM drive. The proposed system does not require additional computation burden or other motor parameters knowledge. The applications of this proposed system are industrial loads, Drives, Traction, boats, etc. The overall system with the proposed control strategy is developed and simulated in MATLAB/SIMULINK environment.

KEYWORDS: Direct Torque Control (DTC), Switching Frequency Reduction (SFR), Single Current Sensor (SCS), Wind Power Plant (WPP)

INTRODUCTION

To overcome the drawbacks of large ripples in torque and flux and maintain fixed switching frequency, many methods have been proposed in the literature and they can be divided into different categories. One of the very popular approaches is incorporating space vector modulation (SVM) in DTC, namely DTC–SVM [1]. Different from the conventional switching table in STDTC, which is composed of a limited number of voltage vectors with fixed amplitudes and positions, SVM can generate an arbitrary voltage vector with any amplitude and length within its linear range hence, DTC–SVM can regulate the torque and flux more accurately and moderately with fixed switching frequency [2], [3]. Although this reduces the number of active switching devices, it requires modifications of both dc link and a specialized machine stator winding structure. A further disadvantage of this topology is that three-phase currents are unidirectional, and hence, this topology is limited to particular applications. Another category of modified DTC does not need the SVM block and all the calculations were implemented in stationary coordinate, hence preserving the merits of conventional DTC [4].

During large torque demand, it is inevitable that the stator voltage reference exceeds the voltage vector limits enclosed bythe hexagonal boundary. Under this condition, the SVM has to be operated in what is termed as dynamic over modulation mode [6]-[8]. These methods have managed to minimize the voltage vector error as well as obtain a fast torque response; however, the majority of them do not guarantee the fastest torque response [5].

At the same time also the performance of so-called low-costdrives, which are the majority of all drive applications, has significantly increased. In these low-cost applications the expenditure of phase-current sensors is not negligible, and as a consequence, different methods have been developed to realize a current- control loop based on a single-current sensor in the dc-link [9].

BASIC PRICIPLE OF DIRECT TORQUE CONTROL (DTC)

DTC uses a simple switching table to determine the most opportune inverter state to attaina desired output torque [1].

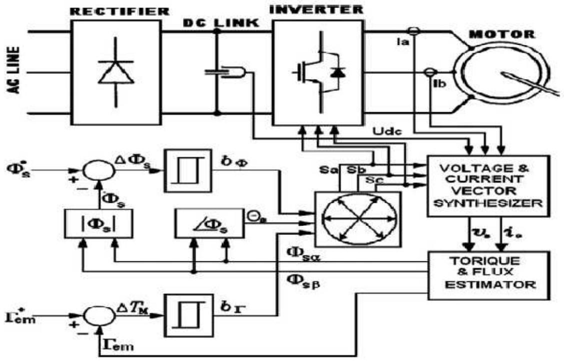

Figure 1: Basic DTC Scheme

DTC uses a simple switching table to determine the most opportune inverter state to attain a desired output torque [1]. 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 [10]. The fundamental functional blocks used to implement the DTC scheme are represented in Figure 1.

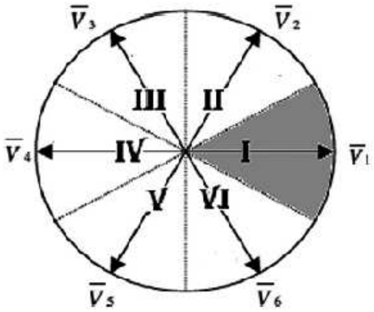

Figure 2: DTC Sectors and Inverter Voltage Vectors

Table 1: Basic DTC Switching Table

b_ϕ	b_Γ	Sector I	Sect II	Sect III	Sect IV	Sect V	Sect VI
1	1	V_5	V_6	V_1	V_2	V_3	V_4
	0	V_3	V_4	V_5	V_6	V_1	V_2
0	1	V_6	V_1	V_2	V_3	V_4	V_5
	0	V_2	V_3	V_4	V_5	V_6	V_1

The basic criteria adopted to select the proper switching configurations are related to the following considerations.

$$\overrightarrow{v_S} = r_s\overrightarrow{\iota_s} + \frac{d\overrightarrow{\varphi_s}}{dt} \tag{1}$$

$$0 = r_r\overrightarrow{\iota_r} + \frac{d\overrightarrow{\varphi_r}}{dt} - j\omega_m\overrightarrow{\varphi_r} \tag{2}$$

$$\overrightarrow{\varphi_s} = L_s\overrightarrow{\iota_s} + M\overrightarrow{\iota_r} \tag{3}$$

$$\overrightarrow{\varphi_r} = L_r\overrightarrow{\iota_r} + M\overrightarrow{\iota_s} \tag{4}$$

Where

$r_{s\ and}\ r_r$ represent the stator and rotor resistances;

$L_r, L_s, and\ M$, self and mutual inductances;

ω_m rotor angular speed expressed in electrical radians.

The electromagnetic torque is expressed in terms of stator and rotor fluxes as

$$T = P\ \frac{M}{\sigma L_S L_r}(\overline{\varphi_s}.j\overline{\varphi_r}) \tag{5}$$

where is the pole pair number and

$$\sigma\ =\ 1 - \frac{M^2}{L_S L_r}$$

In (5) the symbol represents the scalar product. By eliminating $\overrightarrow{\iota_s}$ and $\overrightarrow{\iota_r}$ from (1)–(4) leads to the state-variable form of the induction machine equations with stator and rotor fluxes as state variables

$$\begin{bmatrix} \frac{d\overrightarrow{\varphi_s}}{dt} \\ \frac{d\overrightarrow{\varphi_r}}{dt} \end{bmatrix} = \begin{bmatrix} \frac{-1}{\sigma T_S} & \frac{M}{\sigma T_S\, L_r} \\ \frac{M}{\sigma T_r L_S} & j\omega_m - \frac{1}{\sigma T_r} \end{bmatrix} \begin{bmatrix} \overrightarrow{\varphi_s} \\ \overrightarrow{\varphi_r} \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} \overrightarrow{V_s} \tag{6}$$

Where$\tau_s\ =\ \frac{L_s}{r_s}$ and $\tau_r\ =\ \frac{L_r}{r_r}$.

The flux amplitude can be controlled according to (1), assuming the voltage drop small. The stator flux vector moves in the direction of the stator voltage. Then, selecting step-by-step the voltage vector appropriately, it is possible to drive along a prefixed path with a high dynamic. In steady state conditions, the stator flux vector describes a circular locus, except for the ripple due to the switching effects [4].

There are few examples of efficiency-optimization solutions for DTC schemes. One of them is given in which deals with steady-state efficiency optimization in DTC control of permanent-magnet-synchronous motors. The best-efficiency stator-flux-linkage reference is found from an offline procedure that aims to minimize electrical losses in the motor for a wide operating range. Online computational effort is limited to the access of a lookup table (LUT) that stores the flux-linkage reference as function of the torque and speed value. As for many FOC-based solutions, the method requires the knowledge of inductances and resistances of the motor. Further developments of this work were reported in [8], where it is recognized that the best-efficiency stator-flux-linkage value is not the optimum one for the fastest torque response. The paper presents a solution that combines itself to the best-efficiency LUT and selects a proper flux-linkage reference for fast torque transients only during start-ups.

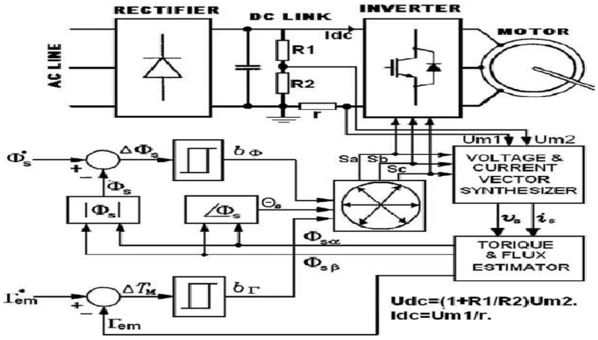

Figure 3: Proposed DTC Scheme

III. SINGLE CURRENT SENSOR DTC SCHEME

The basic DTC scheme (see Figure 1) requires two current sensors at least. The proposed DTC scheme described in this paper uses only one shunt resistor for dc-link current measurement as revealed on Figure 3.

For this purpose, a suitable method to reconstruct the phase currents and voltages is devised with a simple modification of the basic DTC scheme using zone shift strategy. Two modifications of the basic DTC are used for estimating the three-phase currents from a single dc-link current sensor. On the first modification, the control system should be able to generate more voltage vectors. This goal can be achieved approximately by applying, at each cycle period, different voltage vectors for prefixed time intervals, leading to a discrete space vector modulation (DSVM) technique.

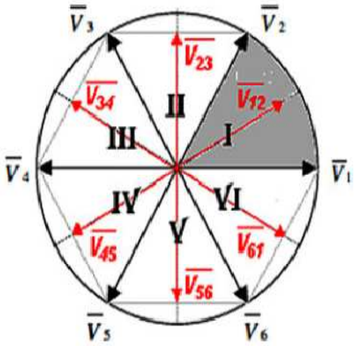

Figure 4: Proposed DTC Sectors and Inverter Voltage Vectors

Table 2: Proposed DTC Switching Table

$b_\emptyset$	b_Γ	Sector I	Sect II	Sect III	Sect IV	Sect V	Sect VI
1	1	V_{56}	V_{61}	V_{12}	V_{23}	V_{34}	V_{45}
	0	V_{34}	V_{45}	V_{56}	V_{61}	V_{12}	V_{23}
0	1	V_{61}	V_{12}	V_{23}	V_{34}	V_{45}	V_{56}
	0	V_{23}	V_{34}	V_{45}	V_{56}	V_{61}	V_{12}

IV. ANALYSIS AND METHODOLOGY

The stator flux vector $\overrightarrow{\emptyset_s}$vector and the torque produced by themotor,$\tau_{em,}$ can be estimated using (7) and (8), respectively. These equations only require the knowledge of the previously applied voltage vector *Vs*, measured stator current *Is*, stator resistance *Rs*, and the motor poles number *p*.

$$\overrightarrow{\emptyset_s} = \int(\overrightarrow{V_s} - R_s\overrightarrow{I_s})\,dt \tag{7}$$

$$T_{em} = y_z \text{With } \vec{y} = \frac{3}{2}p(\overrightarrow{\emptyset_s} * \vec{I_s}) \tag{8}$$

Once the electromagnetic torque and stator flux magnitude are estimated, a hysteresis control is done and the voltage vectors to be applied are obtained from the switching tale.

The stator voltage polar components ($v_{s\alpha}, v_{s\beta}$) on perpendicular (α, β) reference frame result from measured DC link voltage and switching controls logic states$S_\alpha, S_{b,}S_c$

$$V\,s_\alpha = \sqrt{\frac{2}{3}}U_{dc}\left(s_a - \frac{1}{2(s_b+s_c)}\right)$$

$$Vs_\beta = \frac{1}{\sqrt{2}}U_{dc}(s_b - s_c)' \tag{9}$$

And stator current components (I_α, I_β)

$$I_{s\alpha} = \sqrt{\frac{3}{2}}I_a$$

$$Is_\beta = \frac{1}{\sqrt{2(I_b - I_c)}} \tag{10}$$

The stator resistance can be assumed constant. During a switching period, the voltage vector applied to the motor is constant. By integrating the back electro motive force (EMF) the stator flux can be estimated.

$$\emptyset s_\alpha = \int (Vs_\alpha - R_s Is_\alpha)dt$$

$$\emptyset s_\beta = \int \left(Vs_\beta - R_s Is_\beta\right)dt \tag{11}$$

During the switching period, each voltage vector is constant and is then rewritten as

$$\emptyset s_\alpha = \emptyset s_\alpha + (Vs_\alpha - R_s Is_\alpha)T_s$$

$$\emptyset s_\beta = \emptyset s_\beta + \left(Vs_\beta - R_s Is_\beta\right)T_s \tag{12}$$

Where T_s is the control loop period.

The magnitude of the stator flux can be estimated by

$$\emptyset_s = \sqrt{\emptyset_{s\alpha}^2 + \emptyset_{s_\beta}^2} \tag{13}$$

We can find the flux vector zone using the stator flux components$(\emptyset s_\alpha, \emptyset s_\beta)$. By using the flux components, currents components and IM number of poles, the electromagnetic torque can be calculated by

$$T_{em} p\left(\emptyset s_\alpha Is_\beta - \emptyset s_\beta Is_\alpha\right) \tag{14}$$

Six equally spaced vectors voltage vectors having the same amplitude and two zero voltage vectors are the only switching combinations, which can be chosen for an inverter operation. The selection of a voltage vectors is made to preserve the toque and the stator flux inside thee hysteresis band limits.

V. SIMULATION DIAGRAMS AND RESULTS

The model – based on power system tool box was developed to examine the proposed control algorithm and the phase currents reconstruction feasibility was developed in MATLAB/SIMULINK. The simulation diagram of Basic DTC is shown in Figure 5.

The main algorithm operates in two stages. first, it predicts the stator currents from a model of the motor and then adjusts the prediction on the basis of the sensed dc link current.

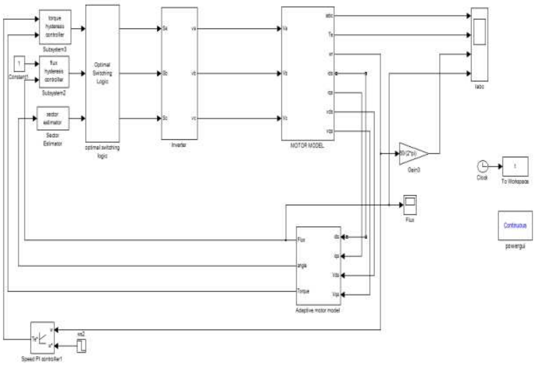

Figure 5: Simulation Diagram of Basic DTC Scheme

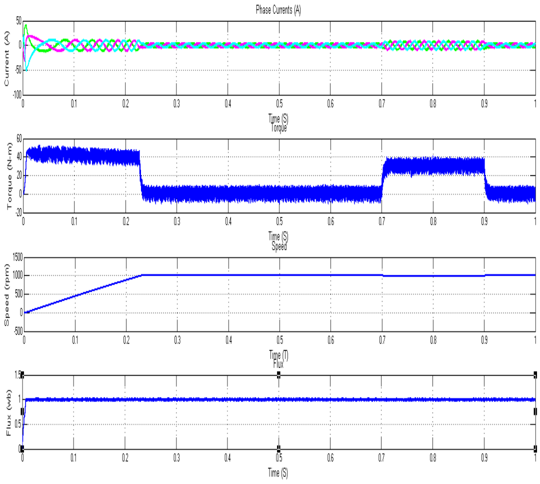

Figure 6: Output Results of Basic DTC Scheme

Figure 6 shows the output results of Conventional DTC scheme which involves phase currents, torque, speed and flux. The current feedback for the closed-loop control is usually obtained by sensing instantaneous phase currents by current sensors. In general, galvanic ally isolated current sensors such as Hall–effect sensors and current transducers are widely used in many applications. The basic DTC system brings disadvantages of in terms of cost by using current sensors to measure dc link voltage and current. To rectify these problems, a modified system is proposed.

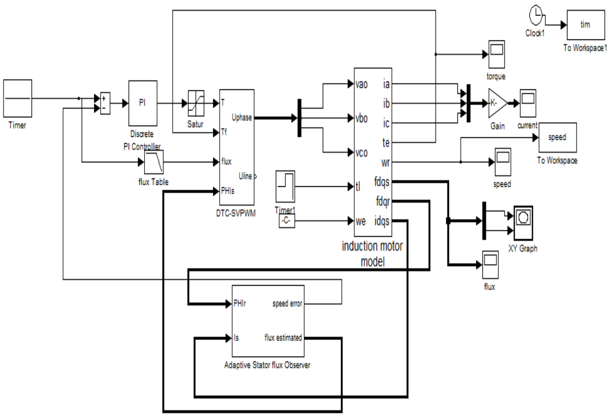

Figure 7: Simulation Diagram of Proposed DTC Scheme

Figure 7 shows the proposed DTC scheme simulation diagram. The proposed DTC scheme uses only one shunt resistor for dc link measurement. Two modifications of the basic DTC are used for estimating the three phase currents from a single dc link current sensor.

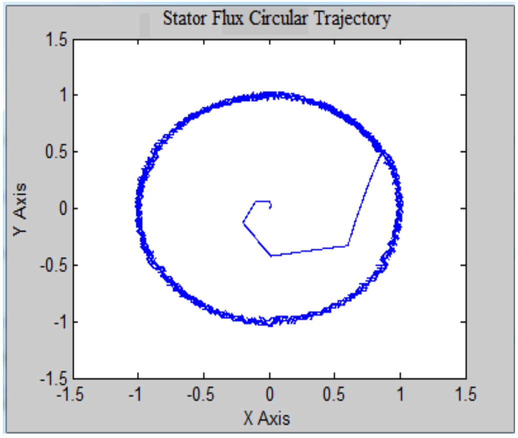

Figure 8: Stator Flux Circular Trajectory

Figure 8 shows that the XY-plot of the estimated stator flux under steady-state condition. The trajectory is same for all speeds of operation. The circular trajectory of the flux also confirms the successful operation of proposed DTC scheme.

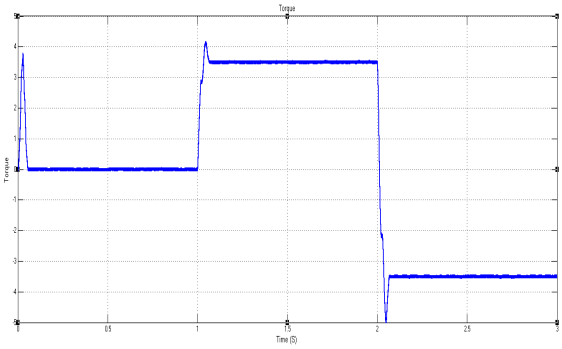

Figure 9: Torque in the Proposed Control Scheme

Figure 9 shows the variations of the motor torque in the proposed control scheme. First, the machine is fluxed with a zero reference torque, then at 1s, we set the torque reference to 3.5Nm (50% of rated torque) and a torque inversion is made at 2s. The flux reference value is set to 0.8 Web. One can see that the torque presents good dynamics.

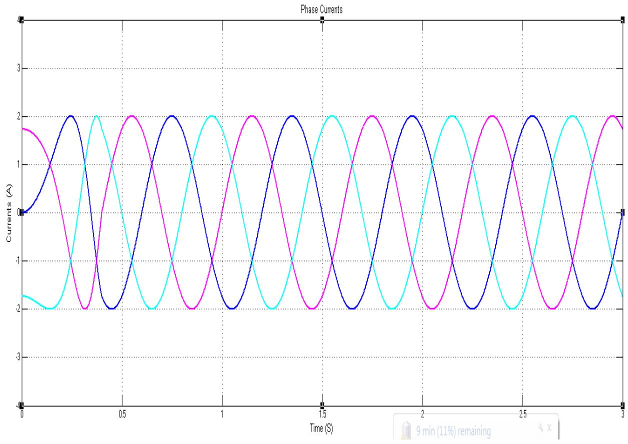

Figure 10: Measured Phase Currents

Figure 10 shows the illustrate the measured and reconstructed phase currents. One can see that the three waveforms are similar.

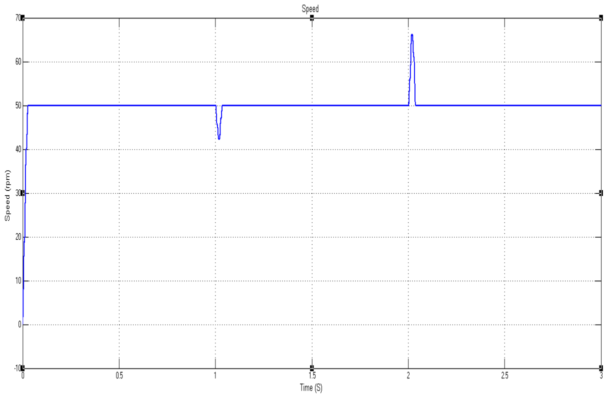

Figure 11: Speed of the Proposed DTC Scheme

Figure 11 shows the output result in terms of speed of the proposed DTC scheme. Speed control is achieved by means of variable frequency. Apart from frequency, the applied voltage needs to be varied because the stator flux magnitude is kept constant by the DTC control

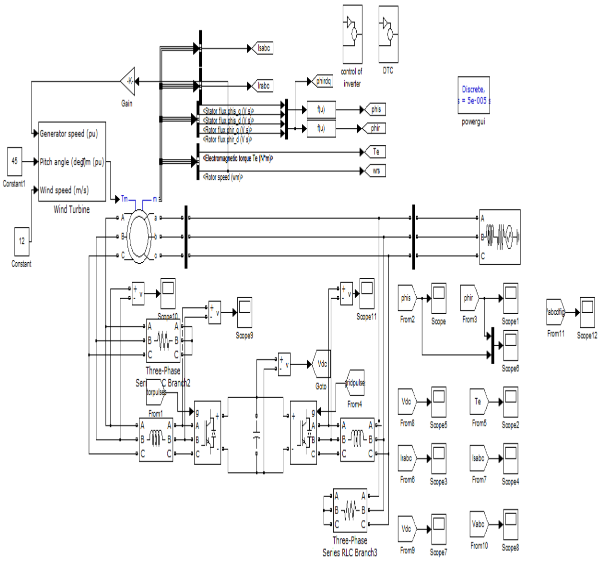

Figure 12: Simulation Diagram of DFIG with DTC Control in Wind Power Plant

Figure 12 shows the double fed induction generator with DTC control in wind power plant. In wind power plant, the turbine rotates with the force of the wind. As the turbine rotates, induction generator generates power. Inorder to generate constant supply, the generator rotates at constant speed. For this, DTC control is used inorder to rotate induction generator at constant speed.

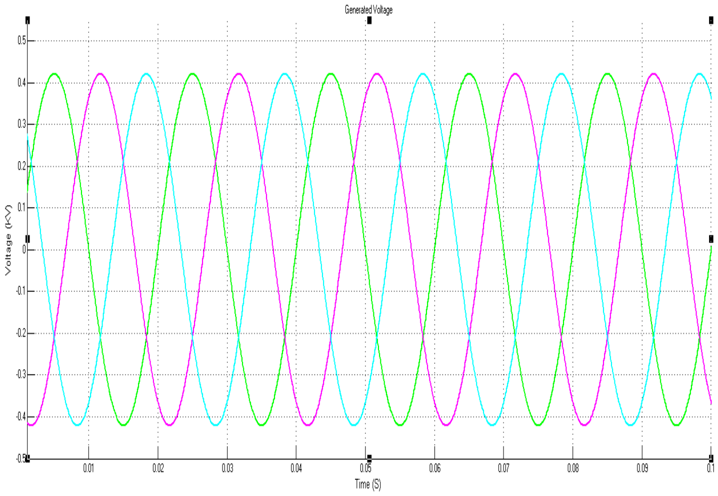

Figure 13: Generated Output Voltage with DTC Control

Figure 13 shows the generated output voltage of double fed induction generator with DTC control. The generated voltage is in KV.

CONCLUSIONS

In the existing system the speed control of induction motor is done by speed sensors which is not effective compared with the proposed system. In this project, a new low-cost DTC scheme for IM drives has been presented using a single shunt resistor inserted in the dc-link path, for phase-current reconstruction. The proposed method reconstructs the stator currents needed to estimate the stator flux magnitude and the electromagnetic torque, by means of a simple modification in the basic DTC scheme, 30^0zone shift strategy is applied.

In the proposed system the DTC control scheme is implemented which helps in effective speed control of induction motor. In the proposed system the speed control of induction motor is done by monitoring voltage, current, direct torque and flux produced in the motor. This proposed DTC scheme is implemented in the wind power plant to maintain the constant speed of the wind generator.

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