DIRECT-DRIVE PMSG-BASED WIND ENERGY
CONVERSION SYSTEMS WITH DISCRETE-
TIME DIRECT TORQUE CONTROL

A.Hari Prasad | M.Chandana | M.L. Dwarakanath

1(Dept of EEE. MTech Scholar, Global College of Engineering & Technology, Kadapa, A.P, India.)
2(Dept of EEE. Assistant Professor, Global College of Engineering & Technology, Kadapa, A.P, India.)
3(Dept of EEE. HOD, Global College of Engineering & Technology, Kadapa, A.P, India.)

Abstract—This paper proposes a novel flux-space-vector-based direct torque control (DTC) scheme for permanent-magnet synchronous generators (PMSGs) used in variable-speed direct-drive wind energy conversion systems (WECSs). The discrete-time control law, which is derived from the perspective of flux space vectors and load angle, predicts the desired stator flux vector for the next time-step with the torque and stator flux information only. The space vector modulation (SVM) is then employed to generate the reference voltage vector, leading to a fixed switching frequency, as well as lower flux and torque ripples, when compared to the conventional DTC. Compared with other SVM-based DTC methods in the literature, the proposed DTC scheme eliminates the use of proportional-integral regulators and is less dependent on machine parameters, e.g., stator inductances and permanent-magnet flux linkage, while the main advantages of the DTC, e.g., fast dynamic response and no need of coordinate transform, are preserved.

Keywords— Direct torque control (DTC), flux space vector, load angle analysis, permanent-magnet synchronous generator (PMSG), wind energy conversion system (WECS).

1. INTRODUCTION

In the conventional DTC, the voltage vector commands are determined primarily by the outputs of two hysteresis comparators. As soon as chosen, the preferred voltage vector will remain unchanged except the hysteresis states are updated. Although this voltage modulation scheme is inconspicuous to execute, it will lead to irregular and unpredictable torque and flux ripples, principally when the DTC is applied on a digital platform. To solve these issues, many techniques have been developed from exclusive views. One traditional inspiration is to increase the number of available voltage vectors, utilising multilevel converters or equally dividing the sampling period into more than one intervals. However, these ways will develop the hardware price, want further prediction for rotor speed, or have a limited ripple discount development. Yet another amazing procedure is to combine the space vector modulation (SVM) algorithm into the DTC. The SVM is in a position to transform the enter voltages into gate indicators for the inverter utilising a fixed switching frequency. A sort of SVM-centered DTC schemes were investigated for parmenent-magnet synchronous machines (PMSMs) within the last few decades. Customarily, they can be categorised into two categories founded on how the voltage references are generated in the stationary reference frame. In the first class, the decoupled voltage references in the synchronously rotating reference frame are obtained after which changed to the stationary reference frame using the rotary coordinate transformation. In the 2d class, the voltage references are got directly from the incremental stator flux vectors in the stationary reference body without coordinate transformation. Each ways can diminish torque and flux ripples, however want proportional--necessary (PI) controllers to keep an eye on the torque and stator flux blunders. The PI gains are by and large tuned with the aid of a trial-and-error method. Poorly tuned PI gains will deteriorate the dynamic performance of the DTC. Furthermore, in line with [9], an actual DTC scheme should no longer include PI regulators. More not too long ago, a predictive current manage and a deadbeat direct torque and flux control had been investigated for floor-set up and interior PMSMs. These manage schemes furnish just right dynamic efficiency, provided that the knowledge of some machine parameters, e.G., stator inductances and everlasting-magnet flux linkage, is accurate. As a result, the efficiency of the manipulate systems can be more or less influenced by way of the variants of the laptop parameters. Furthermore, these manipulate schemes are headquartered on the inverse laptop model or a graphical approach, which broaden the computational complexity.

This paper proposes a discrete-time SVM-based DTC without PI regulators for direct-drive PMSG-based WECSs. The discrete-time control legislation is derived from the prospective of flux area vectors and load angle. A number of computing device parameters, e.G., stator inductances and permanent-magnet flux linkage, are usually not offered within the control regulation. This improves the robustness of the manage method to PMSG parameter editions. By adopting the proposed DTC scheme, the torque and flux ripples are reduced, and the fast dynamic response is retained in comparison with the conventional DTC scheme. The proposed DTC scheme is validated by simulation and experimental outcome for a 2.Four-kW non salient-pole PMSG and a one hundred eighty-W salient-pole PMSG used in the direct-power WECSs.
2. ENHANCING POWER

A permanent magnet synchronous generator is a generator where the excitation field is provided by a permanent magnet instead of a coil. The term synchronous refers here to the fact that the rotor and magnetic field rotate with the same speed, because the magnetic field is generated through a shaft mounted permanent magnet mechanism and current is induced into the stationary armature. Synchronous generators are the majority source of commercial electrical energy. They are by and large used to transform the mechanical power output of steam generators, fuel mills, reciprocating engines and hydro generators into electrical power for the grid. Wind turbines of any large scale use asynchronous generators completely.

Wind power is the conversion of wind energy into a useful form of energy, such as using wind turbines to make electricity, wind mills for mechanical power, wind pumps for pumping water or drainage, or sails to propel ships. At the end of 2009, worldwide nameplate capacity of wind-powered generators was 159.2 gig watts (GW). Energy production was 340 TWh, which is about 2% of worldwide electricity usage and has doubled in the past three years. Several countries have achieved relatively high levels of wind power penetration (with large governmental subsidies), such as 20% of stationary electricity production in Denmark, 14% in Ireland and Portugal, 11% in Spain, and 8% in Germany in 2009. As of May 2009, 80 countries around the world are utilising wind vigour on a commercial ground work. Massive-scale wind farms are linked to the electrical vigour transmission community; smaller facilities are used to furnish electricity to remoted locations. Utility organizations increasingly buy back surplus electrical energy produced through small home turbines.

Wind energy, as a substitute to fossil fuels, is plentiful, renewable, greatly allotted, smooth, and produces no greenhouse gasoline emissions for the duration of operation. However, the construction of wind farms isn’t universally welcomed because of their visible have an effect on and other results on the environment.

The power that can be captured from the wind with a wind energy converter with effective area $A_r$ is given by

$$ P = \frac{1}{2} \rho_{air} C_p A_r v_w^3 $$  \hspace{1cm} (1)  

where $\rho_{air}$ is the air mass density [kg/m$^3$], $v_w$ is the wind speed and $C_p$ is the so-called power coefficient which depends on the specific design of the wind converter and its orientation to the wind direction. Its theoretical maximum value is $16/27 \approx 0.593$ (Betz limit). For a wind turbine with given blades it can be shown that the power coefficient $C_p$ basically depends only on the tip speed ratio $l$, which equals the ratio of tip speed $vt$ [m/s] over wind speed $vw$ [m/s] and the so-called blade pitch angle $\theta$ [deg]. This pitch angle is defined as the angle between the cord of the blade and the plane of rotation.
the blade and the plane of the wind rotor. So, for a wind rotor with radius \( r \), (1) can be rewritten as:

\[
P = \frac{1}{2} \rho C_f \frac{1}{2} \rho v^3 \lambda^2 \theta^2
\]

(2)

As an example, Fig. 2 shows the dependency of the power coefficient \( C_p \) on the tip speed ratio \( \lambda \) and the blade pitch angle \( \beta \) for a specific blade. For this blade maximum energy capture from the wind is obtained for \( \beta = 0 \) and \( \lambda \) just above 6. To keep \( C_p \) at its optimal value for varying wind speed, the rotor speed should be proportional to the wind speed. In practice both constant \( \lambda \) (variable speed) and constant speed operation is applied.

Fig: 4 Power coefficient \( C_p \) as a function of tip speed ratio \( \lambda \) and pitch angle \( \beta \) for a specific blade.

3. DIRECT-DRIVE PMSG-BASED WECS

In the proposed DTC, all the calculations are executed in the stationary \( \alpha \beta \) reference frame. The schematic diagram of the proposed DTC is shown in Fig. 3. A reference flux vector estimator (RFVE) is designed to calculate the desired stator flux vector \( \psi^* \) \( \alpha \beta \) using the estimated and reference values of the stator flux and electromagnetic torque without PI regulators. In this paper, the stator flux linkages are estimated by the programmable low-pass filter (LPF) introduced in [19]. To effectively eliminate the dc drift over a wide speed range, the cutoff frequency of the LPF, i.e., \( \omega_c \), is adjusted according to the rotor electrical speed \( \omega_e \) by \( \omega_c = k \cdot \omega_e \), where \( k \) is a constant. The schematic of the discrete-time programmable LPF-based stator flux estimator is shown in Fig. 4. The time derivative term is approximated by the Euler backward differentiation, which is given as

\[
s = \frac{1}{T_s} \left( 1 - z^{-1} \right)
\]

where \( T_s \) is the sampling period, which is the same as the switching period and control cycle in the proposed DTC. The compensating gain \( g_C \) and phase angle \( \theta_c \) for the output of the LPF are defined as follows:

Fig 5. Schematic of the proposed DTC direct drive PMSG based WECS

Fig 6. Discret time programble LPF base stator flux estimator.

4. SIMULATION STUDY

In this test, the speed of PMSG #1 is kept at 1500 r/min; the torque reference is \(-0.1 \text{ N} \cdot \text{m}\), from the beginning, and then is decreased to \(-0.5 \text{ N} \cdot \text{m}\) at 0.025 s; the command of the stator flux magnitude is 0.0135 V \( \cdot \) s, at the beginning, and then is decreased to 0.013 V \( \cdot \) s at 0.025 s; and both reference variations are step changes. In the conventional DTC, the torque and stator flux hysteresis bandwidths are set as 0.2 N \( \cdot \) m and 0.0003 V \( \cdot \) s, respectively. The PI gains of the PI-DTC are tuned carefully to achieve good control performance for PMSG #1. Fig. 7 compares the torque, stator flux magnitude, and instantaneous phase-A stator current of PMSG #1 controlled by the conventional DTC, the PI-DTC, and the proposed DTC with a 10-kHz sampling frequency, as well as by the conventional DTC with a 67-kHz sampling frequency (named DTC-1). The switching behavior of the conventional DTC determines that its switching frequency is lower than the SVM-DTCs when using the same sampling frequency [14]. Thus, in the DTC-1 case, the sampling frequency of the conventional DTC is increased to 67 kHz, to obtain an equivalent switching frequency of 10 kHz, which is obtained by calculating the average turn-on/off frequency of an inverter leg within 0.05 s [23]. As shown in Fig. 7, the maximum peak-to-peak torque ripples of the conventional DTC, the PI-DTC, the proposed DTC, and the DTC-1 are 1.2, 0.1, 0.1, and 0.33 N \( \cdot \) m, respectively; and the
maximum peak-to-peak ripples of the stator flux magnitudes in the four cases are 0.008, 0.0004, 0.0004, and 0.0012 V • s, respectively. The stator currents controlled by the PI-DTC and the proposed DTC are much smoother with less harmonic contents than those controlled by the conventional DTC and DTC-1. Thus, compared with the conventional DTC, the SVM-DTCs (including the proposed DTC and the PI-DTC) showed.

A distinct superiority in reducing the steady-state torque and stator flux magnitude ripples and stator current harmonics for different loading conditions. This is true even when the conventional DTC is implemented with a much higher sampling frequency (leading to a higher computational cost) so as to have an equivalent switching frequency same as the switching frequency of the proposed DTC and the PI-DTC.

5. CONCLUSION
This paper has proposed a novel discrete-time DTC based on flux space vectors for PMSGs used in direct-drive WECSs. The algorithm is easy to implement and is suitable for digital control systems using relatively low sampling frequencies. The torque and flux ripples have been significantly reduced with the integration of the SVM. In addition, the overall DTC scheme eliminated the use of PI controllers, showed strong robustness to machine parameter variations, and achieved fast dynamic responses. The proposed DTC scheme can be applied to both nonsalient-pole and salient-pole PMSGs. Simulation and experimental results have been carried out to validate the effectiveness of the proposed DTC scheme on a 180-W salientpole PMSG and a nonsalient-pole PMSG used in a 2.4-kW Skystream 3.7 direct-drive WECS.

REFERENCES


