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SVPWM Based Converter for PMSG Based Wind Energy Conversion System

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Abstract

At present, the trend of electricity generation is taking a diversion towards renewable energy sources due to their availability, cleanliness and less pollution. The ever increasing power demand has led to the development of Hybrid energy systems for Distributed Generation applications. Most of these hybrid systems include Wind Energy Conversion System (WECS) because of the ease of generation and availability of wind. Many types of generators are designed for the WECS. Due to the advantages like higher efficiency and low maintenance of Permanent Magnet Synchronous Generator (PMSG) \cite{1}, a PMSG based WECS is considered in this paper. It is also observed that, a very high number of appliances or loads are operating directly on DC. The potential to use DC directly from WECS requires proper rectification (from AC to DC) of power when considered for DC grid applications or for storage in batteries. Literature shows that, for the rectification process the researchers have applied basic Sinusoidal Pulse Width Modulation (SPWM) technique to the WECS or a WECS is designed with Brushless Permanent Magnet DC Generator (BLPMDC) to obtain DC power. In this paper a converter is designed for rectification of the power developed by the WECS and an attempt is made to apply Space Vector Pulse Width Modulation (SVPWM) for switching of rectifier to obtain a pure DC supply from WECS.

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1. Introduction

In recent years the demand of electricity is increased in a large scale as a consequence the electrical networks became complex ones, where a small disturbance in network or utility grid creates a longer duration power failure to the rural areas. A solution for these situations can be obtained from renewable energy sources like solar, wind, tidal, and wave etc. Depending on the power demand and the availability two or more renewable sources can be combined to form a hybrid energy system. Most of the hybrid systems utilize PV and Wind with other renewable sources. WECS has achieved the highest growth in last 10 years. WECS is composed of a wind turbine, an electric generator, power electronic converter and required control system. These are divided into two categories based on the speed of the generator i.e., constant speed and variable speed WECS. Constant speed generation systems were often used in earlier stages of WECS. The generators that are used for constant speed WECS are:

1. Squirrel Cage Induction Generator (SCIG)
2. Wound Rotor Induction Generator (WRIG)
3. Doubly Fed Induction Generator (DFIG)

The drawbacks of constant speed generation systems are low efficiencies, poor power quality and high mechanical stress due to gear box. Development of power electronic converters provided a solution by the use of variable speed WECS for the above drawbacks. The generators used for the variable speed WECS are as follows:

1. Synchronous Generators (with external excitation system)
2. Permanent Magnet Synchronous Generators (PMSG)

A variable speed multi pole PMSG is found to be more advantageous with gearless construction and provides the advantages like good efficiency, low maintenance, reduced losses, reduced costs and good controllability [1]. In this paper a PMSG based WECS is designed in MATLAB/Simulink.

Renewable energy sources like PV, fuel cells provide direct power in the form of DC supply, but the power developed by the WECS is in the form of AC supply. Integration in AC faces many problems like synchronizing the phase, amplitude and frequency of the voltages and currents generated. This complexity can be overcome by integrating PV and Wind in the DC supply form, where there is only one requirement of synchronizing the voltages generated by the systems together. As the integration of renewable sources provides many advantages in DC form when compared to AC, it requires the power generated by the wind power generation to be converted to DC form. For low power applications, AC to DC conversion is often obtained with a diode bridge rectifier with a capacitor filter. The recent advances in power electronic devices like SCRs, IGBTs provided more control over switches of the bridge rectifier. These advances also provide an added advantage of application of Pulse Width Modulation (PWM) Techniques for switching of converter switches. PWM signals are the pulse trains with fixed frequency, magnitude and variable pulse width. The width of pulses changes from pulse to pulse according to the modulating signal. This PWM signal causes the switch to turn ON or OFF when applied to its gate. The width of the pulses is modulated to obtain output voltage control and to reduce harmonics content. Different types of PWM techniques are Single Pulse Modulation, Multiple Pulse Modulation, Sinusoidal Pulse Width Modulation (SPWM) and Space Vector Pulse Width Modulation (SVPWM). Among all, SVPWM technique improves the quality of current and reduces the harmonics efficiently [2]. In this paper, SVPWM technique is designed and applied to universal bridge for successful conversion of power.

2. Design of PMSG based WECS

This section gives the design of WECS, which consists of wind turbine, pitch angle control, drive train, generator and power converter. A block diagram of the WECS is given in figure 1.
2.1. Model of Wind Turbine

Wind turbine converts the kinetic energy of wind into mechanical energy transmitted by shaft. An inbuilt Wind turbine of MATLAB is used in this model. The kinetic energy of the wind is given by the equation 1, and air mass \( m \) is given by equation 2 [3].

\[
E_c = \frac{1}{2} m v^2 \tag{1}
\]

\[
m = \rho v S \tag{2}
\]

Where \( m \) - air mass, \( v \) - wind velocity, \( \rho \) - air density and \( S \) - is surface area covered by the wind turbine.

Wind power is given by the equation 3 [3].

\[
R_w = E_c = \frac{1}{2} m v^2 = \frac{1}{2} \rho S v^3 \tag{3}
\]

The block parameters for the inbuilt wind turbine are given in the table 1[4].

<table>
<thead>
<tr>
<th>Base Power</th>
<th>1 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Wind Speed</td>
<td>8 m/s</td>
</tr>
<tr>
<td>Max Power at Base Wind Speed pu</td>
<td>0.75</td>
</tr>
<tr>
<td>Base Rotational Speed pu</td>
<td>1.2</td>
</tr>
</tbody>
</table>

2.2. Permanent Magnet Synchronous Generator (PMSG)

In WECS, wind turbine is mechanically coupled with a generator through shaft. In this model, a PMSG is used as a generator. An inbuilt permanent magnet synchronous machine from simulink library is used. This PMSG block consists of a torque as input terminal. The sign of this torque input operates the machine as either generator or motor. If the sign is positive it works as a motor and if the sign is negative it works as a generator [5].

The block parameters for the inbuilt Permanent Magnet Synchronous machine to operate as a generator are given in table 2.

<table>
<thead>
<tr>
<th>Line to Line rated Voltage</th>
<th>24 Volts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power</td>
<td>1 kW</td>
</tr>
<tr>
<td>Supply Frequency</td>
<td>50 Hz</td>
</tr>
<tr>
<td>D-axis Inductance</td>
<td>3.21 mH</td>
</tr>
</tbody>
</table>
2.3. Drive Train

To transmit the rotational motion of the turbine rotor to the electrical generator, it requires a drive train. The structure of the drive train depends on the category of wind turbine and generator used. For constant speed generators, drive train employs speed multipliers like gear boxes with certain multiplying ratios. But for the variable speed with multiple pole synchronous generators, drive train is a direct drive transmission system (the generator and turbine are coupled on the same shaft without gear box). In this paper, the PMSG is driven by a two mass drive train [5]. The equation (4) governing the dynamics of the drive train is given by,

\[ T_{sh} = K_{sh}\theta_{tw} + D_t \frac{d\theta_{tw}}{dt} \]  

Where \( T_{sh} \) is shaft torque, \( K_{sh} \) is Shaft shiffness, \( \theta_{tw} \) is shaft twist angle, and \( D_t \) is damping coefficient.

2.4. Pitch Angle Control

Pitch angle control is the means to control, the aerodynamic torque of the wind turbine. To obtain this control various controlling variables can be chosen such as wind speed, generator speed and generator power. To obtain the Pitch angle control of the wind turbine, the wind power at the turbine level must be controlled with the help of power coefficient \( C_p \). Power coefficient is a function of blade pitch angle and tip speed ratio. To obtain pitch angle control, a wind power at the wind turbine is given in by equation (5) [5]

\[ P_{wt} = 0.5 \rho S \lambda^3 C_p(\beta, \lambda) \]  

Where \( C_p \) is power coefficient, \( \beta \) is blade pitch angle and \( \lambda \) is tip speed ratio.

2.5. Power converter

Variable speed WECSs are very popular these days due to the development of power electronic converters, since they provide a smooth variation over a wide range of wind speeds. The design of power converter depends on the output power required by the load. If it is an AC load application then the power converter used will be AC-DC-AC back to back converter for the purpose of storage equipment. If it is a DC load application, the power converter will be AC-DC converter. For low power applications, a basic diode bridge rectifier with capacitor filter will be a better solution. For higher ratings, the bridge rectifier with SCRs or IGBTs will give better results. With the application of SVPWM for switching of SCRs, a good control over the current waveform and the harmonics can be obtained. In this paper, a universal bridge with Diodes and SCRs are designed and a comparison is obtained between the results of diode rectifier and SCR bridge rectifier with SVPWM technique.

3. Design of Space Vector Pulse Width Modulation (SVPWM)

The SVPWM technique is one of the most popular PWM techniques due to the use of higher DC bus voltage. The concept of SVPWM relies on the representation of AC bus quantities as space vectors. Space vector simultaneously represents three phase quantities as one rotating vector, hence each phase is not considered separately. Three phases are considered as a single quantity. The space vector is defined by [6],

\[ f_s = \frac{2}{3} [f_a + e^{j2\pi/3} f_b + e^{j4\pi/3} f_c] \]
where $f_a$, $f_b$, and $f_c$ are the three phase quantities of voltages, currents and fluxes. In bridge rectifier there are two group of switches upper group and the lower group (Six Pulse Bridge Rectifier). Each consists of three switches. Every switch has two states of operation either ON state or OFF state. The total possible switching for each group can be given as $2^3 = 8$ (000, 001, 010, 011, 100, 101, 110, 111). Here 0 indicates the upper group switch is OFF and 1 indicates it is ON. Thus there are six active switching states and two zero switching states for upper group of switches. The operation of lower group of switches is complementary. The space vectors are shown graphically in figure 2.

The tips of the space vectors, when joined together form a hexagon. The hexagon consists of six distinct sectors spanning over 360 degrees with each sector of 60 degrees. The space vectors 1, 2, ..... 6 are called active switching states and 7, 8 are called zero switching states.

4. Simulation and Results

4.1. WECS

PMSG based WECS is simulated in MATLAB/Simulink in two ways one with diode Rectifier Bridge and another with SCRs and SVPWM. These are shown in figure 3(a) and 3(b).
It is observed from figure 3(a) that the output of the wind generation system is given to the diode rectifier bridge without any gate input to the universal bridge but in figure 3(b) the output of the wind generation system is given to the universal bridge of SCRs and gate input is obtained from SVPWM. The DC output of the universal bridge is given to the DC load through inductor and capacitor filters.

4.2. Space Vector Pulse Width Modulation

The equations that govern the working of Space vector pulse width modulation are simulated in MATLAB/Simulink as a model file. This is shown in figure 4.

It is observed from the figure that the equations that govern the function of space vector pulse width modulation are designed by taking frequency as a reference. This block generates switching pulses for upper group switches i.e., $S_a$, $S_b$ and $S_c$ and for the lower group switches the operation is complementary. Hence for each pulse a NOT gate is applied and the complementary pulse for lower group switches are generated. Likewise switching pulses for six switches are generated with help of SVPWM.
4.3. Results and discussions

The output power of the DC loads for both diode bridge rectifier and for SVPWM based rectifier are obtained. These are shown in figure 5.

![Fig. 5. (a) Load Power for Diode Rectifier Bridge.](image1)

![Fig. 5. (b) Load Power for SCR Bridge and SVPWM.](image2)

It is observed from the figures 5, that the power with diode rectifier is fluctuating and tracing a large area but the power across SCR bridge with SVPWM provides almost a constant value of voltage without any fluctuations. It can be observed that the power through a diode rectifier is fluctuating between 40 W to 60 W but the power through the SVPWM based converter starts at 40 W and finally reaches 60 W. The load voltage and load current wave forms are similar to the power wave forms.

5. Conclusion

This paper presents the design of SVPWM based Converter for PMSG based WECS in MATLAB/Simulink. WECS is designed for a rated power of 1 kW. The load applied is in the form of DC. To obtain power conversion a basic three leg converter (Universal Bridge) is used. A comparison is based on a diode rectifier bridge and a SCR based SVPWM converter. A SVPWM based converter provides better DC output when compared to a basic diode bridge rectifier.

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