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Control Strategy Used in DFIG and PMSG Based Wind Turbines an Overview

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ABSTRACT

Nowadays, fossil combustibles are replaced by renewable energy sources. These renewable energies are nontoxic, dirt free, protected and reasonably cheap for the end-users. Renewable energy resources like bio-gas, geothermal, solar, tidal waves and wind have been found as the best alternative energy sources. Among these renewable energy sources, wind energy stands first and foremost for generating electricity.In order to have a constant utilization of wind energy maximum power from wind energy has to be extracted. In this paper, various control strategies prevalent to both the Doubly Fed Induction Generator (DFIG) and Permanent Magnet Synchronous Generator (PMSG) have been analyzed. In addition, control topologies applicable to power electronics converter/inverter used in wind electric generators are discussed.

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1. INTRODUCTION

Wind energy exploited as a monetary type of renewable energy, is growing in recent years. With the rising of oil price, safety measures and green concerns, the total global energydemand is met by small portion of wind energy in 2020 [1]. Wind enery is an indirect energy from the sun. Hubert in 1971 told, A little quantity of the solar radiation received by the Earth is converted into kinetic energy. The main reason for resultant wind is the difference between the net incoming radiation at lower latitude and high latitudes outgoing radiation, temperature gradients, earth revolution, geographic features. The wind energy is generated by converting kinetic energy of moving air into useful energy. As a consequence, the economics of using wind for power supply are extremely responsive to local wind conditions and the wind turbine are used to extract maximum energy from typical wind speed [2]. Wind energy preserves an important contribution to electricity supply in the world. Onshore wind is already an established generation technology. Off-shore wind power generation is cumbersome for researchers in this field. The large and medium capacity find farm which is connected to transmission lines has so many tedious problems because of unpredictable nature of wind [3],[4]. Hence power output from wind generator can be controlled by controlling voltage, frequency, real power control, reactive power, fault ride through. A mechanical torque compensation factor (MTCF) technique is developed to find the dynamic response of aggregated wind farm model [5]. MPPT algorithm using optimum torque is used to obtain a maximum power in tall power turbines because of its effortlessness [6]-[10]. Simplified model of DFIG is studied and improved performance during sag condition has been analyzed [11]. Low voltage ride through problem is discussed for different wind electric generators [12]-[15]. The maximum power point tracking is obtained by growing neural gas (GNG) [16]. Hill climb searching (HCS) algorithm is used to get MPPT in wind turbine [17]. Various control strategy used in PMSG is studied elaborately in [18] and [19]. Square wave PMSG is used to obtain MPPT [20]. According to [21], the speed control of PMSG is done through stator field oriented control. In this, d-axis current is set to zero and the current through q-axis is used to control the revolving speed of the generator according to wind speed so no wind speed detector is required. The current through d-axis and q-axis are required to control active and reactive power. SVPWM converter control switching techniques is used for PMSG [22]. Sensor less vector control technique using PLL is used to obtain good current, good response of static and dynamic performance, accurate speed and angle position of PMSG [23]. Field oriented control technique is used [24].

2. PERMANENT MAGNET SYNCHRONOUS GENERATOR

The two important factors regarding renewable energy are energy management and saving energy. For saving energy the apparatus should be well designed to give a maximum performance. In order to get the maximum energy the synchronous machines are used. The synchronous electrical machines has several features like high efficiency, robust, high power factors, it can be operated for change in frequency, less expensive. The disadvantages are magnetic saturation that cause motor performance poor and controlling is difficult. Relevant to magnetic saturation are found in [25]-[27].

2.1. Classification of PMSM

PMSM are classified into two groups AC and DC machines. AC machines are classified into trapezoidal type and sinusoidal type. Sinusoidal type are further classified as surface magnetic and interior magnetic type.

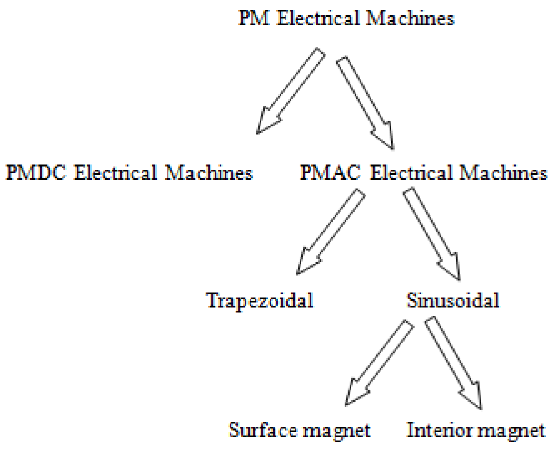

Figure 1. Classification of PM electrical machines

2.2. Principal of operation

The PMSM working principle is similar to working principle of induction machines and switched reluctance motor. In induction machine there are two types of rotor they are squirrel cage and slip ring rotor, in case of switched reluctance machines the rotor are made of iron core where as in PMSM the rotor is made of permanent magnet. A six pole three phase PMSM machine is shown in Figure 2. The three phase supply is given to stator windings a, b, c .The stator windings are placed 120^0 apart from each other. A magnetic field is created by stator windings once supply is given. The rotor is permanent magnet generates magnetic field. The working takes place by interaction of stator magnetic field with rotor magnetic field and cause moment. Figure 3 shows working principle of PMSM. The advantages of PMSM machines are magnetic field created by rotor are due to permanent magnet without electrical supply. The stator windings will produce a revolving magnetic field, the rotating magnetic field speed is equal to supply voltage frequency. The speed is calculated by the formula given below.

$$N_s=120*f/p$$

N_s synchronous speed in (rad/sec), f is frequency in Hz, p is number of pole pairs.

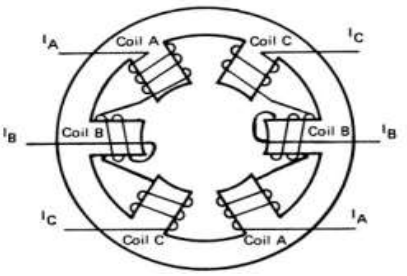

Figure 2. PMSM with 6poles. [28]

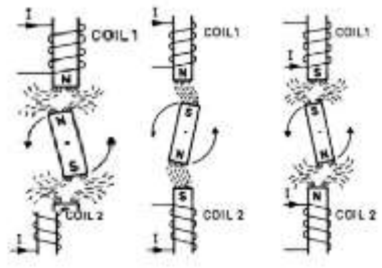

Figure 3. Working principal of PMSM [28]

3. CONTROL STRATEGY

The control strategies used in PMSG and DFIG are classified into scalar control and vector control.The scalar control is further classified into frequency control and V/F control. The vector control is divided into field oriented control and direct torque control. Field oriented control is subdivided into stator oriented control and rotor oriented control. Direct torque control is classified into direct torque control technique and direct power control technique shown in Figure 5.

3.1. Voltage/Frequency control

In this method current and torque are not controlled, instead voltage and frequencies are controlled. The block diagram for V/F method is shown below Figure 4. The advantage of this control technique is simple, low cost. The disadvantage are listed namely poor stability, uncontrolled torque, and the rotor is not synchronized with excitation frequency.

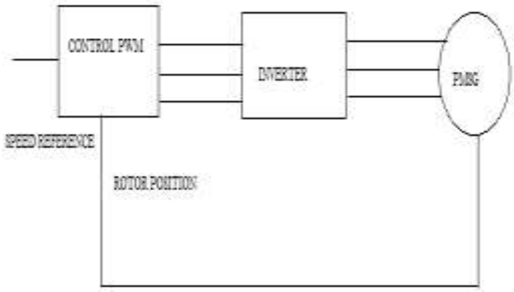

Figure 4. Voltage/Frequency control

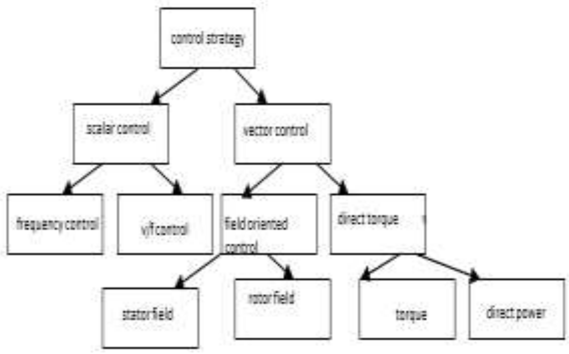

Figure 5. Control strategy

3.2. Field Oriented Control

The target of the Field Oriented Control is to control the mechanical speed of the rotor and to control the torque of the motor by controlling the currents. To carry out these controls the electrical quantities are converted from three phase stationary frame into two phase rotating frame by using Clarke and park transformation techniques [24]. Expression of the Stator Current Vector is shown below. The three phase stator current in stationary frame are given by

$$\vec{\iota_s} = \vec{\iota_a} + \vec{\iota_b} \sin 120^0 + \vec{\iota_c} \sin 240^0 \quad (1)$$

In Figure 6 the sum of three phase currents gives the rotating stator current vector and can be converted into two phase quantity α β in fixed frame.The stator current vector in this fixed frame is give by:

$$i_\alpha = i_a \quad (2)$$

$$i_\beta = \frac{1}{\sqrt{3}} i_a + \frac{2}{\sqrt{3}} i_b \quad (3)$$

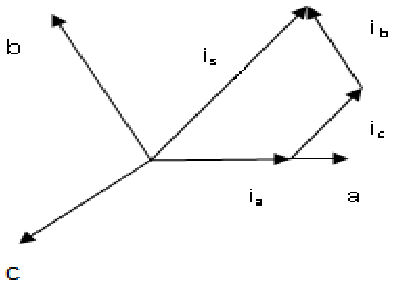

Figure 6. Stator current

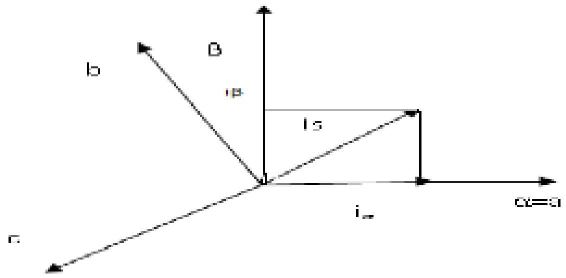

Figure 7. (a,b,c)->(αβ) Projection (Clarke Transformation)

In this new frame, α β is converted into two phase dq system so has to remove the rotor flux dependency. The equations corresponding to Clarke to Park transformation are given by:

$$i_d = i_{\alpha}.\cos(\theta_e) + i_{\beta}.\sin(\theta_e) \quad (4)$$

$$i_q = - i_{\alpha}.\sin(\theta_e) + i_{\beta}\cos(\theta_e) \quad (5)$$

Figure 8 shows the control schemes for FOC PMSG drives.The three phase currents ia,ib,ic are measured through current sensors and it is converted into two phase quantities by applying Clarke transformation block. The output current i_{α} and i_{β} are converted into i_d and i_q by applying Park transformation techniques. The output from Park transformation block i_d and i_q is compared with reference value i_d (set to 0)and i_q and controlled by PI controller. The ouput from PI controller is given to inverse Park transform block from this block a novel stator voltage vector is given to the motor through SVPWM technique. The outer loop is a speed loop which compare the motor speed n with nref and driving the $i_q$ref current.

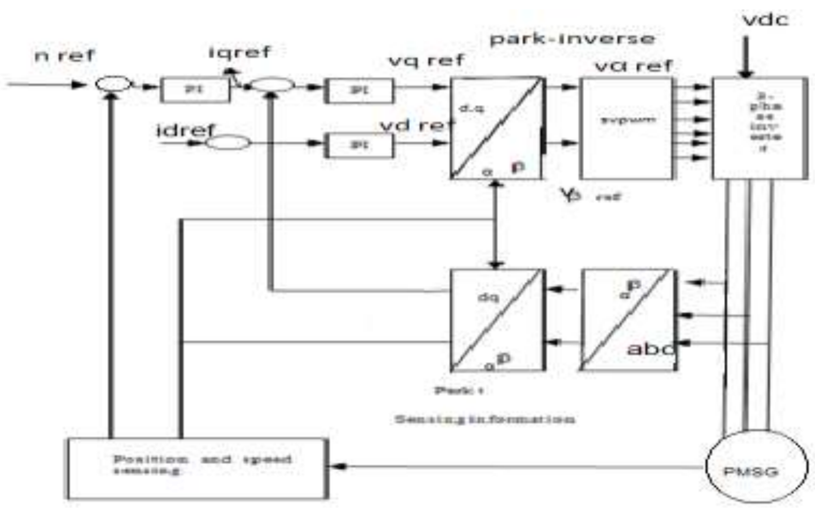

Figure 8. Field Oriented Control

The FOC has several advantages like good torque response, accurate speed control while disadvantages are many transformations are needed [29].

3.3. Direct Torque Control

The variables using in direct torque control are flux linkages and torque. The torque is controlled by using switching table, PI controller, and space vector pulse width modulation technique. The advantages of DTC are dynamic behavior is good, structure is simple. The disadvantages are high pulsation torque, sampling time is fast. In Figure 9, the reference flux linkages is compared with obtained flux linkages the error flux is given to PI control, the output of PI control gives the voltage in d-axis is given to voltage vector calculation block. The output voltage is given to PWM inverter through SVPWM modulation. Similarly the reference torque is compared with obtained torque and the error torque is given to PI control the output of PI control gives the voltage in q-axis and is fed to voltage vector calculation block from there it is given to pwm inverter through SVPWM block. From pwm inverter it is given to PMSG.

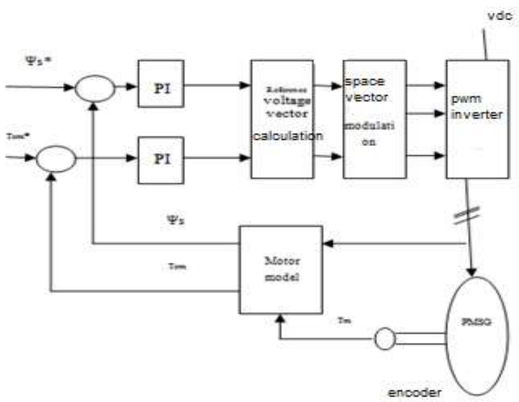

Figure 9. Direct Torque Control

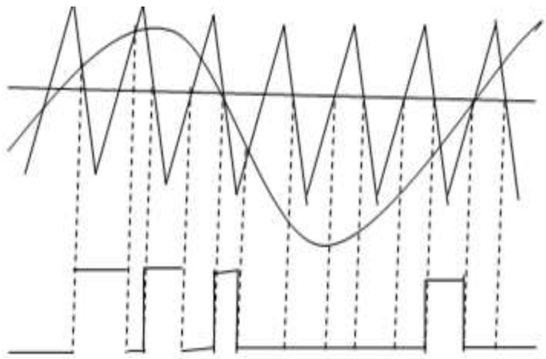

Figure 10. Wave form of sinusoidal pulse width modulation

4. CONVERTOR TOPOLOGY

The main purpose of convertor topology in power inverters is to control the output voltage and to supply variable voltage and frequency to ac drives. Modification in pulse-widths will improve the generation of harmonics. In PWM technique, the input is a fixed dc voltage is given to the inverters and an output is controlled ac voltage. The output is obtained by adjusting inverter components. Various PWM techniques are triangular wave sampling-natural sampling, uniform sampling, selective harmonics elimination, space vector modulation SVM or SVPWM, sinusoidal pulse width modulation, random PWM, calculation based on equal area criterion, and Sinusoidal PWM (SPWM), Current Controlled PWM (CCPWM) techniques [30],[31]. Most recently used PWM techniques in DFIG and PMSG are sinusoidal pulse width modulation and SVM techniques.

4.1. Sinusoidal Pulse Width Modulation Technique

The sinusoidal reference signal is compared with triangular wave signal to generate gating pulse to inverter is shown in Figure 10. The inverter output frequency is depend on reference signal frequency. The modulation index is controlled by peak amplitude and the output voltage is controlled by modulation index V_O=Vs (S1- S4). The number of pulses per half cycle is obtained by the carrier frequency [32]-[34]. The advantage of spwm is the output voltage can be controlled without any additional components. It reduces filtering components, lower harmonics can be reduced.

4.2. Space Vector Pulse Width Modulation Techniques

The SPWM has a major disadvantage lower dc bus utilization. The output voltage from VSI utilizing SPWM technique is 0.5Vdc (peak) or 0.353 rms. Whereas the output voltage from VSI utilizing SVPWM improves by 15.15%.The dc bus utilization is more efficient in SVPWM technique, there is a degree of freedom of space vector placement in a switching cycle [35]-[36]. The common block of SVPWM are low-pass bus filter, three phase generator, ramp generator, alpha beta transformation, switching time calculator, αβ vector sector gates logic. The voltage equations are

$$V_R = V_m \sin\omega t \quad (6)$$

$$V_B = V_m \sin(\omega t - 2\pi/3) \quad (7)$$

$$V_C = V_m \sin(\omega t - 4\pi/3) \quad (8)$$

When a three phase supply is applied to the windings of a three phase ac machine, it lead to a rotating resultant voltage space vector. The resultant voltage space-vector will be rotating consistently at the synchronous speed and will have a size equal to 1.5 times the peak size of the phase voltage. From fig each phase voltage is having highest positive or negative instant magnitude. The voltages at the instants are named as V1 to V6.It consists of six switches ,out of six three switches are upper arm and three switches are lower arm. When the switches are in ‘ON’ condition it is indicated as 1 and when the switches are in ‘OFF’ condition it is indicated at 0 [37]-[40]. Thus the six switches of the three legs will have a total of eight different switching combinations. The two switches in every inverter leg conduct in an opposite manner. Out of these eight combinations, two combinations are zero output voltage and it is said to be zero state and remaining six combinations are said to be non zero state and gives output voltage. Switching states of the inverter have been indicated by a 3-bit .The switching states are indicated in table 1.The power electronics inverter does not produce perfectly ideal sinusoidal voltages. So space-vector PWM technique is used. The six zero state voltage vectors are indicated as V1 toV6 (101,100,110,010,011,001) and have a magnitude of Vdc.

The two non zero state voltage vectors are indicated as V7, V8 (000,111), it is at the origin of the voltage vector plane. The voltage space-vector plane formed by the non zero state and zero state voltage vectors [41]-[46]. The six non zero vectors are joined to form a hexagon and it is divided into six identical zone (1-6). The resultant vector(vR) can be obtained by considering two non zero vector and two zero vector [47]-[51]. The following illustrative example may be helpful. Example: Let us presume that a resulting vector ‘VR’ of size α(Vdc), two-faced in sector-1and making an angle ‘θ’ from non zero vector V1 is to be realized. Let us further presume that ts are the sampling time for which the desired vector VR may be assumed to be stationary in space along the described direction. Now as per the above discussion the desired vector is to be realize using non zero vectors V1, V2 and zero vectors V7, V8 [52]-[55]. Let the respective sampling time along these vectors be t1, t2, t7 and t8 are

$$t1+ t2 + t7 + t8 = ts \quad (9)$$

Table 1. Switching Pattern

Voltage vector	Switching vector	A+	B+	C+	A-	B-	C-	Line to Line Voltage Vab	Vbc	Vca
V_0	000	OFF	OFF	OFF	ON	ON	ON	0	0	0
V_1	100	ON	OFF	OFF	OFF	ON	ON	$+V_{dc}$	0	$-V_{dc}$
V_2	110	ON	ON	OFF	OFF	OFF	ON	0	$+V_{dc}$	$-V_{dc}$
V_3	010	OFF	ON	OFF	ON	OFF	ON	$-V_{dc}$	$+V_{dc}$	0
V_4	011	OFF	ON	ON	ON	OFF	OFF	$-V_{dc}$	0	$+V_{dc}$
V_5	001	OFF	OFF	ON	ON	ON	OFF	0	$-V_{dc}$	$+V_{dc}$
V_6	101	ON	OFF	ON	OFF	ON	OFF	$+V_{dc}$	$-V_{dc}$	0
V_7	111	ON	ON	ON	OFF	OFF	OFF	0	0	0

5. CONCLUSION

In this paper, various control strategies and convertor topologies have been investigated and compared. During the investigation ,among the control strategies used, direct torque control has many advantages like simple structure ,minimum number of transformation,efficient decoupled torque and speed control .Among the convertor topologies investigated SVPWM has many advantages such as improved power factor, less THD ,and less switching losses. When the switching frequency is high SVPWM gives improved result. After scrutinizing all the citied papers, it is found that DTC with SVPWM is a potential candidate for analyzing the performance and better efficiency of wind electric generators.

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