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A Survey on Different Harmonic Techniques in Dfig Based Wind Energy Conversion Systems

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Abstract: *Harmonic reduction is becoming an important for electricity consumers. This increases the need for harmonics reduction techniques. The main objective of this paper is to survey the various recently used technologies and filters for reducing harmonics. Also this paper presents a review on various topologies, power converters and control schemes used with the operation of the DFIG.*

I. Introduction

Greenhouse gas reduction has been one in all the crucial and inevitable international challenges. The problem has get focus particularly within the last twenty years as evidences on global warming have been reported. This has drawn increasing attention to renewable energies as well as wind energy [1]. WECS has annual installation growth rate of 31.7% in 2009 with its growth rate is incessantly increasing for the last few years. The wind energy is currently one in all the quickest growing and engaging renewable energies [2]. The increasing price-competitiveness of wind energy against different standard fuel energy sources like coal and gas is another positive [3].

WECS consists of three major aspects; aerodynamic, mechanical and electrical as shown in Figure 1. The electrical aspect of WECS can further be divided into three main components, which are wind turbine generators (WTGs), power electronic converters (PECs) and the utility grid. In recent years, the demand for electricity goes on increasing which in turn arises the need for dynamic and complex electric power system with the utilization of renewable energy sources. In this increasing complex system, the harmonics are presented in the load current. This harmonics produced is greatly due to usage of many power electronic devices. So the power systems need to harmonic reduction techniques. The various harmonic techniques are presented in the power system. In this paper to analyse the different harmonic reduction techniques involving in the doubly fed induction generator based wind energy conversion system. These reduction techniques the different type of filters are involved like active filter, passive filter, hybrid filters ect.., In early days the wind generator are designed fixed speed but now the wind power generators are working variable speed turbines. It is used to improve the wind energy production. This variable speed wind energy conversion system the DFIG is most preferable because it’s delivers high energy output and low cost.

II. Wind Energy Conversion System (Wecs)

Greenhouse gas reduction has been one in all the crucial and inevitable world challenges. The difficulty has inherited focus particularly within the last 20 years as evidences on global warming have been reported. This has drawn increasing attention to renewable energies as well as wind energy [1]. WECS has annual installation rate of growth of 31.7% in 2009 with its rate of growth is continuously increasing for the last few years. The wind energy is now one of the fastest growing and attractive renewable energies [2]. The increasing price-competitiveness of wind energy against other conventional fossil fuel energy sources such as coal and natural gas is another positive [3]. WECS consists of three major aspects; aerodynamic, mechanical and electrical as shown in Figure 1. The electrical aspect of WECS can further be divided into three main part, that are wind turbine generators (WTGs), power electronic converters (PECs) and the utility grid.

A. Wind Turbine Generators

With the consideration to its operation speed and the size of the associated converters, WTGs can be classified into three categories namely:

- Fixed Speed Wind Turbine (FSWT)
- Variable Speed Wind Turbine (VSWT) with partial scale frequency converter (PSFC)
- Variable Speed Wind Turbine (VSWT) with full scale frequency converter (FSFC)

FSWT including Squirrel-Cage Induction Generator (SCIG), led the market until 2003. The Doubly-Fed Induction Generator (DFIG), which is the main concept of VSWT with PSFC, overtook FSWT and has been leading WTG concept. It nearly has 85% of the market share [3]

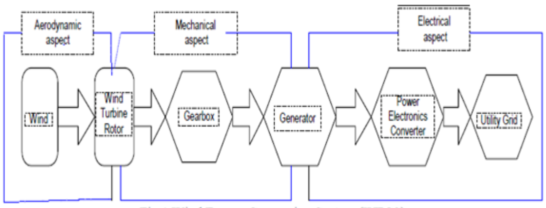

Fig.1 Wind Energy Conversion System (WECS)

B. Variable Speed Wind Turbines

The wind turbines may be of horizontal axis or vertical axis types. These turbines can be fixed speed and variable speed wind turbines. The fixed-speed wind turbines rotate at almost a constant speed, which is determined by the gear ratio, the grid frequency, and the number of poles of the generator. The maximum conversion efficiency can be achieved only at a given wind speed, and the system efficiency degrades at other wind speeds. The turbine is protected by aerodynamic control of the blades from possible damage caused by high wind gusts. The fixed-speed turbine generates highly fluctuating output power to the grid, causing disturbances to the power system. This type of turbine also requires a sturdy mechanical design to absorb high mechanical stresses [6]. On the other hand, variable-speed wind turbines can achieve maximum energy conversion efficiency over a wide range of wind speeds.

The turbine can continuously adjust its rotational speed according to the wind speed. In doing so, the tip speed ratio, which is the ratio of the blade tip speed to the wind speed, can be kept at an optimal value to achieve the maximum power conversion efficiency at different wind speeds [4]. To make the turbine speed adjustable, the wind turbine generator is normally connected to the utility grid through a power converter system [5]. The converter system enables the control of the speed of the generator that is mechanically coupled to the rotor (blades) of the wind turbine. The main advantages of the variable-speed turbine include increased wind energy output, improved power quality, and reduced mechanical stress [6]. The main drawbacks are the increased manufacturing cost and power losses due to the use of power converters. Nevertheless, the additional cost and power losses are compensated for by the higher energy production. Furthermore, the smoother operation provided by the controlled generator reduces mechanical stress on the turbine, the drive train and the supporting structure. This has enabled manufacturers to develop larger wind turbines that are more cost-effective. Due to the above reasons, variable-speed turbines dominate the present market.

III. Power Converter Topology For Dfig

The doubly fed induction generator (DFIG) has received much attention in the wind energy conversion. If a wound rotor induction machine (DFIG) is used, it is possible to control the generator by accessing the rotor circuits. A significant advantage in using doubly fed induction generators (DFIG) is the ability to output more than its rated power without becoming overheated. It is able to transfer maximum power over a wide speed range in both sub- and super-synchronous modes. The DFIG along with induction generators are excellent for high power applications in the MW range. More importantly, converter power rating is reduced since it is connected to the rotor, whilst the majority of the power flows through the stator.

A. Static Kramer Drive and SCR Converter Methods

The Static Kramer Drive consists of a diode rectifier on the rotor side and a line commutated inverter connected to the supply side [7], Fig. 2. With this converter, a sliding mode control is developed which provides a suitable compromise between conversion efficiency and torque oscillation smoothing. The controller regulates the thyristor inverter firing angle to attain the ideal compromise. The sliding mode control law forces the generator torque to be a linear function of the generator speed around the operating point of maximum power transfer [7]. This converter is only able to provide power from both stator and rotor circuits, under super-synchronous operation. To solve this problem, other methods replace the diode rectifier with another thyristor rectifier (SCR) [8,9] The inclusion of a second SCR allows the generator reactive power demand to be satisfied by the rotor-side converter system. When connected to the wind turbine, it is show that optimum performance is obtained by adjusting the gear ratio, of the gear box, to its optimum value [8]. In comparison to the Kramer Drive, this system produces more power output due to the lack of reactive power available with a diode rectifier. More detailed control of the two rectifiers is given A range of both firing angles for each mode of operation (sub- and super-synchronous modes) is given as a plot showing the optimum firing angle at different wind speeds giving greatest power transfer. It is discovered that between 7.5 and 8.5m/s, maximum power can be generated in both sub- and super-synchronous modes [9]. Major drawbacks of this approach include firing and commutation problems with the rotor-side converter and harmonic distortion to the grid, created by the supply-side thyristor converter. Watthana and Bunlung, studied the sliding mode control of wind turbines utilizing DFIG by using cramers drive in converter topology.

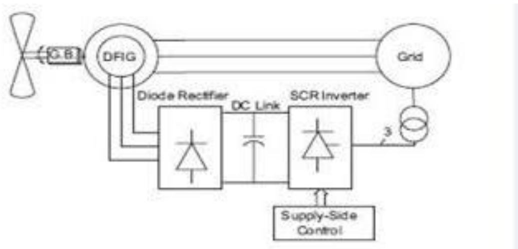

Fig 2.Static Kramer Drive and SCR Converter

B. Back - to - Back PWM Converters

A more technologically advanced method using back-to-back converters has been developed, Fig. 3. Much work has been presented using this type of converter [10-15]. Although the converter used in these works are extremely similar, great differences lie within the control strategy and complexity. One option is to apply vector control to the supply-side converter, with a reference frame orientated with the d-axis along the stator voltage vector [10,11]. The supply-side converter is controlled to keep the DC-link voltage constant through regulation of the d-axis current. It is also responsible for reactive power control through alteration of the q-axis current [10,11]. As for the rotor side, the choice of decoupled control of the electrical torque and the rotor excitation current is presented [10]. The machine is controlled in a synchronously rotating reference frame with the d-axis orientated along the stator-flux vector, providing maximum energy transfer. Conversely, in [11], the rotor current was decomposed into d-q components, where the d-axis current is used to control the electromagnetic torque and the q-axis current controls the power factor. Both types of rotor-side converter control employ the use of PI controllers. PWM switching techniques can be used [10], or alternatively space vector modulation (SVM) used in order to achieve a better modulation index in [11]. Often control schemes aided by a rotor speed encoder obtain excellent tracking results. However these encoders are expensive and the cost due to lost accuracy without the encoder may not be as large. The use of speed sensors has been described [12 ,13].To accompany the capacitor in the DC-link, a battery may be used as a storage device. With the extra storage device, the supply side converter now controls the transfer of real power between the grid and the battery, as the DC voltage is now fixed [9]. The supply-side controller is made up of three PI controllers, one for outer loop power control, and the other two for the d-q axis inner current control loop. Energy is stored during high winds and is exported to the grid during calm conditions to compensate for the drop in stator power. During long periods of high or low wind speeds, the control algorithm is modified to regulate the bus voltage until the conditions change. In this case the rotor side converter is gated in order to control the real and reactive power of the machine. Another different option for rotor control has been identified [13]. The algorithm searches for the peak power by varying the rotor speed, and the peak power points are recognized as zero slopes on the power speed curves. The control works continuously, as a significant shift in power causes the controller to shift the speed which in turn causes the power to shift once again. Once the change in power no longer exceeds the minimum set value, the controller takes no further action. Once again, d-q axis control is used to control the real and reactive power of the machine. It is important to ensure the dynamics of the speed controller are not extremely fast, else large transients in generator torque may occur [13]. The typical control objectives described above can be attained through control theory based on voltage space vectors (VSV). The application of certain voltage vectors may accelerate the rotor flux, and increase the active power generated by the stator. Other voltage vectors may also increase or decrease the rotor flux magnitude, resulting in a reduction in the reactive power drawn by the stator and an improved power factor. This direct power control method requires a series of tables to determine which of the six sectors the controller is operating in. From the choice of sector the applied voltage vectors can be determined from another table. The controller tables and details are provided in[14]

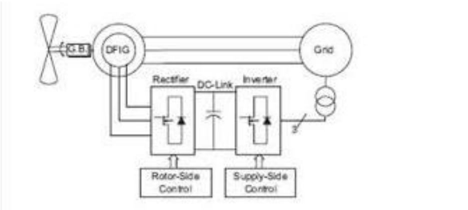

Fig3.Back - to - Back PWM Converters

C. Matrix Converter

The matrix converter is capable of converting the variable AC from the generator into constant AC to the grid in one stage, Fig. 4. Two distinct advantages arise from this topology, the converter requires no bulky energy storage or DC-link and control is performed on just one converter. The utilization of a matrix converter with a DFIG has been explored [16, 17]. The use of a stator-flux oriented control was employed on the rotor matrix converter. The d-axis current was aligned with the stator-flux linkage vector. Simple PI controllers can be employed to control the d-q axis currents. The regulation of the d-axis current allows for control of the stator-side reactive power flow, where as the q-axis current helps regulate the stator-side active power [16].

Another option is to control the rotor winding voltage, which consequently manipulates the power factor of the DFIG [17]. The matrix converter consists of nine bidirectional switches (18 total), arranged in a manner such that any input phase may be connected to any output phase at any time. Each individual switch is capable of rectification and inversion. The matrix converter is controlled using double space vector PWM, employing the use of input current and output voltage SVM. The details of this method exceed the scope of this paper and can be further examined in [17]. One of the major drawbacks of a matrix converter i s that 18 total switches are required, causing an increase in converter semiconductor cost. The grid connected wind-power generation scheme using DFIG in conjunction with a direct AC-AC matrix converter is proposed in [18, 19], it employs a SFO vector control algorithm, it basically highlight the matrix converter based rotor current control scheme. The performance of grid–connected WECS based on DFIG fed by matrix converter is proposed in [20]. A simple and easy modulation scheme called DDPWM is proposed in [21] to confirm reliable application of matrix converter for the DFIG. [22] presents a control strategy for a DFIG using an indirect matrix converter. The control of terminal voltage and frequency along with the power factor at the interface with the grid using matrix [23].

IV. Control System For Dfig

A. Maximum Power Point Tracking (MPPT) Control

The control of a variable-speed wind turbine below the rated wind speed is achieved by controlling the generator. The main goal is to maximize the wind power capture at different wind speeds, which can achieved by adjusting the turbine speed in such a way that the optimal tip speed ratio λopt is maintained. The typical characteristics of a wind turbine operating at different wind speeds, where Pm and ω_m are the mechanical power and mechanical speed of the turbine, respectively. The Pm versus ω_m curves are obtained with the blade angle of attack set to its optimal value. For the convenience of analysis and discussion, the mechanical power, turbine speed, and the wind speed are all expressed in per-unit terms. For a given wind speed, each power curve has a maximum power point (MPP) at which the optimal tip speed ratio λopt is achieved.

The relations between the mechanical power, speed, and torque of a wind turbine can be used to determine the optimal speed or torque reference to control the generator and achieve the MPP operation. Several control schemes have been developed to perform the maximum power point tracking (MPPT), and a brief description of three MPPT methods is given in the next subsections. According to the power curve illustrated in Figure.11, the operation of the wind turbine can be divided into three modes: parking mode, generator-control mode, and pitch-control mode:

- Parking mode: When the wind speed is below cut-in speed, the turbine system generates less power than its internal consumption and, therefore, the turbine is kept in parking mode. The blades are completely pitched out of the wind, and the mechanical brake is on.
- Generator-control mode: When the wind speed is between the cut-in and rated speed, the blades are pitched into the wind with its optimal angle of attack. The turbine operates with variable rotational speeds in order to track the MPP at different wind speeds. This is achieved by the proper control of the generator.
- Pitch-control mode: For higher than rated wind speeds but below the cut-out limit, the captured power is kept constant by the pitch mechanism to protect the turbine from damage while the system generates and delivers the rated power to the grid. The blades are pitched out of the wind gradually with the wind speed, and the generator speed is controlled accordingly. When the wind speed reaches or exceeds the cut-out

speed, the blades are pitched completely out of the wind. No power is captured, and turbine speed is reduced to zero. The turbine will be locked into the parking mode to prevent damage from the strong wind.

B. Rotor-Side Converter Control

The rotor-side converter (RSC) provides the excitation for the induction machine rotor. With this PWM converter it is possible to control the torque hence the speed of the DFIG and also the power factor at the stator terminals. The rotor-side converter provides a varying excitation frequency depending on the wind speed conditions. The function of the receiving end converter is to feed in the active power transmitted by the sending end converter while maintaining the DC voltage at the desired level. Additionally, the reactive power channel can be used to support the grid voltage during faults and also in steady-state. The PI controller maintains DC voltage through active converter current under consideration of a feed-forward term representing the power transfer through the DC link. AC voltage control is performed by two PI controllers. The controller in the upper branch is slow and only responsible for set-point tracing in steady-state operation. The second controller is very fast and is activated during grid faults. The magnitude of the current outputs is limited. In steady-state operation the DC voltage control has higher priority.

C. Grid-Side Converter Control

The grid-side converter controls the flow of real and reactive power to the grid, through the grid interfacing inductance. The objective of the grid-side converter is to keep the dc-link voltage constant regardless of the magnitude and direction of the rotor power. The sending end converter is responsible for transmitting the active power produced by the wind farm, while maintaining the AC voltage in the wind farm grid. Furthermore, it can be used for frequency control which in turn controls the changes in the generator slip of the connected DFIG wind turbines. Thus, active power transfer through the low-rated converter in the rotor circuit of the DFIG can be limited without a reduction of total Power. As the power control is performed by the wind turbines, a simple voltage magnitude controller can be used for the sending end converter, thus fulfilling the aforementioned requirements. The frequency can be directly regulated without the need for a closed loop structure.

V. Harmonic Reduction Techniqes

A. Direct Power Control Method

The method for power quality improvement of Wind Energy Conversion System (WECS) by compensation of grid harmonic currents produced by non-linear loads. The proposed method which has been applied to a Doubly Fed Induction Generator (DFIG) through rotor side converter (RSC), provides simultaneous speed control and power quality improvement. The Direct Power Control (DPC) method with constant switching frequency has been used for RSC control and power quality improvement has been performed by compensation of harmonic's active and reactive power of nonlinear load. Also, Grid Side Converter (GSC) control provides constant DC voltage for RSC and acts with unity power factor condition. Direct power control scheme of DFIG as shown in figure 2 has proposed. The stator active and reactive power control performed by PI controllers.

B. Sliding Mode Control

Wind energy conversion system (WECS) analysis and control for power generation along with problems related to the mitigation of harmonic pollution in the grid using a variable-speed structure control of the doubly fed induction generator (DFIG). A control approach based on the so-called sliding mode control (SMC) that is both efficient and suitable is used for power generation control and harmonic-current compensation. The WECS then behaves as an active power filter (APF). The method aims at improving the overall efficiency

VI. Conclusion

In this paper, the detailed study of DFIG along with its topology, relevant power converter devices, appropriate control parameters are presented. The influence of DFIG on the performance, system stability, system reliability, power quality and power transmission has been reviewed. This comprehensive review will be helpful for researchers working in the area of DFIG.

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