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Wind Energy Conversion System with DGIF

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Abstract – *The wind energy conversion system (WECS) includes wind turbines, generators, control system, interconnection apparatus.* [1] *This paper describes Doubly-fed induction generators (DFIGs) are by far the most widely used type of doubly-fed electric machine, and are one of the universal type of generator used to produce electricity in wind turbines. Doubly-fed induction generators have a number of advantages over other types of generators when used in wind turbines. The rotor speed fluctuations and the stator current fluctuations can be checked to be under prescribed limits with the predictive control strategy.*

Key Words: Wind Energy, DFIG, Wind energy conversion system, etc.

1. INTRODUCTION

Wind energy is the best smart alternative energy that guarantees green environment. The wind energy conversion schemes, although costlier as compared to other systems of generation of electricity is preferred as it does not require any fuel and fuel burning. The running cost of the wind turbine is almost nil but for the periodic maintenance that it requires. The basic device in the wind energy conversion system is the wind turbine which transfers the kinetic energy into a mechanical energy. The wind turbine is connected to the electrical generator through a coupling device gear train. The output of the generator is given to the electrical grid by employing a proper controller to avoid the disturbances and to protect the system or network. Block diagram of WECS is shown in figure 1.

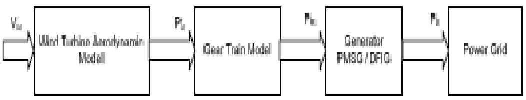

Figure 1: WECS Block Diagram

The different types of electrical generators used usually in association with the wind turbines are the, Permanent magnet DC generator, Permanent Magnet Synchronous Generator (PMSG), Squirrel Cage Induction Generator(SCIG),Self Excited Induction Generator(SEIG),Synchronous Generator (SG) and, Doubly Fed Induction generator (DFIG). Of all these type the DFIG is the most popular scheme because it has several striking advantages over the other types of electrical generators. The advantages of the DFIG are that they are suitable for operation where the wind velocities may undergo changes over a wide range. The electronic converter that is to be used with the DFIG needs to be of nearly 1/3rd the rating of the DFIG. DFIGs are used for large power conversion systems in the order of 100KW to about 7 MW range.

Principles of Doubly-Fed Induction Generators (DFIG), includes the operation of doubly-fed induction generators, as well as their use in wind turbines. It also covers the operation of three-phase wound-rotor induction machines used as three-phase synchronous machines and doubly-fed induction motors. Although it is possible to use these machines by themselves.

Figure 2: Doubly-fed induction generators are commonly used in wind turbines to generate large amounts of electrical power.

1.1 Doubly-fed induction generator operation:

Doubly-fed induction generators (DFIGs) are widely used type of doubly-fed electric machine, and are one of the most common types of generator used to produce electricity in wind turbines. Doubly-fed induction generators have a number of advantages over other types of generators when used in wind turbines. [2]

The primary advantage of doubly-fed induction generators when used in wind turbines is that they allow the amplitude and frequency of their output voltages to be maintained at a constant value, no matter the speed of the wind blowing on the wind turbine rotor. Because of this, doubly-fed induction generators can be directly connected to the ac power network and remain synchronized at all times with the ac power network. Other advantages include the ability to control the power factor (e.g., to maintain the power factor at unity), while keeping the power electronics devices in the wind turbine at a moderate size.

The DFIG is very similar to the Wound Rotor Induction Motor or the slip ring induction motor. Other than the usual three phase balanced stator windings, the rotor is also wound with a balanced three phase winding and the terminals of the rotor windings are brought over to a set of three slip rings.[3]

The DFIG works in association with a power electronic system, those having great power handling capability that consists of two numbers of back to back connected three phase Graetz bridge converters with a common DC link. The nodes of one of the two converters are connected to the rotor terminals of the DFIG. The nodes of the other converter are connected to the grid and these two converters are respectively named the machine side converter and the grid side converter.

1.2 Wind Energy Conversion System:

With reference to figure 1 the DFIG based WECS system consists of a wind turbine, a DFIG along with a matrix converter placed between the stator and the rotor.

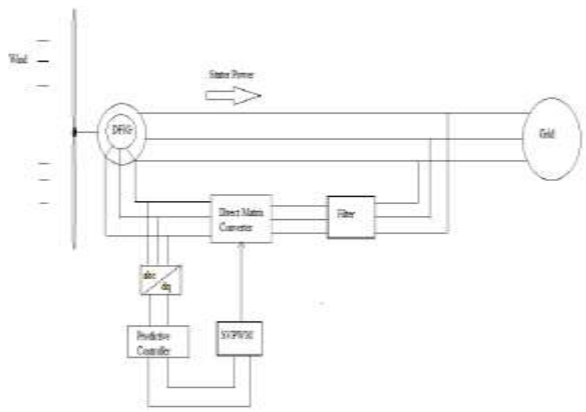

Figure 3: Block diagram representation of Wind Energy Conversion System

Structurally the DFIG is like a wound induction machine with the stator and rotor windings. The power that flows into the grid can be either from the stator or the rotor thus two paths are available for power transaction between the grid and the generator and hence it gets the name DFIG. From the fundamental principles there are two magnetic fields produced by the stator and the rotor and due to the interaction between these two magnetic fields a torque is produced. If the produced torque is positive then the machine runs as an induction motor and if the torque is negative the machine is in the generator mode.

The direction of power flow happening in the DFIG can be from the stator windings to the rotor windings and then taken over to the grid through the direct matrix converter (DMC).Various control schemes have been proposed and validated for the DMC used in the management of power flow in a DFIG based grid integration system.

1.3 Doubly-fed induction generators used in wind turbines:

Most doubly-fed induction generators in industry today are used to generate electrical power in large (power-utility scale) wind turbines. This is primarily due to the many advantages doubly-fed induction generators offer over other types of generators in applications where the mechanical power provided by the prime mover driving the generator varies greatly (e.g., wind blowing at variable speed on the bladed rotor of a wind turbine). To better understand the advantages of using doubly-fed induction generators to generate electrical power in wind turbines, however, it is important to know a little about large-size wind turbines. [4]

Large-size wind turbines are basically divided into two types which determine the behavior of the wind turbine during wind speed variations: fixed-speed wind turbines and variable-speed wind turbines. In fixed-speed wind turbines, three phase asynchronous generators are generally used. Because the generator output is tied directly to the grid (local ac power network), the rotation speed of the generator is fixed, and so is the rotation speed of the wind turbine rotor. Any variation in wind speed naturally causes the mechanical power at the wind turbine rotor to differ and, because the rotation speed is fixed, this causes the torque at the wind turbine rotor to vary accordingly. Whenever a wind burst occurs, the torque at the wind turbine rotor thus increases significantly while the rotor speed varies little. Therefore, every wind burst stresses the mechanical components (notably the gear box) in the wind turbine and causes a rapid increase in rotor torque, as well as in the power at the wind turbine generator output. Any variation in the output power of a wind turbine generator is a source of instability in the power network to which it is connected.

This is where doubly-fed induction generators come into action, as they allow the generator output voltage and frequency to be maintained at constant, no matter the generator rotor speed (and thus, no matter the wind speed). This is achieved by feeding ac currents of variable frequency and amplitude into the generator rotor windings. By adjusting the amplitude and frequency of the ac currents fed into the generator rotor windings, it is possible to keep the amplitude and frequency of the voltages (at stator) produced by the generator constant, despite variations in the wind turbine rotor speed (and, consequently, in the generator rotation speed) caused by fluctuations in wind speed. By doing so, this also allows operation without rapid torque variations at the wind turbine rotor, thereby diminishing the stress imposed on the mechanical components of the wind

turbine and smoothing variations in the amount of electrical power produced by the generator. Using for the same reason, it is also possible to adjust the amount of reactive power exchange between the generator and the ac power network. This allows the power factor of the system to be controlled (e.g., in order to maintain the power factor at unity).
Finally, using a doubly-fed induction generator in variable-speed wind turbines allows electrical power generation at lower wind speeds than with fixed-speed wind turbines using an asynchronous generator.

To conclude, using a doubly-fed induction generator instead of an asynchronous generator in wind turbines offers the following advantages:

1. Operation at variable rotor speed while the amplitude and frequency of the generated voltages remain constant.
2. Optimization of the amount of power generated as a function of the wind available up to the nominal output power of the wind turbine generator.
3. Virtual elimination of sudden variations in the rotor torque and generator output power.
4. Generation of electrical power at lower wind speeds.
5. Control of the power factor (e.g., in order to maintain the power factor at unity).

2. Three Schemes of Induction Generators used in WECS:

An induction generator is indistinguishable in comparison of an induction motor in construction. The SCIG, DFIG, and WRIG are the commonly used induction generators. The power is generated when the induction generator is made to rotate above the synchronous speed by a source of mechanical torque such as the wind turbine. Figure 4 illustrates the torque-speed characteristics of an induction generator.

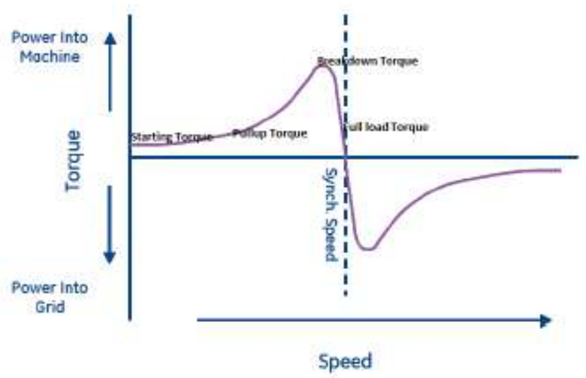

Figure 4: Torque - Speed Characteristics of an Induction Machine

From Figure, it can be noted that below the synchronous speed, the machine operates as an induction motor and above the synchronous speed, the machine acts as an induction generator. In the motoring mode, power is fed into the machine and in the generating mode, the power flows from the machine to the grid. In the generating mode, reactive power is consumed and hence it is compensated by providing compensating capacitors.

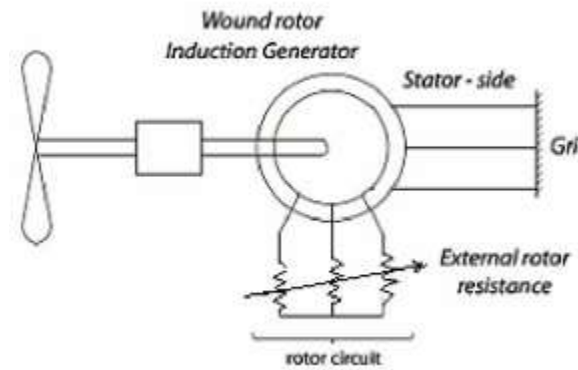

Figure 5: Block diagram of the WRIG based WECS

The DFIG can also be viewed as the evolution of the SCIG and the WRIG made to run at super synchronous cascade, with bidirectional partially rated power converters. Figure 5 shows the DFIG based WECS, where a back-to-back power electronic converter is connected between the slip ring terminals and the utility grid. The DFIG drive is basically a static scherbius drive. The bi-directional power flow occurs in the rotor circuit of the DFIG. Since the output power is tapped from both the stator and the rotor side, it is called doubly-fed or double-output induction generator (DFIG/ DOIG). Thus, the DFIG based WECS is the only scheme, where the output power is greater than the rated power, which is delivered safely without overheating.

3. Operation of the DFIG

The stator circuit of the DFIG is directly connected to the grid while the rotor is connected by means of a power electronics converter. The back-to-back converters consists of two converters namely the machine side converter and the grid side converter. Between these two converters, a capacitor is connected in order to maintain the DC-link voltage constant or to keep the voltage ripples as small as possible. With the machine side converter, it is possible to control the speed or the torque of the machine and also to maintain the power factor at the stator terminals of the machine. In addition, the function of the grid side converter is to keep the DC-link voltage constant.

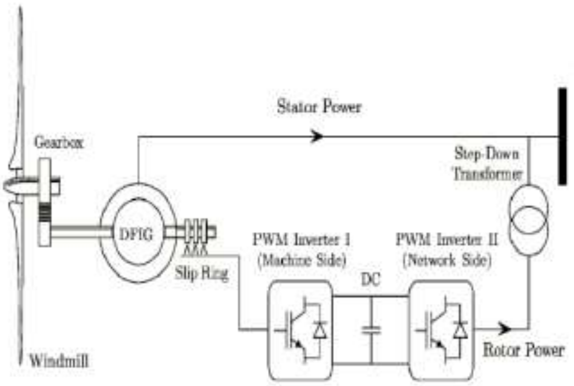

Figure 6: Block diagram of DFIG based WECS

The transformer is usually connected in the rotor side converter due to the difference in the voltage levels of the rotor and stator. Also, a filter is used to minimize the harmonics injected into the grid due to the switching of the power electronic converters.

3.1 Control of A Doubly Fed Induction Generator for Wind Energy Conversion System Using Matrix Converter:

A control technique for a wind energy conversion system is supposed to partially function as a PLL & grid control loop (D-Q Reference frame). The control is specified in an equivalent reference frame achieved by using the Park transformation to the three-phase quantities.

The control system consists of the zero-sequence component, which facilitates the compensation of zero sequence harmonics. It indicates that drop in power loss and mitigation of current and voltage harmonics can be achieved in the available system.

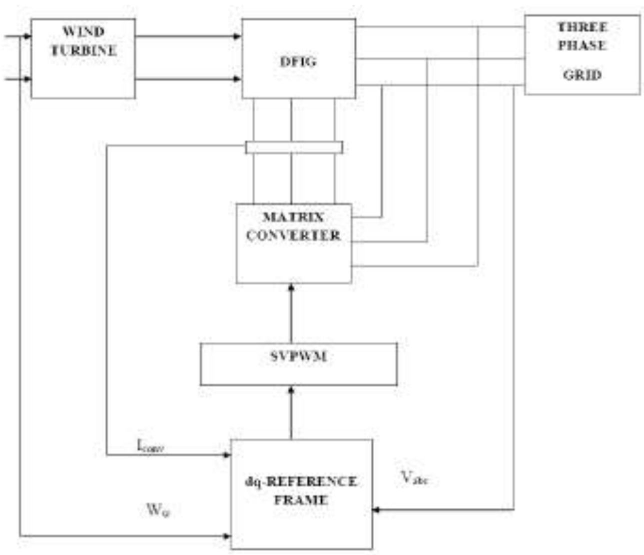

Figure 7: Proposed Block Diagram

A novel modulation approach utilized is PLL control method with grid loop controller and it will boost the output current harmonics of a wind energy conversion system, inclusive of a Doubly Fed Induction Generator (DFIG) and a matrix converter is introduced. The design and analysis of a control mechanism for a DFIG based wind energy generation under imbalanced load conditions are studied. The control goals are

(i) To restrict the machine side currents,
(ii) To eliminate the ripples in the torque,
(iii) To eliminate the dc-link voltage fluctuation through converter controls and
(iv) To boost the THD.

A D-Q reference frame mechanism is presented. This technique is implemented in the machine -side and grid-side converters of the DFIG to improve the voltage ride-through capacities of DFIG-based wind turbines. During the analysis of power quality, the impacts of high penetration electric vehicles and renewable energy based generator systems, inclusive of wind turbines, grid connected photovoltaic, and fuel cell power generation units are presented. A proportional control mechanism is realized in the d-q reference frame side to decrease the machine side current harmonics and torque pulsations. The primary objective of the control mechanism is to keep the voltage and frequency constant at the output of the generator. A control mechanism is introduced with the aspiration of upgrading the DFIG based proposed system to achieve a reduced THD. The voltage harmonics mitigation is an essential task, which cannot be carried out by current source inverters (CSIs). Here the novel approach is utilized for mitigating the harmonics current of the power system. For this, the controller in the wind turbine system is utilized in the form of a reference frame sector with control loop method. In this system, grid side converter (GSC) control is employed for generating the currents in such a manner that they have the harmonics equal and 180 degree out of phase with harmonics of nonlinear load currents resulting in the cancellation of nonlinear load current harmonics.

3.2 Advantages of DFIG:

1. Operation at variable rotor speed by keeping the amplitude and the frequency of the voltage delivered constant.
2. Maximum power tracking is made easier by variable speed operation.
3. Elimination of the rotor torque variations and reduced mechanical stress.
4. Generation of power at low wind speeds.
5. Independent active and reactive power controls.
6. Capability to keep the DC-link voltage constant at different generator speeds.
7. DFIG can be made to run as an SCIG in the event of converter failure. [6]

3.3 Disadvantages of DFIG:

1. Complex power conversion circuitry.
2. Presence of slip ring requires periodic maintenance.
3. Since the stator directly connects to the grid, it is quite sensitive to grid disturbances.
4. DFIG has a sluggish response to grid voltage transients.
5. The doubly-fed induction machine (DFIM) when used as a DFIG has minimum stator and rotor resistances (to reduce copper loss) and hence are poorly damped systems and direct closure of the stator to grid with proper excitation and synchronization, causes the oscillating transient with large amplitude.

4. Conclusions:

The control of the harmonics regulator is similar to the main control of the DFIG system. The harmonics regulation techniques studied tackle with the dc component in various frequencies, rendering the control mechanism convenient to be achieved and offer good dynamic stability under differential wind speed. [5]

The speed control of the DFIG includes three modes of operation
a) Minimum rotor speed;
b) Maximum power production; and
c) Maximum rotor speeds.

For minimum rotor speed operation, the optimal value of $\mathbf{C_p}$ cannot be reached and the DFIG is operated at the constant speed and the pitch angle is set to zero (β=0).

For maximum power production operation, the speed Control loop of the WECS makes it to operate at optimal $\mathbf{C_p}$, in order to maximize the power production and also pitch angle is set to zero (β=0). For maximum rotor speed operation, the DFIG is operated to produce the rated power, if the rated power exceeds then the pitch angle is increased from zero.

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