A Casestudy of Harmonics in Doubly Fed Induction Generator Based Wind Energy System

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Abstract - Wind energy technology has evolved rapidly over the last three decades with increasing rotor diameters and the use of sophisticated power electronics to allow operation at variable rotor speed. As the size of wind turbine has become larger, the technology has switched from fixed speed to variable speed. The drivers behind these developments are mainly the ability to comply with Grid Code connection requirements and reduction I mechanical loads achieved with variable speed operation. Currently the most variable-speed wind turbine configuration are doubly fed induction generator wind turbine (DFIG) and fully rated converter (FRC) wind turbine based on a synchronous or induction generator. Harmonic distortion is mainly associated with variable-speed wind turbines because these contain power electronic converters which are important source of high-frequency harmonic currents. It is increasingly of concern in large offshore wind farms where the very extensive cable networks can lead to harmonic resonances and high harmonic currents caused by existing harmonic voltages already present on the power system or by the wind turbine converters. This phase develops a framework for the analysis of harmonics in a doubly fed induction generator. Having the stator connected directly to the grid it the flux level in the machine is nearly constant. This means that changes in either the flux or torque producing current in the rotor circuit are limited by the transient time constant of the machine.

Index Terms – DFIG-Doubly Fed Induction Generator,FRC-Fully Rated Conveter,PWM-Pulse Width Modulation,SVO-STATOR Voltage Orientation,THD-Total Harmonic Distortion,PI-Proportional Integrator,UPQC-Unified Power Quality Conditioner.

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1 INTRODUCTION

1.1 General

The penetration of wind energy into the electrical grid has increased tremendously in the last few years in India. Five to ten years ago, the standard wind turbine was a simple and highly reliable stall controlled turbine. This type of turbine was designed to produce electricity whenever the wind speed was high enough and the grid was stable. In situations of grid instability, the turbine would disconnect. For a small number of wind turbines, this works fine, but in the case of a large penetration of wind energy turbines have to help in stabilizing the grid. This requires turbines that are more controllable. A way to make more controllable turbines is the variable speed. Variable speed turbines can store some of the power fluctuations due to turbulence by increasing the rotor speed. By pitching the rotor blades these turbines can control the power output at any given wind speed. The doubly fed induction generator with a power converter is a simple and highly controllable way to transform the mechanical energy from the variable speed rotor to a constant frequency electrical utility grid.

1.2 Wind Energy Generation

For more than thousand years, wind energy has been used by humans. Until the end of the 19th century, wind power was only used in mechanical constructions such as grain grinding. During the 1980s turbines size increased but the penetration of wind energy into the electrical grid was marginal. There was no major problem with the induction generators drawing reactive power from the grid. More advanced drive trains have been made since the beginning of the 1980s but not on a large commercial basis. The drive train topologies can be divided into two groups: fixed speed and variable speed. Both groups can again be split into two groups one with induction generators and one with synchronous generators. In addition there is a drive train without a gear box. The generators used here are with multipole synchronous machines. Today the biggest commercial turbines are 4-5 MW. Enercon has developed a prototype of a 5 MW synchronous multipole direct driven turbine, and NEG Micon is producing a 4.2 MW doubly fed induction generator turbine with gear box. Both are with pitch controlled rotor.

1.3 Wind Energy

The turbines start production at wind speeds above 2 m/s and reach maximum power production around 12-15 m/s (v_{Pmax}) depending on rotor diameter. Most of the turbines shut down at wind speeds above 25 m/s. When the wind speed is above 12-15 m/s, the rotor has to waste the excess power by letting it pass by the rotor, in order not to damage the turbine. Commercial wind turbines are designed to make maximum power at a given wind speed. For a fixed speed turbine the power production is only optimized for one wind speed. Figure shows the normalized rotor speed vs. normalized electrical power. The power output for a fixed speed turbine can be drawn on the figure as a vertical line at n/n_n equal to one, optimal production is only met at 11 m/s. The curves in the above can be shifted left or right, in order to optimize the turbine to a given site. A variable speed turbine on the other hand can optimize its speed, so optimal power is met for any wind speed, this is showed by the thicker line in Fig. belows. Power extraction from the wind can be controlled in different ways, including stall control and pitch control.

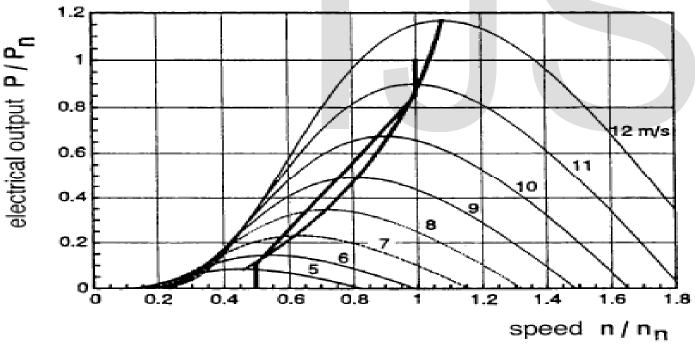
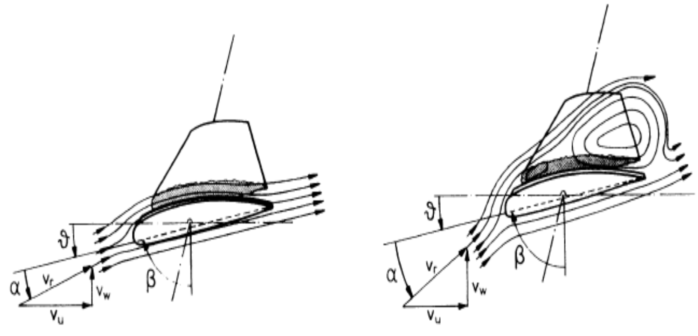


Figure 1.31 Electrical power vs rotor speed

1.4 Stall control

The control principle of stall control is fairly simple. With passive stall, the rotor blades are mounted with a fixed angle to the rotor hub. At wind speeds below v_{Pmax}, laminar flow is obtained around the rotor blades. When wind speeds are above v_{Pmax}, the flow starts to detach from the blade and turbulence occur behind the rotor blade, see below fig. In order to use the stall phenomenon to control the maximum power, the stall region has to be rather accurate. How clean the blades are a factor for the stall point. If the surface of blades is covered with dirt and insects the maximum production is decreased since the stall will occur at lower wind speeds. Mechanical power equation shows that the density of the air is a factor of the power production therefore the power production depends on the air temperature. The blade angle on a stall controlled turbine is chosen so that its production is maximized at a given temperature which in turn causes problems with changing seasons. One of the disadvantages of this power limiting control principle can be seen in above where power around v_{Pmax} gives a little overshoot.



(a) laminar flow (b) stalling

Figure 1.41 Air flow behavior at the rotor blade

1.5 Active stall

A more advanced way to control the power is active stall. With active stall, the blades are mounted on a hub that is capable of a fast change of the blade angle a few negative degrees. The power controller will try to maintain maximum production at any given wind speed by pitching the blade. Above rated wind speed, i.e. rated power, the controller will pitch the blade in order to enforce the stall effect. By actively controlling the stall, the power curve looks like where the power overshoot is not present. Active stall eliminates negative side effect of passive stall such as temperature dependant maximum production and blade contamination.

1.6 Pitch control

When controlling a wind turbine with pitch control, blade angle is changed with a positive angle, as opposed to stall where a negative angle is used. Instead of forcing stall to occur, the blades are pitched out of the wind. As in stall controlled turbines the controller will try to maintain max Cp. Above rated wind speed, the blades are pitched out of the wind and when the wind speed reduces again, the blades are pitched back into the wind. This result in a lot of trimming of the pitch angle compared to active stall. The angle the blades have to be pitched is about 10-20 degrees.

Since pitch control limits power by pitching the blade out of the wind, fast power fluctuations in the wind above rated wind speed will also result in a fast electrical power fluctuation above rated power, unless the blades can be pitched fast enough to overcome the fluctuation. This cannot be accomplished. Therefore some kind of variable speed has to be used together with pitch controlled turbines. For stall controlled turbines, power limitation occurs due to the physics of the aerodynamics of the stall principle.

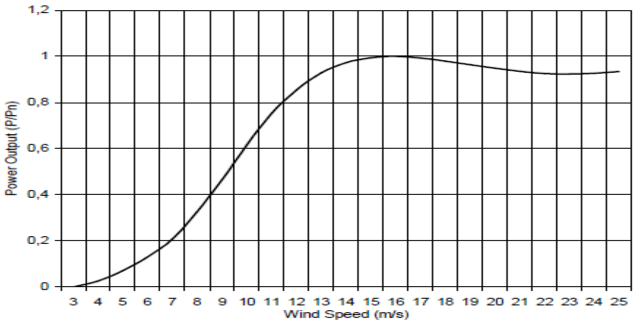


Figure 1.61 Power curve for an active stall controlled wind turbine.

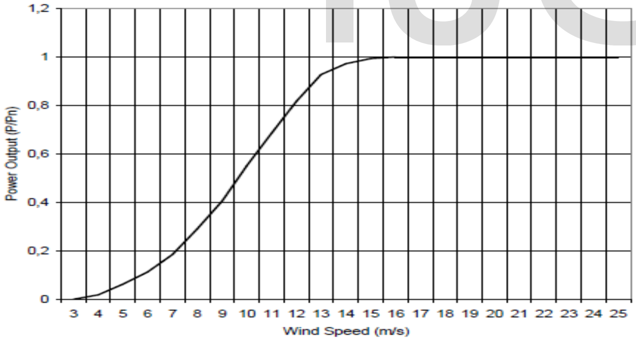


Figure 1.62 Power curve for a pitch controlled wind turbine

1.7 Literature Servey

1.71 General

For a variable speed wind turbine the generator is controlled by power electronic equipment. There are several reasons for using variable-speed operation of wind turbines among those are possibilities to reduce stresses of the mechanical structure acoustic noise reduction and the possibility to control active and reactive power. The major advantage of the doubly-fed induction generator, which has made it popular, is that the power electronic equipment only has to handle a fraction (20 to 30 %) of the total system power. This means that the losses in the power electronic equipment can be reduced in comparison to power electronic equipment that has to handle the total system power as for a direct-driven synchronous generator, apart from the cost saving of using a smaller converter.

1.72 Survey Details

[1] Harmonic Analysis of a DFIG for a Wind Energy Conversion System-Lingling Fan, *Senior Member, IEEE*, Subbaraya Yuvarajan, *Senior Member, IEEE*, and Rajesh Kavasseri, *Senior Member, IEEE* -This paper has presented a systematic method to analyze the harmonics caused by nonsinusoidal rotor injection and unbalanced stator conditions in a DFIG. The key contributions of the paper are: 1) a generalized steady-state equivalent circuit for DFIGs suitable for analysis under harmonic and unbalanced conditions; 2) a systematic method to calculate electromagnetic torque by computing the interactions of harmonic stator and rotor currents, derived from the equivalent circuit. 3) the development of positive- and negative-sequence equivalent circuits, which enables one to analyze unbalanced conditions on the stator side by a suitable interconnection of the sequence circuits.

[2] Wind Turbine Current-Source Converter Providing Reactive Power Control and Reduced Harmonics- Pierluigi Tenca, *Member, IEEE*, Andrew A. Rockhill, *Student Member, IEEE*, and Thomas A. Lipo, *Life Fellow, IEEE-* This paper presents a current-source inverter topology that is suitable for multi-megawatt wind turbines. The proposed scheme utilizes two series-connected three-phase inverters that employ fully controllable switches and a proper interconnection transformer with the mains. In order to improve the efficiency and to allow the use of high-power devices, the inverters are switched at the mains frequency. The overall control technique allows to independently impose two desired quantities that can be selected out of the set of three composed of: 1) the total average voltage at the dc side of the inverters, which is directly related to the turbine speed; 2) the fundamental power factor at the mains interconnection point, which can be chosen unitary, leading, or lagging; and 3) the amplitude of one desired component of the spectrum of the mains line currents. The two chosen quantities univocally determine the third one. At specific operating points of the turbine, a significant reduction of the fifth and seventh harmonics can already be achieved without additional filters and/or active harmonic compensation.

[3] Current Source Topology for Wind Turbines with Decreased Mains Current Harmonics, Further Reducible via Functional Minimization- Pierluigi Tenca, *Member*, *IEEE*, Andrew A. Rockhill, *Member, IEEE*, Thomas A. Lipo, *Life Fellow, IEEE*, and Pietro Tricoli, *Member, IEEE* **-**The paper presents a current-source inverter topology tailored for large multi-megawatt wind turbines. The proposed topology can inherently benefit from the distance between the generator and the mains because the consequent length and possible layout of the power cables may enable the realization of a significant portion of the dc-link inductance. In order to improve the efficiency and to allow the possible utilization of rugged inexpensive thyristors pulsewidth modulation (PWM) modulation is not used. Unity fundamental power factor at the mains is guaranteed at any load condition while the fifth and seventh harmonics of the mains line currents can be reduced by proper system design at a desired turbine speed, considered most suitable for its operation.

[4] Control of a Doubly Fed Induction Wind Generator under Unbalanced Grid Voltage Conditions- Ted K. A. Brekken, *Member, IEEE*, and Ned Mohan*, Fellow, IEEE*- Wind energy is often installed in rural, remote areas characterized by weak, unbalanced power transmission grids. In induction wind generators, unbalanced three-phase stator voltages cause a number of problems, such as overcurrent, unbalanced currents, reactive power pulsations, and stress on the mechanical components from torque pulsations. Therefore, beyond a certain amount of unbalance, induction wind generators are switched out of the network. This can further weaken the grid. In doubly fed induction generators (DFIGs), control of the rotor currents allows for adjustable speed operation and reactive power control. This paper presents a DFIG control strategy that enhances the standard speed and reactive power control with controllers that can compensate for the problems caused by an unbalanced grid by balancing the stator currents and eliminating torque and reactive power pulsations.

[5] Dynamic Modeling and Control of DFIG-Based Wind Turbines Under Unbalanced Network Conditions- Lie Xu, *Senior Member, IEEE*, and Yi Wang, *Member, IEEE*- This paper presents an analysis and control design of a doubly-fed induction generator (DFIG)-based wind generation system operating under unbalanced network conditions. A DFIG system model in the positive and negative synchronous reference frames is presented. Variations of stator active and reactive powers and generator torque are fully defined in the presence of negative sequence voltage and current. Alternative DFIG control targets during network unbalance, such as reducing stator current unbalance, torque, and power pulsations minimization, are identified. A rotor current control strategy based on positive and negative (dq) reference frames is used to provide precise control of the rotor positive and negative sequence currents. In contrast, with the proposed control strategy, enhanced system control and operation such as minimizing oscillations in either active power, or electromagnetic torque, or stator or rotor currents can be achieved.

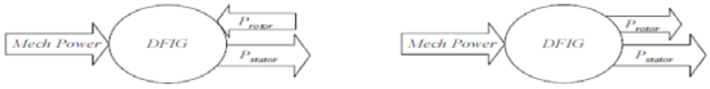
[6] Modeling and enhanced control of DFIG under unbalanced grid voltage conditions- Jiabing Hu Yikang He- This paper presents a mathematical model of a doubly fed induction generator (DFIG) based on stator voltage orientation (SVO) in the positive and negative synchronous reference frames under unbalanced grid voltage conditions. The oscillations of the DFIG electromagnetic torque and the stator active and reactive powers are fully described during grid voltage unbalance. A new rotor current controller implemented in the positive synchronous reference frame is proposed. The controller consists of a proportional integral (PI) regulator and a harmonic resonant (R) compensator tuned at twice the grid frequency. Thus, the positive and negative sequence components of DFIG rotor currents are directly regulated by the PI + R controller without the need of involving positive and negative sequence decomposition, which indeed improves the dynamic performance of DFIG-based wind power generation system during small steady state and relatively larger transient network unbalances.

[7] Evaluation of the Effects of Rotor Harmonics in a Doubly-Fed Induction Generator With Harmonic Induced Speed Ripple- This paper is concerned with the low-frequency harmonics which originate from the rotor inverter of a doubly-fed induction generator (DFIG). By including the mechanical speed response, it expands the transformer approach previously taken to analyze the harmonic transfer in the machine.Anumerical method is proposed to calculate the stator current sidebands, which can be used to predict the voltage fluctuation at the system busbar. It is shown that the pulsating torque associated with the rotor harmonics can induce speed ripple depending on the inertia, causing a significant change in the stator current spectrum.

2 Doubly-Fed Induction Generators

2.1Typical DFIG configuration

The doubly fed induction generator (DFIG) is, as the name indicates, an induction generator where both stator and rotor terminals are available for power flow. When the machine works as a generator, the power flow in the machine is as shown in Figure 2.1 where input is mechanical power. The active power transmitted to the grid is the sum of stator power *Ps* and rotor power Pr, assuming the power inverter is loss less, Pr = Pgrid. Pgrid is the active power from the grid side converter. The total power of the loss less system is simply the sum of stator and rotor power



(a) $\omega < \omega_0$ (b) $\omega > \omega_0$

Figure 2.1 Power flow of DFIG below and above synchronous speed

$$P_{total} = P_s + P_{grid}$$

The active power from the rotor is proportional to the slip *s* of the generator

$$P_r = -s \cdot P_s$$

where the slip here is defined as

$$s = \frac{\omega_s - \omega_r}{\omega_s}$$

2.2 Classification of DFIG

In the literature, many different kinds of DFIGs have been presented and many of are also used in practice. DFIGs can be grouped into brushed or brushless, and then again into other subgroups :-

Standard DFIG, Cascaded Doubly Fed Induction Generator (CDFG), Single-Frame Cascaded Doubly Fed Induction Generator (S-CDFG), Brushless Doubly Fed Induction Generator (BFDG), Doubly-Fed Reluctance Generator (DFRG).

3 Doubly-Fed Induction Generator based Wind turbines

3.1 General

The DFIG is currently the system of choice for multi-MW wind turbines. The aerodynamic system must be capable of operating over a wide wind speed range in order to achieve optimum aerodynamic efficiency by tracking the optimum tip-speed ratio. Therefore, the generator's rotor must be able to operate at a variable rotational speed. The DFIG system therefore operates in both sub- and super-synchronous modes with a rotor speed range around the synchronous speed. The stator circuit is directly connected to the grid while the rotor winding is connected via slip-rings to a three-phase converter.

3.2 Steady-state operation of the Doubly-Fed Induction Generator

The DFIG is an induction machine with a wound rotor where the rotor and stator are both connected to electrical sources, hence the term 'doubly-fed'. The rotor has three phase windings which are energized with three-phase currents. These rotor currents establish the rotor magnetic field. The rotor magnetic field interacts with the stator magnetic field to develop torque. The magnitude of the torque depends on the strength of the two fields (the stator field and the rotor field) and the angular displacement between the two fields. Mathematically, the torque is the vector product of the stator and rotor fields.

Conceptually, the torque is developed by magnetic attraction between magnet poles of opposite polarity where, in this case, each of the rotor and stator magnetic fields establish a pair of magnet poles, Figure 3.1. Clearly, optimum torque is developed when the two vectors are normal to each other. If the stator winding is fed from a 3-phase balanced source the stator flux will have a constant magnitude and will rotate at the synchronous speed. We will use the per-phase equivalent circuit of the induction machine to lay the foundations for the discussion of torque control in the DFIG. The equivalent circuit of the induction machine is shown in Figure 3s.2. The stator side has two 'parasitic' components, Rs and Ls, which represent the resistance of the stator phase winding and the leakage inductance of the phase winding respectively.

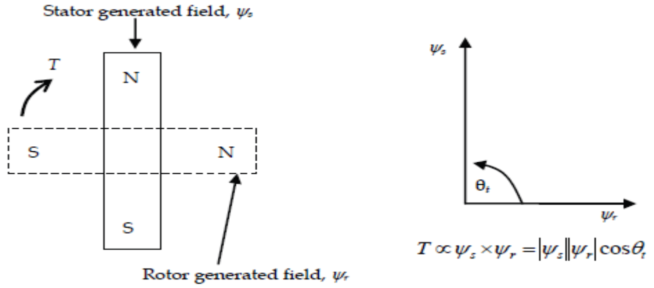


Figure 3.1 Magnetic pole system generated by currents in the stator and rotor windings. The stator and the rotor field generate a torque that tends to try and align poles of opposite polarity. In this case, of rotor experiences a clockwise torque.

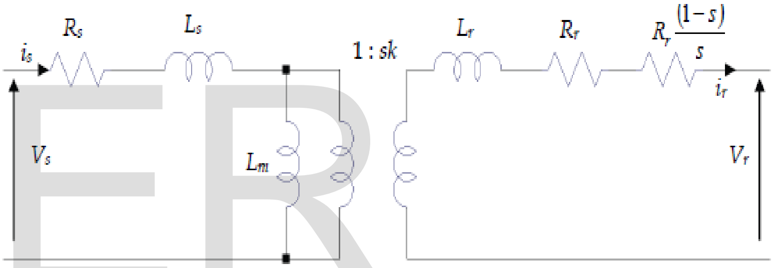


Figure 3.2 Per-phase equivalent circuit of an induction machine

Like the stator circuit, the rotor circuit also has two parasitic elements. The rotor leakage reactance, *Lr*, and the rotor resistance *Rr*. In addition, the rotor circuit models the generated mechanical power by including an additional rotor resistance component, *Rr*(1–*s*)/*s*. Note that the rotor and stator circuits are linked via a transformer whose turns ratio depends on the actual turns ratio between the stator and rotor (1:*k*), and also the slip, *s*, of the machine.

$$s = \frac{n_s - n_r}{n_s} \qquad (1$$

where n_s and n_r are the synchronous speed and the mechanical speed of the rotor respectively. The synchronous speed is given by

$$n_s = \frac{60 f_e}{p} \text{ rpm}$$

where p = number of pole pairs and f_e is the electrical fquencyof the applied stator voltage.

As the rotor accelerates beyond synchronous speed (the super-synchronous mode) the frequency of the rotor voltage begins to increase again, but has the opposite phase sequence to the sub synchronous mode. Hence, the frequency of the rotor voltage is

$$f_r = sf_e$$

The mechanical torque generated by the machine is found by calculating the power absorbed (or generated) by the rotor resistance component Rr (1–s)/s. This is shown to be

$$P_{mech} = 3\left|i_r\right|^2\left(\frac{1-s}{s}\right)R_r$$

In an ideal induction machine, we can ignore the rotor and stator phase winding resistance and leakage inductance. The per-phase equivalent circuit then becomes simple, Figure.3.3. The phasor diagram for the machine is shown. Note that the stator generated flux component is normal to the rotor current (hence rotor flux) phasor giving the optimum conditions for torque production (note this is true for low values of slip only). Using this simplified circuit diagram, the mechanical torque production is then:

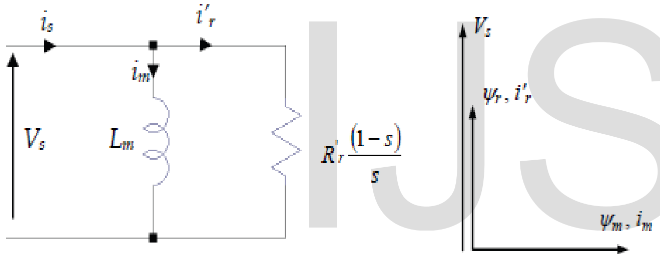


Figure 3.3 Simplified equivalent circuit of the induction machine assuming low values of slip and negligible stator and rotor leakage reactance. Phasor diagram demonstrates optimal orientation of magnetising current and rotor current.

$$T_{mech} = 3\left|i_r^{'}\right|^2\left(\frac{1-s}{s}\right)\frac{R_r^{'}}{\omega_m}$$

$$\text{As } \omega_m = \frac{(1-s)\omega_m}{p} \text{ and } \psi_m = L_m i_m = \frac{V_s}{\omega_s} = \frac{\left|i_r^{'}\right|R_r^{'}}{s\omega_s}$$

Then

$$T_{mech} = 3\left|i_r^{'}\right|^2\left(\frac{1-s}{s}\right)\frac{R_r^{'}}{\omega_m} = 3p\frac{\left|i_r^{'}\right|R_r^{'}}{s\omega_s}\left|i_r^{'}\right| = 3p\psi_m\left|i_r^{'}\right|$$

4 Harmonic Analysis

4.1 General

Electrical equipment with power electronics connected to the grid cause nonsinusoidal grid currents, due to nonlinear characteristics of the power electronics. Since the grid voltage is nearly sinusoidal and the voltage produced by the power electronics is often far from sinusoidal, the current from the power electronics will contain harmonics. According to Fourier analysis, any periodic waveform consists of a sum of sinusoidal waveforms with different frequency and phase, i.e. the fundamental frequency ω_1 and multiples of the fundamental frequency $h\omega_1$.

4.2 An Overview of Harmonics

Harmonics can be grouped into positive, negative and zero sequence. Harmonics of the order h = 6k + 1, k = 1; 2; 3; : : : are of a positive sequence. These harmonics will rotate in the direction of the fundamental. The lowest order positive sequence harmonics are 7th, 13th and 19th. Harmonics of the order h = 6k ¡ 1, k = 1; 2; 3; : : : are of a negative sequence. These harmonics will rotate in the opposite direction of the fundamental. The lowest order negative sequence harmonics are 5th, 11th and 17th. Harmonics of the order h = 3k, k = 1; 2; 3; : : : are of zero sequence. The lowest order of zero sequence harmonics are 3rd, 9th and 15th. It is practical to have a measure of the distortion of a distorted current waveform. This can be done by calculating the total harmonic distortion (THD), defined as

$$THD = \sqrt{\sum_{h=2}^{h=h_{\max}} \left(\frac{I_h^2}{I_1^2}\right)}$$

where $h_{\max}$ is the maximum number of harmonics to be included, typically 40 or 50, depending on the standards the equipment has to comply with. In the above equation THD for the distorted current is found. Similar THD can be calculated for a distorted voltage.

4.3 Analysis of Harmonics and Interharmonics in a DFIG

When a symmetrical three phase induction machine is connected to a system of symmetrical three phase voltages, the air-gap flux will contain harmonics. This is mainly due to none perfect distribution of the windings, both in the stator and rotor. It has been shown in the literature that a doubly fed induction motor fed by a cycloconverter has a certain amount of harmonic content in its current, if the stator is connected to a fundamental frequency voltage source. By using modern self-commutated IGBT inverters with a relatively high switching frequency, the inverter will not cause any low harmonic content in the voltage. The lower part of Fig shows the spectrum of the rotor current when the rotor is fed by an inverter. In it was assumed that the voltage source was a pure sinus. This is not the case in most electrical grids, where a small content of 5th, 7th, 11th and 13th harmonics are always present.

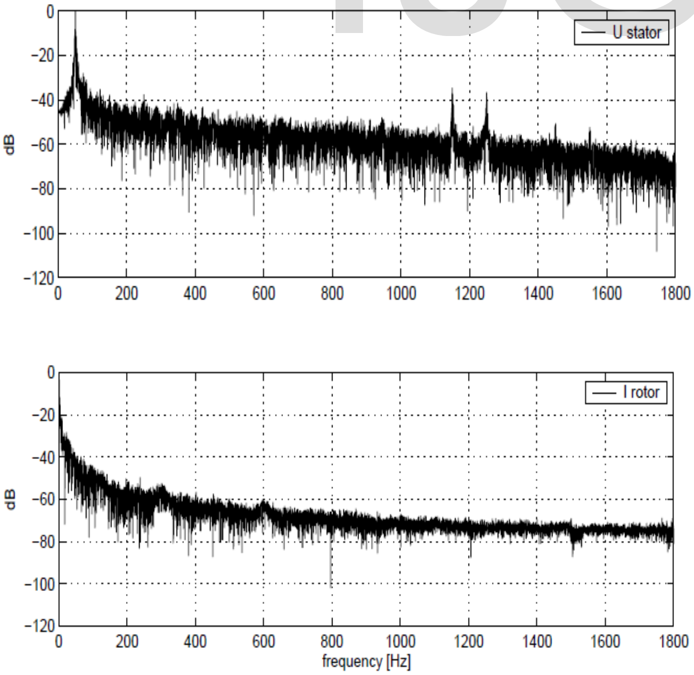


Figure 4.1 Frequency spectrum of DFIG at synchronous speed without stator connected to grid (1500 RPM)

Due to the non-sinusoidal distribution of the stator and rotor windings the air-gap flux will contain higher harmonics, referred to as MMF space harmonics. A normal induction generator with a squirrel cage rotor will cause some 5th, 7th, 11th and 13th harmonics in the stator current, due to the induced voltage in the stator. With a short circuited rotor there will be no induced voltage in the rotor, resulting in higher harmonics of the rotor frequency.

With the DFIG, on the other hand, the rotor circuit is connected to a voltage source, causing a current from the rotor and its higher harmonics. The left side of Table shows the harmonics in the stator, the right side shows the harmonics in the rotor. The first term comes from the higher harmonics due to the stator. The second term comes from the harmonics in the rotor. The first two lines are harmonics due to stator harmonics. The last two lines are the harmonics due to the slip, these are called slip harmonics. n = 1; 2; 3; and m = 1; 2; 3;

Stator harmonics	Rotor harmonics
$(6m-1)f_{grid} - 6(n-1)f_{slip}$	$(6m)f_{grid} - (6n-5)f_{slip}$
$(6m+1)f_{grid} + 6(n-1)f_{slip}$	$(6m)f_{grid} + (6n-5)f_{slip}$
$(6m-1)f_{grid} - 6(n)f_{slip}$	$(6m)f_{grid} - (6n-1)f_{slip}$
$(6m+1)f_{grid} - 6(n)f_{slip}$	$(6m)f_{grid} - (6n+1)f_{slip}$

Table 4.1 Stator and rotor current harmonics

4.3 Saturation

If the main flux paths get saturated, a third harmonic voltage is produced in each stator phase voltage. Because these third harmonic voltages all are in phase, they do not cancel out. The third harmonics are present with amplitude approximately one fifth of the slot harmonics.

4.4 Slot Harmonics

Slots in the rotor and stator are another source of harmonics in the machine. The slot harmonics are produced by variations in the reluctance due to the slots. The slot harmonics in the air-gap MMF induce slot harmonic voltages in the rotor and stator voltages. Every time the magnetic field in the air-gap passes by a stator slot, it increases the rotor and stator voltage in steps, so even with a pure sinus voltage source, the current from the generator contains harmonics.

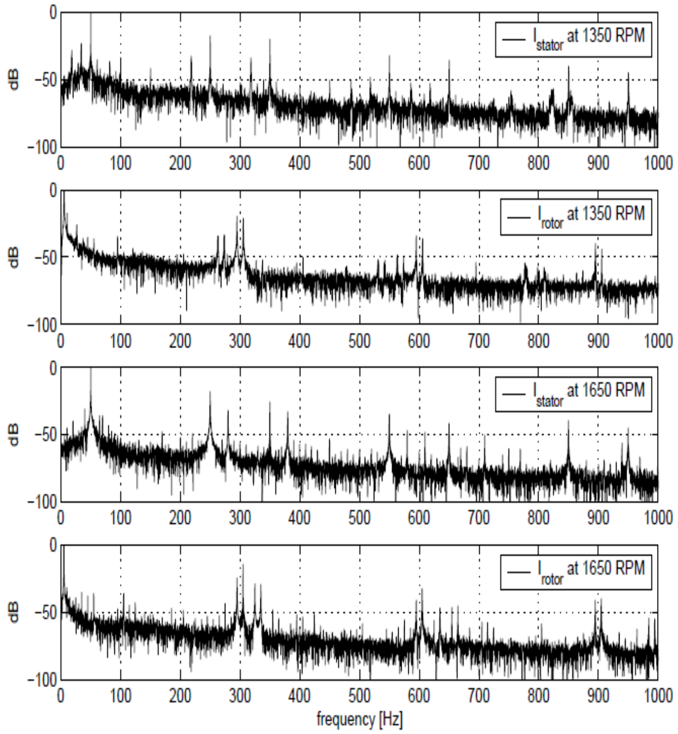


Figure 4.2 Frequency spectrum of DFIG stator and rotor current measured at ± 10% slip.

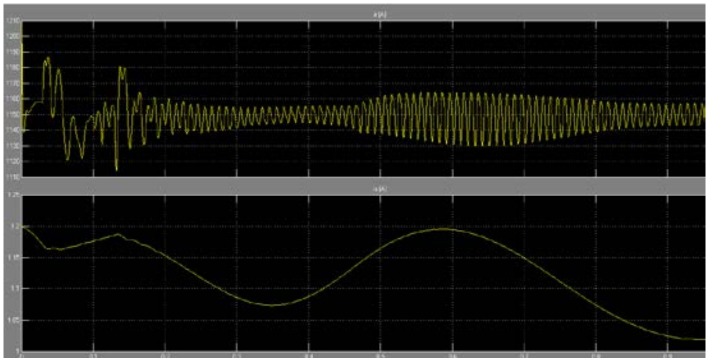
Induction machines normally have skewed rotors, but this is not the case for DFIG machines. If the rotor is not skewed, it gives higher amplitude slot harmonics. The slot harmonics can be used in speed sensing. Since the slot harmonics are very distinctive, it is fairly easy to extract them from the frequency spectrum and use the signal for speed prediction.

5 Simulation Results

5.1 General

Electrical power systems are combinations of electrical circuits and electromechanical devices like motors and generators. Engineers working in this discipline are constantly improving the performance of the systems. Requirements for drastically increased efficiency have forced power system designers to use power electronic devices and sophisticated control system concepts that tax traditional analysis tools and techniques. Further complicating the analyst's role is the fact that the system is often so nonlinear that the only way to understand it is through simulation. Land-based power generation from hydroelectric, steam, or other devices is not the only use of power systems. A common attribute of these systems is their use of power electronics and control systems to achieve their performance objectives. SimPowerSystems software is a modern design tool that allows scientists and engineers to rapidly and easily build models that simulate power systems.

5.3 Performance of DFIG Wind Turbine



6 Conclusion

In this phase 1 the harmonics level have been investigated under steady state operation of the DFIG. As always there are many more interesting aspect that can be considered such as unsymmetrical voltage dips, voltage harmonics, phase shifts and frequency dips in the grid voltage. Other aspects that could be of interest is to use the wind turbine, equipped with a doubly-fed induction generator, to support the electrical grid statically or dynamically. Since the machine-side inverter is connected in shunt to the grid via the doubly-fed induction machine (which acts as a transformer) and if the grid-side inverter is connected in series with the grid, the system is close to a unified power quality conditioner (UPQC). Therefore an interesting aspect is to investigate the possibility to run the wind turbine equipped with a doubly-fed induction generator as a UPQC. The great advantage is that with little additional cost, the wind turbine also works as an UPQC, which most certainly increase the value of the wind turbine.

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