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DYNAMIC PERFORMANCE OF GCIG WIND TURBINE UNDER UNBALANCE CONDITION

Harish Saini[*1], Sonu Manderna[2], Surys Prakash[3] & Rajnish Mitter[4]
[*1]M.Tech Scholar, LIET, Alwar
[*2,3,4]LIET, Alwar

ABSTRACT

In wind power station, induction generators are used as generating machine. Transient stability analysis of induction generator used in wind power station, joint to infinite bus, before balanced and after unbalanced short circuit faults for one main purpose in power system security and operation. That is necessary to know transient behaviour of induction generator, while joining to network, in usual faults. In this thesis we present active power, torque and speed of induction generator at balanced and unbalanced short circuit faults with dynamic equation of induction machine, with single equation of induction machine we present transient active power, torque, speed. Analysis of induction generators used in wind power system during three phase fault, two phase fault, single phase fault and two phase to earth fault conditions, the natural approximation to derive analytical formulas for transient conditions is proposed, and the transient behaviour of induction generator is analysed.

Keywords: *Transient Stability, transient behavior, Signals Intelligence, unbalance behaviour, grid connected generator, standalone system.*

I. INTRODUCTION

Induction generators are used in very vast area these days because of their relative advantageous features. These features are brush- less construction, low cost, less maintenance, self-protection against system faults, good dynamic response and capabilsity to generate power at variable speed. The small-scale power generating system for areas like single community or remote industry where grid extension is not feasible may be termed as stand-alone generating system. Portable generating-sets, emergency generators and captive power plants as required for critical applications like hospitals and continuous industrial process come under the category of stand-alone generating systems. Induction generator is best suitable for generating electricity from wind, especially in remote areas, because external power supply to produce the excitation magnetic field is not needed. Generation of pollution free power has become the main aim in the field of electrical power generation. The depletion of fossil fuels, such as coal also improves the importance of switching to renewable and non-polluting energy sources such as solar, wind energy and many more, among which wind energy is the most efficient and wide spread source of energy. Wind is a free and renewable energy source. From the recent scenario it is also evident that wind energy is very important in the power generation sector. If the wind energy can be effectively used it can solve the problems such as environmental pollution and unavailability of fossil fuel in future. The above fact gives the interest for development of a wind power generation system which would have better performance and efficiency. Continuous research is going on taking into account different transient issues in this sector.

Wind energy is the subject of much recent research and development. In order to overcome the problems associated with synchronous generator wind turbine system and to maximize the wind energy capture, many new wind energy system will take variable speed wind turbine. IG (Induction Generator) is one of the component of Variable speed wind turbine system. GCIG offers several advantages when compared with fixed speed generators including speed control. These merits are primarily achieved via control of rotor. Many works have been proposed for studying the behavior of GCIG based wind turbine system. Most existing models widely use vector control Induction Generator.

The development of wind energy for electrical power generation got a boost noe a days of the twentieth century, aviation technology resulted in an improved understanding of the mechanism acting on the blades moving through air. High speed and high efficiency with low cost of turbines is the condition for successful electricity generation. Wind energy is one of the most economic and easily available forms of renewable energy. Wind blows from a region of higher to lower atmospheric pressure. The difference in pressure is caused by (A) the fact that surface of earth is not uniformly heated by the sun and (B) the rotation of earth. Wind energy is the byproduct of solar energy in the form of the kinetic energy of air. Wind has been known to man as a natural source of mechanical power. Of the various renewable energy sources, wind energy has emerged as the most viable source of electrical power and is economically competitive with conventional sources.

The electrical energy is rising and there is a steady rise of the demand on power generation, transmission, distribution and utilization. The extractable energy from the 0-100m layer of air has been estimated to be the order of 10 12 KWh/annum.

The terms "wind energy" or "wind power" is the process by which the wind is used to generate electricity. Wind turbines convert the kinetic energy into mechanical power. This mechanical power can be used for specific tasks or a generator can convert this mechanical power into electricity. Since earliest recorded, wind power has been used to move ships, grind grain and pump water.

II. MATERIALS AND METHODS

1. Grid connected induction generator system

Induction generators and motors produce electrical power when their rotor speed is more than the synchronous frequency. For a typical four-pole motor operating on a 50 Hz electrical grid, synchronous speed is 1600 rotations per minute. Similar four-pole motor operating on a 50 Hz will have synchronous speed equal to 1500 rpm. In normal motor operation, stator flux rotation is more than the rotor rotation. This is initiating stator flux to generate rotor currents, which create rotor flux with magnetic polarity opposite to stator. In this way, rotor is dragged along behind stator flux, by slip. In generator operation, a prime mover (turbine, engine) drives the rotor more than the synchronous speed. Stator flux still induces currents in the rotor, but since the opposing rotor flux is now cancelling the stator coils, active current is produced in stator coils, and motor is now operating as a generating machine, and sending power back to the electrical grid.

Grid and stand-alone connection:

In induction generators the magnetizing flux is produced by a capacitor bank connected to the machine in case of stand-alone system and grid connection it draws magnetizing current from the grid side.

- For a grid connected system, frequency and voltage of the machine will be detected by the electric grid, since it is very small compared to the whole system.
- For stand-alone systems, frequency and voltage are complex function of machine parameters, capacitance used for excitation purpose, and load value type.

Grid connected induction generators extract their excitation from the grid. The generated power is fed to the supply system when the IG is run above synchronous speed. Machines with cage rotor type feed only through the stator and generally operate at low negative slip. But wound rotor type machines can feed power through the stator as well as rotor to the bus system over a wide range known as Doubly Fed Induction Machines.

2. GCIG System configuration

The GCIG system is composed of four main items: the prime mover, the induction machine, the load and the grid-excitation capacitor bank. The general layout of the GEIG system is shown in Figure

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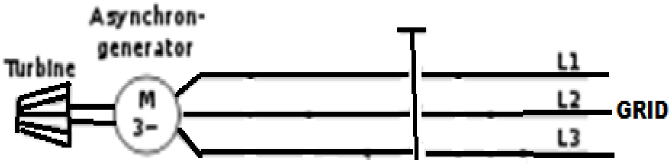

Schematic diagram of a standalone grid-excited induction generator

The real power required to the load is supplied by the induction generator by extracting power from the prime mover (turbine). When the speed of the turbine is not maintained constant, both the speed and shaft torque vary with variations in the power demand in the loads. The self-excitation capacitors connected at the stator side terminals of the induction machine must produce sufficient reactive power to supply the needs of the load and the induction generator. A squirrel cage induction generator (GCIG) is more attractive than a conventional synchronous generator in this type of system because of its low unit cost, absence of DC excitation source, brushless cage rotor construction and lower maintenance required. A suitable size three- phase capacitor bank connected at the generator terminals is used as lagging VAr source to meet the excitation demand of the cage machine and the load. The machine operated in this mode is known as a Self-excited Induction Generator (GCIG). However, the main drawback of the standalone GCIG is its poor voltage and frequency regulations under variable loads. A change in the load impedance directly affects the excitation of the machine because the reactive power of the excitation capacitors is shared by both the machine and the load. Therefore, the generating voltage drops when the impedance of the load is increased resulting in poor voltage regulation. Poor frequency regulation occurs (an increase in the slip of the induction machine) when the load is increased.

The grid-excitation phenomenon of an induction machine is still under considerable attention although it is known for more than a half century. When a induction machine is driven by a mechanical prime mover, the residual magnetism in the rotor of the machine induces an electromagnetic force emf in the stator windings at a frequency proportional with the rotor speed. This EMF is applied to the capacitors connected to the stator side terminals and causes reactive current to flow in the stator windings. So a magnetizing flux in the machine is established. The value of the stator voltage is limited by the magnetic saturation with in machine. The induction machine is then capable of operating as a generator without

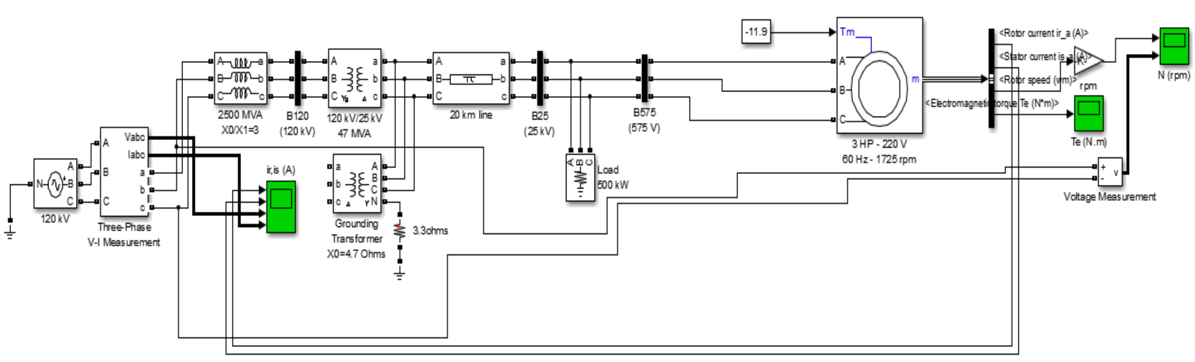

Fig.2 Simulation model of grid-excited induction generator

a grid supply in isolated locations. Once the machine is loaded and self-excited, the magnitude of the steady- state voltage generated by the GCIG is determined by the nonlinearity of the magnetizing curves, the value of the self-excitation capacitance, speed, machine parameters and terminal loads. As the load and speed of the GCIG changes, the demand for lagging VArs to maintain a constant AC voltage across the machine terminals also changes.

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3. GCIG System performance

The performance characteristics of the GCIG system depend mainly on the following:

- The parameters of the induction machine
- The machine operating voltage, rated power, power factor, rotor speed and operating temperature and the induction machine parameters directly affect the performance of the GCIG system.
- The Self-excitation processed. The connection of a capacitor bank with the induction machine stator terminals is necessary in the case of standalone operation of the system. The capacitor connection scheme (delta or star) and the use of fixed or controlled grid-excitation capacitors have a direct impact on the performance of a GCIG system.
- Load parameters
- The power factor, starting/maximum torque and current, generated harmonics and load type also affect the performance of the GCIG system directly.
- Type of prime mover whether the primary source is hydro, wind biomass or combinations, the performance of the GCIG system is affected.

An overview of the self-excitation phenomenon was presented in this chapter. The performance characteristics and operational problems of GCIG systems were also given. The prime mover, the induction machine, the load and the self-excitation capacitors are the four main items comprising the GCIG system. However, this thesis is focused on studying and analyzing the steady-state nonlinear behavior of the GCIG system as a nonlinear dynamic system. Poor voltage and frequency regulation are two major drawbacks of the GCIG
system under variable load conditions.

4. Dynamic response Of GCIG Under Unbalance Condition

Unbalancing can be done in voltage magnitude as in several views it can be voltage dip (also the word voltage sag) is a sudden reduction (between 10% and 90%) of the voltage at a point in the electrical system, and sudden change in the load (dynamic load) .There can be many causes for a voltage sag: short circuits somewhere in the grid, switching operations are concerned with a temporary disconnection of a supply, the flow of the large currents that are caused by the starting of large motor loads, or large currents drawn by arc furnaces and by transformer saturation. Voltage dips due to short-circuit faults causes the majority of equipment trips and therefore of most interest. Faults are either symmetrical (three- phase or three phase-to-ground faults) or nonsymmetrical (single-phase or double-phase or double-phase-to ground faults). Depending on the type of fault, the magnitudes of the voltage dips of each phase might be equal (symmetrical fault) or unequal (nonsymmetrical faults). The magnitude of a voltage sag at a certain point in the system depends mainly on the type of the fault, the distance from the fault, to the system configuration, and the fault impedance.

The dynamics of the GCIG has two poorly damped poles in the transfer function of the machine, with an oscillation frequency near to the line frequency. These poles will cause oscillations in the flux if the grid connected induction machine is exposed to a grid disturbance. After so many disturbances, an increased rotor voltage will be needed to control the rotor currents. When this required voltage increases the voltage limit of the converter, it is not possible to control the current as desired.

Analysis of machine under unbalance conditions

In this paper, performance and behaviour of a three-phase induction motorunder unbalanced voltage imposed by power system grid is studied. The phase currents, the transferrable power to the motor, stator current and efficiency of the motor are propose. In fact, influence of power system and its unbalances on the motor itself are monitered. In order to predict the performance of a three phase induction motor, symmetrical components analysis is normally used. This is utilized to calculate different parameters of the machine under unbalanced voltage operation. A star connected, 20HP (15Kw), 400V 3-phasesquirrel-cage induction motor has been used under unbalanced voltage operation for performance analysis of a motor.

Normal and unbalanced conditions analysis

Normal case: In this section normal operating condition has been investigated. It is necessary to provide this to develop a reference for comparison purposes. This model has been simulated. At normal condition, motor was supplied by its rated voltage which is 326.6 volts peak for each phase. The voltages applied are as follows:

$Va = 326.6\angle 0$, $Vb = 326.6\angle 240$, $Vc = 326.6\angle 120$, $f = 50Hz$ ………………(1)

Unbalanced cases: In this part the unbalance in the phase and the magnitude of the voltage has been considered. In order to design the model of electrical motor symmetrical components can be used. A wide variety of research has been done on modelling of unbalanced condition. In the unbalanced voltage operating condition the torque can be summarised as follows [20, 21]:

$T = P\omega = (P0 + P2)/\omega = T0 + T2$ ………………..(2)

In which, $T0$ is the DC torque. $T2$, is the torque component whose frequency is two times the supply frequency. In a simple way assuming induction motor as a RL load the torque can be written as:

$T = \eta \times E \times I/\omega$ ……………(3)

In which I and E are input current and voltage of each phase respectively. Assuming sinusoidal waveforms for current and voltage this equation can be rewritten as:

$T = K\cos(2\pi\, 50t + \alpha) \times \cos(2\pi\, 50t + \beta)$……………. (4)

So,

$T = K/[\cos(\alpha - \beta) + \cos(2\pi\, 100t + \alpha + \beta]$………….(5)

Based on equation (5) the resulting torque would include a DC term and with a new term whose frequency is twice the fundamental frequency of the applied voltage. In order to find out the unbalanced supply voltage this extra torque component can be used.

Unbalance in the voltage magnitude

In this case an unbalance of 22% and 16% of the rated voltage is assumed in phase B and C voltages respectively. So, the value of the voltages for phases A, B and C would be as follows:

$Va = 326.6\angle 0$,
$Vb = 326.6 * 0.8\angle 240$,
$Vc = 326.6 * 0.85\angle 120$

In order to have a better analysis of the torque components frequency analysis has been made using DFT. According to this figure there is a DC component and a 100 Hz component(second order) as expected. The magnitude of this component is of such quantity to be measured. Comparing to the case of the normal operation the average torque is decreased while the ripple has increased significant.

Unbalance in the voltage phase

In this part an unbalance of 12% is assumed for the phase of applied voltages of phase B and C. The applied 3 phase voltages are as follows:

$Va = 326.6\angle 0$,
$Vb = 326.6\angle 216$,
$Vc = 326.6\angle 132$

sed on the figure there is a significant increase in the torque waveform while the average torque has decreased a little bit comparing to normal case.

Unbalance in the voltage magnitude and phase

In this case an unbalance of 12% is applied for voltage Phase and magnitude. The applied voltages are as follows:

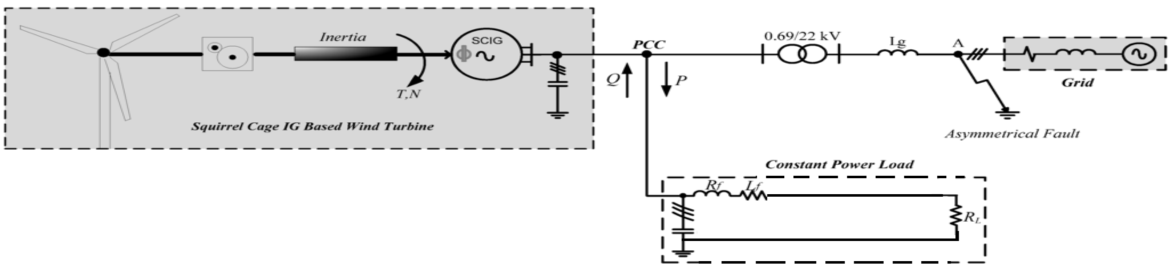
$Va = 326.6\angle 0$,
$Vb = 326.6 * .9\angle 216$,

Vc= 326.6*.9∠132

As expected in this case the ripple is increased more and the average torque is decreased. From the performance point of view alternating torque is unaccepted so it is important to detect and avoid any kind of unbalancing in the voltage.

5. Grid connected induction machine underfaults

Consider GCIG in which, immediately after a 3-phase fault occurs, the stator voltage and flux reduces to zero. The voltage drop depends, on the location of the fault. The rotor current then increases to attempt to maintain the flux linkage within the rotor windings constant. GCIG under fault can be shown in fig. However, for a GCIG the increase in the rotor current immediately after a fault will be determined by two factors. The first is to change stator flux and the second is the change in the rotor injected voltage.



block diagram of GCIG with fault in grid side

Behavior immediately after the fault

In the fault instant, the voltage at the GCIG terminal drops and it leads to a corresponding decrease of the rotor and stator flux in the generator. This results is a reduction of the electromagnetic torque and active power. As the stator flux decreases, the magnetization that has been stored in the magnetic field has to be released or wasted.

During the fault, as the stator voltage decreases significantly, high current transients appear in the stator and rotor windings. In order to compensate in the increasing rotor current, the rotor converter increases the rotor voltage reference, which implies a “rush” of power from the rotor side terminals through the converter. On the other side, as the grid voltage has dropped immediately just after the fault, the grid side converter is not able to transfer the whole power from the rotor through the converter further to the grid. The grid side converters control of the dc-voltage reaches thus quickly its limitation. As a result, the additional energy goes into charging the dc-bus capacitor and the dc-voltage rises rapidly. During the fault, the rotor voltage and stator flux have been reduced, the injected rotor voltage has changed and the rotor speed has been increased. Immediately the fault is cleared and the stator voltage is restored to the previous value, and the demagnetized stator and rotor oppose this change in flux thus leading to an increase in the stator and rotor currents.

III. RESULTS AND DISCUSSION

The dynamic performance of the induction generator is shown respectively in figure during unbalanced condition at grid. Initially generator is operating at rated condition with a load torque to base torque. The unbalancing at the terminals is simulated by setting to zero at the instant passes through zero going positive. After few cycle the source voltage is again applied. Which are superimposed upon the transients of the rotor circuits.

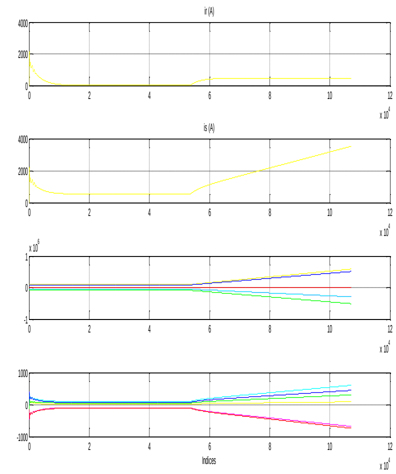


FIG. Current components and time

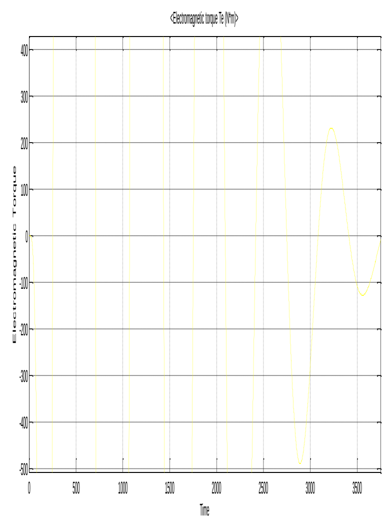


FIG. Electromagnetic torque - time characteristics

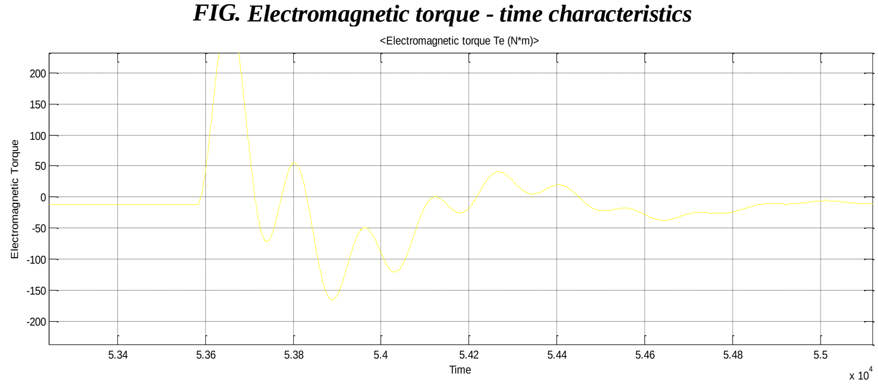


Fig.(b) torque – time

Similarly the transient offset in the rotor currents appears as decreasing to the rotor speed. In case of these machines, both rotor and stator transient are highly damped and subside before the unbalancing is removed and the voltages reapplied.

IV. CONCLUSION

This thesis presents a study of the dynamic performance of variable speed GCIG coupled with either wind turbine or a induction motor and the power system is subjected to disturbances; such as voltage dip, unbalanced operation or short circuit faults. The dynamic behavior of GCIG under power system disturbance was simulated both using MATLAB coding and SIMULINK platform using matrix /vector space control concept. Accurate transient simulations are required to analyse the influence of the wind power on the power system stability. The GCIG considered in this analysis is a wound rotor induction generator with slip rings. The stator is directly connected to the grid and the rotor is interface via a back to back partial scale power converter. Power converter are usually controlled using vector control techniques which allow the decoupled control of both active and reactive power flow to the grid. In the present investigation, the dynamic IG performance is presented for both normal and abnormal grid conditions. The control performance of IG is satisfactory in normal grid conditions and it is found that, both reactive and active power maintains a study pattern instead of fluctuating wind speed and net electrical power supplied to grid is maintained constant. During grid disturbance, considerable torque pulsation of IG and torsional oscillation in drive train system has been observed. In view of that, future scope aims to

- Develop a controller, which can effectively improve the dynamic stability, transient response of the system during faulty grid conditions.
- To develop a protection system for power converter and IG for large disturbances like 3- phase fault of little cycle duration as the power converter is very sensitive to grid disturbance.

REFERENCES

1. *Ned Mohan, Ted K. A. Brekken "Control of a Doubly Fed Induction Wind Generator Under Unbalanced Grid Voltage Conditions" IEEE Transaction Energy conversion, vol.no22. 1, march 2007 page 129-135.*
2. *Y. Zhou, P. Bauer "Control of DFIG under Unsymmetrical Voltage dips" Power Electronics Specialists Conference, 2007. PESC 2007. IEEE 17-21 June 2007 Page(s):933 – 938*
3. *A. Beugniez, T. Ghennam "Centralized supervision of reactive power generation for a wind farm" Power Electronics & Application European conference on 2-5 sep 2007. On page(s): 1-10 ISBN: 978-9275815-10-8*
4. *Jesus Lopez, Pabolo Sanchis "Control of DFIG under Symmetrical Voltage dips" IEEE july 2008. Page(s) 2456-2462.*
5. *Rubén Penaa, Roberto Cardenasb,∗, Enrique Escobarb, Jon Clarec, Pat Wheelerc "Control strategy for a Doubly-Fed Induction Generator feeding an unbalanced grid or stand-alone load" Electric Power Systems Research (2009) 355-364.vol.79*
6. *Johan Morren, Sjoerd W. H. de Haan, "Ridethrough of Wind Turbines with Doubly-Fed Induction Generator During a Voltage Dip" IEEE transaction on energy conversion june, 2005 pages 435-441 vol.20*
7. *Sae-Kok, W.,Grant, D.M. "Open Switch Fault Diagnosis for a Doubly-Fed Induction Generator" Power Electronics and Drive Systems, IEEE 2007. PEDS '07. 7th International Conference on 27-30 Nov. 2007 Page(s):131 – 138*
8. *L. Dusonchet, F. Massaro and E. Telaretti "Transient stability simulation of a fixed speed wind turbine by Matlab/Simulink"*
9. *Zhixin Miao, Lingling Fan "the art of modeling and simulation of induction generator in wind generation application" simulation modling practice and theory 16 (2008) 1239- 1253, science direct.*
10. *Ruben Pena , Roberto Cardenas , Jon Clare "Control strategy for a DFIG feeding unbalances grid or stand alone load" Electric Power System Research 79(2009) 355-364 science direct.*
11. *Wei Qiao; Harley, R.G "Improved Control of DFIG Wind Turbines for Operation with Unbalanced Network Voltages" Industry Applications Society Annual Meeting, 2008. IAS '08. IEEE 5-9 Oct. 2008 Page(s):1 – 2*

12. *Johan Morren , Sjoerd W. H. de Haan " Ride through of Wind Turbines with Doubly-Fed Induction Generator During a Voltage Dip" IEEE Transaction on energy conversion, VOL. 20, NO. 2, JUNE 2005.*