CONTRAST THE PERFORMANCE OF DOUBLY FED INDUCTION GENERATOR DURING SYMMETRICAL AND NON SYMMETRICAL FAULT CONDITION BY VARYING WIND SPEED

DISSERTATION-II

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Rajpal Singh (11616436)

Under the Guidance of
Parminder Singh
Assistant Professor, L.P.U

School of Electronics and Electrical Engineering
Lovely Professional University
Phagwara, Punjab

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CERTIFICATE

This is to certify that Rajpal Singh bearing Registration no. 11616436 have completed objective formulation/Base Paper implementation of the thesis titled, **“**Contrast the performance of Doubly Fed Induction Generator during symmetrical and non symmetrical fault condition by varying wind speed**”** under my guidance and supervision. To the best of my knowledge, the present work is the result of his original investigation and study. No part of thesis has ever been submitted for any other degree at any university.

Parminder Singh
Assistant Professor
School of Electronics and Electrical
Lovely Professional University
Phagwara, Punjab

Date:

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Rajpal Singh
Reg.No: 11616436

DECLARATION

I, Rajpal Singh, student of M. Tech under Department of Electronics and Communication of Lovely Professional University, Punjab, hereby declare that all the information furnished in this Dissertation-II report is based on my own intensive research and is genuine.

This report does not, to the best of our knowledge, contain part of my work which has been submitted for the award of my degree either of this University or any other University without proper citation.

Rajpal Singh

Reg.No.
11616436

ABSTRACT

An important aspect of WPP (wind power plant) studies is to evaluate the symmetrical and unsymmetrical fault characteristics of the plant into the transmission. This paper considers the behavior of unbalance condition, especially the short-circuit current, voltage fluctuation, torque pulsation and variable speed of wind turbines with a doubly fed induction generator. The short circuit characteristics are useful for designing system protection equipment. The task for protection engineers is challenging due to the topology differences between the conventional generating units and different types of wind turbine generators. In DFIG (doubly fed induction generator) rotor excitation control provided for adjusting speed and reactive power control. These rotor side control converters consist of IGBT thyristor. The crowbar protection is used to bypass the interconnection between grid and wind turbine. The converter control devices consist of thermal operating condition. To protect the power converter from thermal breakdown and continuous operation of grid control modeling has been designed. This is useful to get the required operation of rotor control unit without affecting the wind power generating system.

LIST OF ABBREVIATIONS

DFIG –	Doubly-fed induction generators
p.u. –	per unit
SC –	Short Circuit
WTGs –	Wind turbine generators
WPP –	Wind power plant
IGBTs –	Isolated Gate Bipolar Transistors
PWM –	Pulse width modulation
RSC –	Rotor side control
STFCL –	Switch type fault current limiter
LVRT -	Low voltage ride through

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CHAPTER 1

Introduction

In this modern era energy and environmental issues become the biggest challenge around the world. Concerning to energy needs and environmental issues, renewable energy technologies are considered as best to full fill the energy requirement for future purpose. Renewable sources are solar energy, wind energy, hydropower, geothermal energy, and biomass energy. Among all of the sources wind power generation has different application. In this about wind power generation technology, protection component design, its application, operation under unbalance condition and variable speed is discussed. Since wind power generation technology has received world-wide attention. The DFIG (Double Fed induction Generator) currently the best suited for multi-MW wind turbines. In wind turbine generation the generator side rotor must be able to operate at variable rotational speed to achieve optimum aerodynamic efficiency. This can be possible only by tracking the optimal tip-speed ratio. The DFIG system therefore operates in both sub-synchronous and super-synchronous modes with a rotor speed around the synchronous speed. The stator circuit is directly connected to the grid while the rotor winding is connected through slip-rings to three phase converter. For example ±30% of synchronous speed is bearable in variable speed system. The DFIG offers adequate performance for the speed range requirement to exploit typical wind resources. The calculation of symmetrical and unsymmetrical fault performance is very important for selection of relay and assigning the suitable equipment for protection of power system. As renewable energy sources are merging into the conventional system causing change in power system performance characterises. Significantly wind power sources and solar power sources are at upmost that are imparting into the conventional power system. The wind availability is on irregular bases. This Irregularity causes due to the mix energy i.e. along with wind energy there are several form of energy’s are available in air. The localisation of wind farm is possible only in rural areas; but rural grids are finding to be weak and unstable, and are easily prone to sag, fault and unbalance. In Induction wind generator, unbalance three-phase stator voltage causes a problems, such as over current, reactive power pulsation and stress on mechanical component from torque pulsation. Therefore, for some instant of time unbalance, induction wind generator is switched out of the network. Moreover the unbalance weakens the grid interconnectivity. The energy induced by the wind turbine of Type III generators i.e. double fed generator is the most common type of generators offering different behaviour compared to conventionally employ synchronous generators. In double fed induction generators, control of rotor currents allows for adjustable speed operation and reactive power control.

Problem statement

In the present scenario due to interconnection of wind power plant and power grid raises a new steady state stability challenges due to some power issues under unbalance condition such as voltage sags or faults which occur in the wind power generation plant. To limit such unbalance condition assigning the proper protection system for balanced operation of power system.

Objective

Doubly-fed induction generators (DFIG) are the machines that gaining attention for large wind turbines in wind power generation.

The objective is to develop a methodology for a DFIG that can achieve:

- The short-circuit protection
- Reducing the voltage sags duration to improve power quality.
- Observe the performance of double fed induction generator during balance and unbalance condition.
  - Variable speed and reactive power control
  - Compensation of problems caused by an unbalanced grid
  - Lower down reactive power pulsations
  - Balance stator currents

Scope of the study

The scope of this project is to study behaviour of symmetrical and unsymmetrical faults under variable wind speed. Under such unbalance condition to prevent the power system from transient condition and provide a rotor side control.

- The goal of short-circuit protection is to clear faults quickly to restrict explosions and fires, so that utility equipment such as transformers and cables can be prevented from further damage.
- Proper coordinating protective devices to isolate the smallest possible portion,
  - Reliability of the system can be achieved.

    - Fewer customers will affect.
- To protect the power converter from overheating and bypass it under such condition.
- Providing proper reactive control under variable speed operation.
- Rotor side converter protection.

Thesis outline

Chapter-2 deals with the literature review.

Chapter-3 deals with introduction of DFIG and converter control modelling.

Chapter-4 Proposed work plan with timeline.

Chapter-5 deals with results and summery.

CHAPTER 2

Literature Review

In [1] the DFIG during voltage dip under goes into unbalance to protect the converter and to limit the high current in the rotor a set of resistors provided in rotor winding to bypass the high current. With these resistors, wind turbine stay interconnected with the grid. This is reason generator and converter stay connected; the synchronism of operation remains established during and after the fault condition. In this way normal operation can be continued immediately after the fault has been cleared. An additional feature is that reactive power can supplied to the grid during long dips in order to facilitate voltage restoration. Without special controlling action, large transients would occur.

In [2] paper the short-circuit behaviour of wind turbines with a doubly fed induction generator is discussed. These wind turbines are protected by the crowbar protection which protects the rotor winding of induction generator. The differences between a conventional induction generator and a crowbar-protected doubly fed induction generator are highlighted and results obtained are found to be 15% less. If the rotor voltage is high the crowbar impedance is small which means the high short circuit current is supplied by the turbine to the grid. The value of maximum current decreases with increase in rated power.

In [5] the sc-current impact of different wind turbine generator at the terminal of the generator is explored. The largest sc-current is obtained for the three-phase fault. The time duration of the fault is the short because the flux air gap collapses without the support of sufficient voltages. Although the three phase fault is the least to occur, however, planners use this fault to calculate circuit breakers duty and design the other switch gear devices for protection. The SLG (single line to ground) is the most likely to occur in the power grid. Although a power converter is installed at the rotor side, the controllability of power converter is significantly compromised during a fault condition. The current carrying capability of power converter is bounded by power semiconductor used.

In [6] the instability of DFIG (doubly fed induction generators) during grid fault is major problem, but it directly affects the rotor speed. According to new grid code requirements, wind turbines remain interconnected to the grid even under grid disturbances. Also they must contribute to voltage support during and after grid faults. The crowbar protection system is a need to avoid the disconnection of the doubly fed induction wind generators from the network during faults. By inserting the crowbar in the rotor circuits for a short period of time provide a more efficient terminal voltage control. But the switching ON and OFF of the crowbar system is depends only on the DC-link voltage level of the back-to-back converters. The crowbar resistance value should be high enough to guarantee lower reactive power consumption for wind turbines connected even during faults; however the crowbar resistance is lower when the fault occurs close to the wind farm.

In [8] paper author attempts to illustrate the behaviour of short-circuit (SC) current contributions for different types of wind turbine generators (WTGs). In wind power plant (WPP) a large number of turbines interconnected by underground cable. Also all turbines in the plant are connected to the substation transformer, where the voltage is stepped up to transmission level. An important aspect of WPP study is to analyze short-circuits (SC) current contribution of the plant into the transmission network under different fault conditions. The effect of wind turbine types, the transformer configuration, and the reactive compensation capacitor will be considered. The voltage response at different buses will be observed. The SC line currents will be presented along with its symmetrical components. The power converter is limited by the current-carrying capability of the power semiconductor used. Thus, the SC current contribution of wind turbine is limited to 110% of rated current (assuming that the temporary overload current is designed to be 110% rated). The SC currents from the WTG can be kept balance by controlling the power converter.

In [10] DFIG control strategies are discussed that develop the standard speed and reactive power control. In induction wind generators, unbalanced three-phase stator voltages cause a number of problems, such as unbalanced currents, reactive power pulsations, and stress on the mechanical components. Their condition occurs, when a certain amount of unbalance causes switching out of wind generator from the network grid. Not only this weakens the grid system but also affect the overall system performance. In this analysis doubly fed induction generator (DFIG), is used to control the rotor currents. The controlling of rotor currents allows the controlling of reactive power and variable speed operation, so it can operate at maximum efficiency over a wide range of wind speeds. Also with controllers compensate is provided for the problems caused by an unbalanced grid. These approaches take in account balancing of the stator currents and eliminating torque and reactive power pulsations. This improves the quality of the power fed into the grid by reducing the wear on the mechanical components.

In [11] the short-circuit behaviour of a Wind Power Plant for different types of wind turbines are studied. In this both symmetrical and unsymmetrical faults are considered. As the importance of WPPs increases, planning engineers must look into to evaluate short-circuit current (SCC) contribution of the grid into the transmission network under different fault conditions. This information is useful while designing the size the circuit breakers, to set up the appropriate system protection, and to set up the transient suppressor in the circuits within the WPP. This task can be challenging to protection engineers due to the differences between different types of wind turbine generators (WTGs) and the conventional generating units. But any how in this paper type-I and type- IV wind generators are discussed and time domain simulations and steady-state calculations are used to perform the analysis.

In [12] this paper discuss about the sustainability of DFIG (Doubly-Fed Induction Generator) during the abnormal condition on grid. The SC (short-circuit) current involvement of DFIG received a much consent. For the selection of the suitable ratings of crowbar (chopper resistors) approximations are to be carried out. For simulation studies taking wind speed variations into account, or when the rotor shaft speed deviation becomes significant, the turbine's speed and its pitch control systems have to be considered. Wind turbines with a doubly fed induction generator have a crowbar to protect the power electronic converter that is connected to the rotor windings of the induction generator. DFIG Rotor side converter is very much sensitive to Grid Fault. A single line to ground fault at grid is taken for study. Voltage dip occurs on stator voltage and current rises instantaneously, with this rotor side current increased which will result in damage of rotor side converter. The necessary conditions for deciding the upper and lower limit of resistance should be high to limit the short-circuit current and should be low to avoid a too high voltage in the rotor circuit.

In [13] the behaviour of a wind energy conversion system that uses the structure of Doubly-Fed Induction Generator (DFIG) under faulty conditions is presented. Wind power stations much placed in remote areas; so they are characterized by weak grids and are often submitted to power system disturbance like faults. DFIG consists of an asynchronous machine, in which the stator is connected directly to the grid and its rotor, is connected to the grid via two electronic power converters (back-to-back converter). In the three-phase rectifier and the inverter with IGBTs the Pulse Width Modulation (PWM) and SPWM technique is respectively used. The behaviour of these machines during grid failure is an important issue to design a power controller to supply the deficit reactive power to the grid and help in grid recovery.

In [14] this section the behaviour of the wind farms during voltage sags presented using 2 different control strategies. Two main control strategies focused on the protection system and the RSC control including the estimation of the stator current compensation. The results have reflected that the strategies which the reference currents are calculated to compensate the stator flux variation during voltage sags can avoid over currents in the rotor windings, in some cases, without the use of a crowbar system. The connection of wind farms to the electrical power system has increased very fast in the last years requiring the ability of the wind turbines to assist network during voltage sags. Most of the modern wind turbines are based on doubly fed induction generator with a back-to-back power converter connecting the rotor windings to the grid. One limitation of doubly fed induction generator is the operation during grid faults. The rotor side converter can be damage by high currents induced by the stator windings. The presented results confirm that the operation of the RSC during voltage sags on the grid can reduce the high currents induced on the rotor and stator windings, preserving the converters, and also contributing to the power quality levels of the power system.

In [15] this paper studied the effects on wind farm operation of two protection strategies used in DFIG during severe voltage dips, the well-known crowbar system and the current compensation control strategy. Modern wind turbines operate with variable speed and most of them are based on doubly fed induction generators (DFIG), with a back-to-back power converter. During voltage dips, the stator terminals can cause over currents in the rotor windings, which could threaten the converter integrity. The use of crowbar systems is the most common technique to avoid this situation. The crowbar activation disables the control of the rotor side converter during a short period of time. Once the rotor side converter is blocked, the DFIG operates like a typical induction generator and thus consumes reactive power. In this paper, the performance of the well-known crowbar protection is compared with a current compensation strategy.

In [16] this paper, the influence of the notch filters on the proportional integral (PI) parameters is discussed and the simplified calculation models of the rotor current are established. The fault current characteristics of the DFIG are studied in this paper on condition that an unbalanced fault occurs and the rotor windings are excited by the AC/DC/AC converter. Under unbalanced fault conditions, the electrical variables oscillate at twice the grid frequency in the synchronous do frame. In the engineering practice, notch filters are usually used to extract the positive and negative sequence components. Based on this, the fault characteristics of the stator current under asymmetrical fault conditions are studied and the corresponding analytical expressions of the stator fault current are obtained. Finally, digital simulation results validate the analytical results. The research results are helpful to meet the requirements of a practical short-circuit calculation and the construction of a relaying protection system for the power grid with penetration of DFIGs.

In [17] this paper analyzes the behaviour of DFIG; for the conditions of 50% drop in the output voltage and nearly complete loss of voltage-100% drop in the output voltage under the symmetrical fault. The short circuit current calculation of any equipment in the power system is very important for selection of appropriate relay characteristics and circuit breaker for the protection of the system. The power system is undergoing changes because of large scale penetration of renewable energy sources in the conventional system. Major renewable sources which are included in the power system are wind energy and solar energy sources. The wind energy is supplied by wind turbine generators of various types. Type III generators i.e. Doubly Fed Induction Generator (DFIG) is the most common types of generator employed offering different behaviour compared to conventionally employed synchronous generators.

In [18] in this paper a control methodology for the smooth operation of DFIG wind turbine with unbalanced grid voltage is presented. In case of three phase unbalanced grid voltage conditions on wind generator, causes number of problems such as over current, unbalanced voltage, reactive power pulsations and tension on mechanical components. The advantage of using doubly fed induction generator (DFIG) is that it provides the rotor excitation control for adjustable speed and reactive power control. This paper introduces a control technique that enhances variable speed and also improves reactive power control operation by balancing the rotor current to achieve simultaneous regulation of the positive / negative sequence current of DFIG. From results it can conclude that compensating control technique greatly reduces the second harmonics and also improve the quality of power fed into the grid.

In [19] in this paper LVRT strategy for a wind turbine driven DFIG (doubly fed induction generator) with STFCL (switch type fault current limiter) is proposed. The increasing wind power generation has made the power systems more and more sensitive to various grid faults, which resulted in new grid codes. One of the most important grid codes is the low voltage ride through (LVRT), which requires the wind energy conversion systems to remain connected to the grid during voltage dips. Voltage dips mainly occur when large loads are connected to the grid or the results of grid faults like lightning strikes and short circuit events. LVRT issue in wind turbine driven DFIG leads to disconnection of wind turbine from grid. This is mainly due to power electronic converter which is sensitive to the low voltage problems. If voltage dip occurs at the grid side, it affects the generator causing the mismatch between the power being produced and delivered to the grid.

CHAPTER 3

3.1 Introduction to Doubly-Fed Induction Generator for Wind Power

This chapter introduces working operation and control of DFIG (Double-fed induction generator) system. Looking into the advantage DFIG is system of choice for multi-MW wind turbine system. Depending upon the size and generating capacity wind turbine are categorized. Basically large size turbines are divided into two types which determine the behaviour of wind turbine during variable wind speed: fixed speed wind turbine and variable speed wind turbines. Fixed speed wind turbine consists of three phase asynchronous generator this is because the generator output is directly connected to the grid i.e. local ac power network, the rotary speed of generator is fixed (in practice it can vary a little as slip allowed to vary over arrange typically 2% to 3%). To reach optimum aerodynamic efficiency the aerodynamic system must be capable of operating over a wide wind speed range this can be done by tracking the optimum tip-speed ratio. Therefore the Wind generator must be capable of operating in variable rotational speed conditions, by keeping the rotor speed approx to the synchronous speed. DFIG system operates both sub-synchronous mode and super-synchronous mode by doing so the rotor synchronism is maintained. Connectivity of stator circuit is with the grid and on the other end rotor winding is connected with the three phase power converter via slip-rings. Converter used in this is basically of arrangement back to back converter. Those are AC-DC-AC converter connected to the rotor side. Power electronic converter used has significance; they used to maintain power level and limiting the losses. Power converter need only be rated to handle fraction of power i.e. about 30% of the generated power. Comparatively to other devices losses in power electronic converter are less. The cost of the system is less this is because due to partially-rated power electronics. Moreover in this chapter will describe the basic features, normal operation of DFIG system, and power converter control along with model for wind power applications.

3.2 Steady State operation of Double –Fed Induction Generator (DFIG)

The DFIG is a machine in which both rotor and stator of machine are electrically connected with the sources hence the term 'doubly-fed'. A three-phase wound-rotor induction machine can be used as DFIG. The three phase rotor windings energised with three-phase currents and establish rotor magnetic field. Resultant of both rotor magnetic field and stator magnetic fields develop a torque. The obtained torque strength depends on the two fields (stator fields and rotor fields) and also the angular displacement between these two fields. In mathematically form the torque is vector product of stator and the rotor fields. The rotor magnetic field and stator magnetic field establish a pair of magnetic poles and torque is obtained by magnetic attraction of magnetic poles which are of opposite polarity. The stator winding of generator is connected to three-phase balanced source. By supplying balanced power stator would have constant magnitude and will rotate at synchronous speed. In this per-phase circuit of induction machine used to lay the foundation for discussing the torque control of the DFIG.

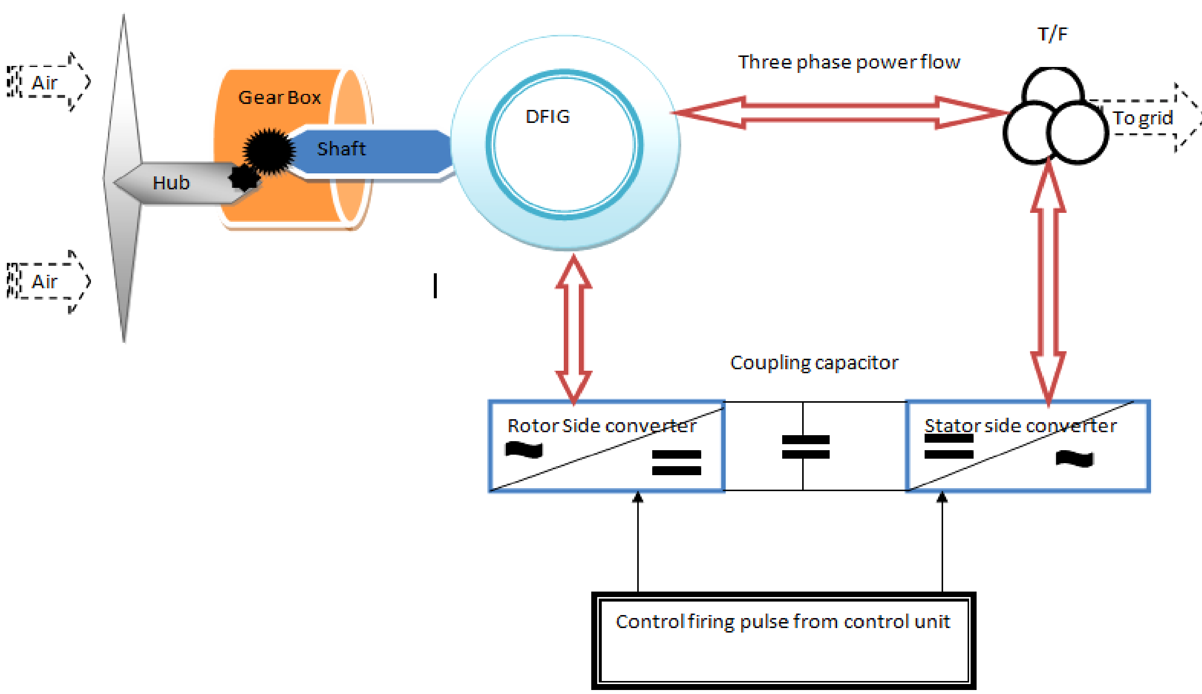

Fig. 3.1. DFIG with converter control

3.3 Rotor power converters

The back to back voltage source converters are used connecting DFIG to the grid. This section will detail the AC-DC-AC converter used on the rotor which consists of two voltage-sourced converters, i.e., rotor-side converter (RSC) and grid-side converter (GSC), which are connected "back-to-back." Between the two converters a dc-link capacitor is placed, as energy storage, in order to keep the voltage variations in the dc-link voltage small. The rotor-side converter make possible to control the torque or the speed of the DFIG. The RPC also help in improving the power factor at the stator terminals. While the main objective for the grid-side converter is to keep the dc-link voltage constant. On grid side converter works at the grid frequency (it can be leading or lagging so as to absorb or generate a reactive power control). Transformer can be inserted or can be utilised between the grid-side inverter and grid. The rotor-converter is designed in such a manner it can operate at various frequencies depending upon the turbine speed. Back-to-back converter arrangements have its own significance. They convert variable voltage, variable frequency output into a fixed voltage output on grid side. The DC link capacitance is work as energy storage bucket. It not only store the energy but also work as energy booster between generator and the grid.

3.4 The Rotor side converter (RSC)

The rotor winding of DFIG is supplied through the rotor side converter. The main purpose of providing rotor converter to rotor winding is to control the current input. By controlling current input to rotor, rotor flux is aligned optimally with respect to stator flux so that required torque is generated on shaft of machine. The RSC uses a torque controller to adjust the output wind power and at machine stator terminal reactive power or voltage is measured. The actual electrical output power from the generator terminals, added to the total power losses (mechanical and electrical) is compared with the reference power obtained from the wind turbine characteristic. Usually, a Proportional-Integral (PI) regulator is used at the outer control loop to reduce the power error (or rotor speed error) to zero. The output of this regulator is the reference rotor current that must be injected in the rotor winding by rotor-side converter. This q-axis component controls the electromagnetic torque. The actual component of rotor current is compared and the error is reduced to zero by a current PI regulator at the inner control loop. The output of this current controller is the voltage generated by the rotor-side converter.

3.5 The Grid-Side converter (GSC)

The GSC control is used to regulate the voltage across the DC link and sometime is used to compensate harmonics. Moreover, it is applicable to generate or absorb the reactive power for voltage support when needed. The functioning of GSC depends upon the two controlling loop factors i.e. outer controlling loops factor and inner current regulation. The outer regulation loop consists of dc voltage regulation. The obtained output of dc voltage regulator is reference current for current regulation. The inner current regulation loop consists of a regulator considering the magnitude and phase voltage generated by converter from current regulator which is further produced by the voltage regulator.

3.6 Converter losses

The converters used are basically electronic converter and are fractionally rated compare to power. The losses contributed by converter are mainly switching and conducting losses. In switching losses i.e. turning-on and turning-off losses of the transistors are considered. But in case of diode only switching-off losses are applicable, i.e. reverse recovery energy. The turn-on and turn-off losses for transistor and reverse recovery energy losses for diode can be founded. And the conducting losses imparted due to the increase in current through transistor and diode. Here transistor and diode behave as voltage drop, and along with a resistor in a series. The switching losses are defined to be directly proportional to that of current for a given dc-link voltage. In case of dc-link voltage and switching frequency, the switching losses of the IGBT and diode can be modelled as constant voltage drop which are independent of the current rating of the IGBT valves. The dc-link circuitry model describes the capacitance voltage changes as a function of the input power source in dc-link. The stored energy in capacitor is as follow:

$$W_{dc} = \int P_{dc} dt = \frac{1}{2} C V_{dc}^2$$

Where capacitance is represented by C, V_{dc}^2 is the voltage W_{dc} termed as stored energy, and P_{dc} input power to the dc-link. So the voltage and energy derivatives represented as

$$\frac{dV_{dc}}{dt} = \frac{P_{dc}}{CV_{dc}}$$

$P_{dc}$is results as P_{dc}= P_{in}– P_c. Where P_{in} represents the input power obtained from rotor side converter and P_c is output power in grid side converter. Variation in the dc-link are defined by term P_{dc} and constant when P_{dc}= 0.

3.7 Basic technique for controlling Real and Reactive Power with use of RSC

The real and reactive power flow is controlled by the grid side converter. The GSC partly controls the power from turbine system to the grid. Power is fed through GSC via a set of interfacing inductors. In previous as discussed that GSC can generate a balanced set of three-phase voltage at the generated frequency and the voltage, E can be have the controllable phase and magnitude. The real and reactive power control is defined by load angle control technique. Although there are many alternative controls available provide superior transient response but usually basic technique is used to control i.e. load angle control. The operational characteristics of synchronous generator connected to the network are copied by load angle control. In load angle control method the term load angle is defined as the value of angle inserted to control the reactive power, angle is obtained between voltage generated by grid side converter 'E' and the grid voltage 'V' . Load angle is denoted byδ.

$$P = \frac{VE \sin \delta}{X_s}$$

$$Q = \frac{V^2}{X_s} - \frac{VE}{X_s} \cos \delta$$

Where reactance of interfacing inductance is represented by X_s

For small value of the δ equation can be

$$P = \frac{VE\delta}{X_s}$$

$$Q = \frac{V^2}{X_s} - \frac{VE}{X_s}$$

From above it is clear that δ can be used as to control the, P, and similarly E can be used to control the Q.

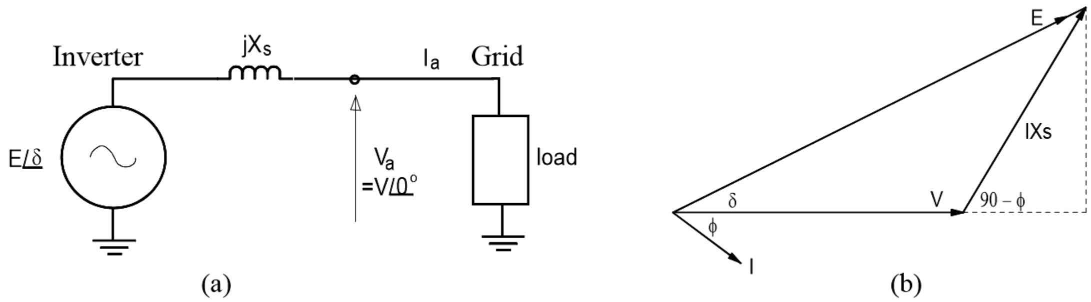

Fig. 3.2 (a) Single line diagram of steady state generator-side converter connected to grid and (b) phasor diagram representing load angle control of grid side converter.

Consider at any instant, the power is supplied by GSC depends on the state of dc-link voltage. DC-link voltage is monitored by the grid side converter controller. In case the DC-link voltage rises, thus by increasing the load angle, more real power can be exported and results in balancing the dc-link voltage. If power continuously keeps on rising supplied by RSC and exported by GSC dc-link will fall below its nominal value. In such situation grid side controller will then reduce exported real power to allow dc-link voltage profile to recover to its nominal value. Basically dc-link voltage indicates power flow in balance, between generated energy and the exported energy in rotor side converter. In case the mismatch of input and output power is seen among the dc-link capacitor which leads to the change in dc-link voltage and whole operation get interrupted. So keeping all the conditions and grid code compliance energy supplied must have a good quality so that it meet basic requirement to connected network. The grid code includes many conditions and performance indicators that are energy quality supplied by the grid side converter, fault levels, anti-islanding, and disconnection and there are many more issues. So the relevant grid code in operation must be defined prior to work on the wind turbine power electronic and control. The grid code has importance to have a control system and operation of turbine system. There are many conditions that occurred and create situations what to do if turbine losses its main connection, so it could be due to any reason may be fault or any other. Without this main connection energy transmission is not possible. In wind turbine if generator side controller keeps on generating power then the dc-link capacitance will be overcharged. In such condition it required that grid fault stop the generator to generating energy, then no more restraining torque is will be required to control the blade speed. In such wind turbine, loss of supply will cause an over speed condition, as the blade system will accelerate due to the aerodynamic torque produced by the blades. To avoid such condition shorting resistors or crowbar circuit, are mainly putted across the rotor circuit of generator. This is so because energy generated by the blade system can be absorbed. Also over-speed condition can be controlled up to a safe and manageable level. Adding more to it there are sometime aerodynamic and mechanical braking mechanism inserted to wind turbine. Aerodynamic braking system is a pitch control based. The mechanical braking system is used as an additional over speed safety measure.

3.8 Control system

In this section two control techniques are discussed vector control and decoupled control technique is used. Nomenclature used for the abbreviations is as follow

v_f, i_f, φ_f	Voltage, Current, and flux vector
R_s, R_r	Stator and rotor winding resistors
L_s, L_r, L_{ls}, L_{lr}	Stator, rotor winding self-inductance and leakage-inductance
L_m	Magnetizing inductance
ω_s, ω_r, ω	Slip synchronous, rotor and slip angular frequencies
P, Q	Active and reactive power
s, r	Stator and rotor subscripts
g	Grid side vale subscripts
c	Converter value subscripts
d, q	d-axis and q-axis component subscripts
n	nominal value subscripts
ref	reference value superscripts

In DFIG control technique, vector control technique is used. Vector control provide a way that torque and rotor excitation can be independently handled or controlled. Active and reactive power supplied to the grid is controlled by the decoupled control. Vector control of generator along with optimal tracking controller is advantages for having a maximum power in wind power application. Speed control of generator is depends on the converter control. By controlling the active power the rotational speed of generator and speed of rotor of the turbine can be controlled. Further this can be used to obtain an optimal tip-speed ratio as there is variation in wind speed thereby selecting a maximum power from the incident wind. Controls on grid side converter have the future for optimising the grid integration with contrast to steady state operation conditions. Also Grid side control proves a potential to improve the power quality and voltage stability.

3.9 Rotor side Converter control

In DFIG excitation to induction machine's rotor is provided by the RSC i.e. rotor side converter. Torque is controlled with the help of PWM converter and thus speed of DFIG is controlled. Also PWM converter provides a power factor at stator terminals. The rotor-side converter capable of providing variable excitation frequency which directly dependent on speed of the wind turbine. Induction machine is controlled by dq-axis frame. Synchronously rotating dq-axis frame is used to control the induction machine, where d-axis along the stator flux vector positioned in common implementation. This is called stator flux orientation vector control (SFO). Decoupled control between electrical torque and rotor excitation current is obtained. The active and reactive power controls are independent of each other. There are exceptional other options for the directional rotating frames. In traditional vector control of induction machine orientation frames i.e. rotor flux and magnetizing flux can be utilized. So the stator voltage orientation is also commonly used in DFIG vector control. The detailed control scheme, the general park's model of induction machine is introduced. Motor convention in a static stator orientated reference frame; without saturation, voltage equation can be expressed as

$$\overrightarrow{v_s} = R_s\overrightarrow{\iota_s} + \frac{d\overrightarrow{\varphi_s}}{dt}$$

$$\overrightarrow{v_r} = R_r\overrightarrow{\iota_r} + \frac{d\vec{\varphi}_r}{dt} - j\omega\overrightarrow{\varphi_r}$$

Where $\overrightarrow{v_s}$ is the stator voltage imposed by the grid. The rotor voltage $\overrightarrow{v_r}$ is controlled by the rotor-side converter and used to perform generator control. The flux vector equations are

$$\overrightarrow{\varphi_s} = L_s\overrightarrow{\iota_s} + L_m\overrightarrow{\iota_r}$$

$$\overrightarrow{\varphi_r} = L_m\overrightarrow{\iota_s} + L_r\overrightarrow{\iota_r}$$

Where L_s and L_r are the stator and rotor self-inductances:$L_s = L_m + L_{1s}, L_r = L_m + L_{1r}$ under stator-flux orientation (SFO), in dq-axis component form, the stator flux equations are:

$$\begin{cases} \varphi_{sd} = L_s i_{sd} + L_m i_{rd} = \varphi_s = L_m i_{ms} \\ s_q = 0 \end{cases}$$

Defining leakage factor

$$\sigma = 1 - \frac{L_m^2}{L_s L_r}$$

and equivalent inductance as

$$L_0 = \frac{L_m^2}{L_s}$$

The rotor voltage and flux equations are (scaled to be numerically equal to the ac per-phase values):

$$\begin{cases} v_{rd} = R_r i_{rd} + \sigma L_r \frac{di_{rd}}{dt} - \omega_{slip} \sigma L_r i_{rq} \\ v_{rq} = R_r i_{rq} + \sigma L_r \frac{di_{rq}}{dt} - \omega_{slip} (L_o i_{ms} - \sigma L_r i_{rd}) \end{cases}$$

$$\begin{cases} \varphi_{rd} = \frac{L_m^2}{L_s} i_{ms} + \sigma L_r i_{rd} \\ \varphi_{rq} = \sigma L_r i_{rq} \end{cases}$$

Where the slip angular speed is$\omega_{slip} = \omega_s - \omega_r$.

The stator flux angle is calculated from

$$\begin{cases} \varphi_{s\alpha} = \int (v_{s\alpha} - R_s i_{s\alpha}) dt \\ \varphi_{s\beta} = \int (v_{s\beta} - R_s i_{s\beta}) dt \end{cases} , \theta_s = \tan^{-1} \left(\frac{\varphi_{s\beta}}{\varphi_{s\alpha}} \right)$$

Where θ_s represents stator flux vector position. The rotor side converter control scheme is provided in a generic way along with two series of two PI-controllers. Reference q-axis rotor current i_{rq}* can be calculated with two way i.e. outer speed control loop or from a reference torque control for the generator, instead of regulating the active power directly. In speed control mode, speed error signal is measured by one outer PI-controller. This error signal is obtained in terms of maximum power tracking point. Another PI-controller is helpful to produce reference signal of d-axis rotor current component to have a control on reactive power needed from the generator. Considering all reactive power to the machine is supplied by the stator, reference value is represented i_{rd}* may be set to the zero value. The switching characteristics of IGBT switches of the rotor side converter can be neglected and it is assured to rotor converter is able to allow demand value at any time. The control system requires the measurement of both stator and rotor currents, also stator voltage and mechanical rotor position. The natural computational converters are used for implementation in machine hence there is no requirement to know the rotor induced EMF. The stator is connected to the grid, as the affect of stator resistance is small stator magnetising current i_{ms} is considered to be constant. Rotor excitation current control is realised by controlling rotor voltage. The i_{rd} and i_{rq} error signals are processed by associated PI controllers to give v_{rd} and v_{rq}, respectively.

From the rotor voltage equations define

$$\begin{cases} v'_{rd} = R_r i_{rd} + \sigma L_r \dfrac{di_{rd}}{dt} \\ v'_{rq} = R_r i_{rq} + \sigma L_r \dfrac{di_{rq}}{dt} \end{cases}$$

To ensure good tracking of the rotor dq-axis currents, compensation terms are added to v′rd and v′rq to obtain the reference voltages vrd* and vrq* according to

$$\begin{cases} v^*_{rd} = v'_{rd} - \omega_{slip}\sigma L_r i_{rq} \\ v^*_{rq} = v'_{rq} - \omega_{slip}(L_m i_{ms} - \sigma L_r i_{rd}) \end{cases}$$

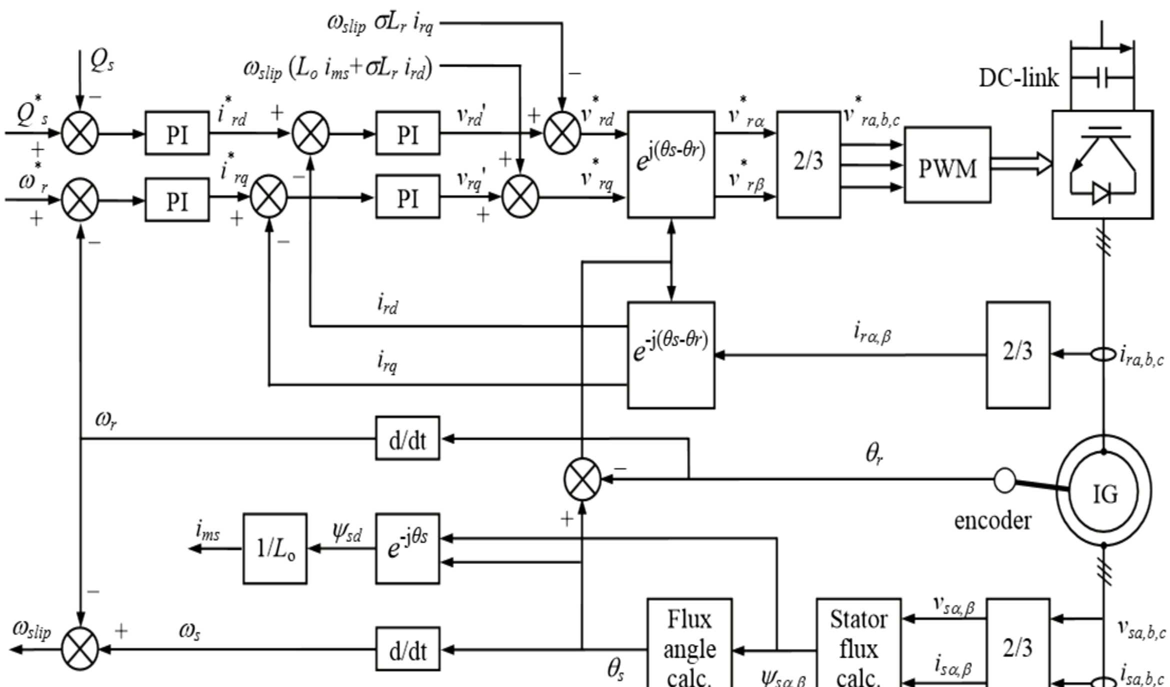

Fig.3.3 vector control diagram for rotor side converter.

The electromagnetic torque is

$$T_e = -\frac{3}{2} p Im\{\overrightarrow{\varphi_s}\overrightarrow{i_r^*}\} = -\frac{3}{2} p L_0 i_{ms} i_{rq}$$

Above equation can be applicable for stator voltage oriented control. For stator flux orientation, stator flux represented as $i_{ms}$is which is nearly equal to the stator voltage. Since it is difficult to measure the torque, but for torque mode controls it is preferred to have a open loop. The torque characteristics can be controlled by the q-axis component of the rotor currenti_{rq}.

3.10 Converter protection system

The DFIG is fed from the Converters. So it is important to ensure the proper protection of DFIG along with the converter protection. Currently crow-bar protection system is used for converter. In crow-bar system consist of series of resistances that are connected with the rotor winding in a parallel when there is any occurrence of an interruption. The function of crowbar is to bypass the rotor side converter. The active crowbar control system connects crowbar resistances when there is necessity and also disables it to resume the DFIG control. During low grid-voltage condition dc-link capacitor overcharging power drops. To overcome this braking resistors are used in parallel with the dc-link capacitor. These also protect the IGBTs from the overvoltage and can be used to dissipate energy, but this has no effect on the rotor current.

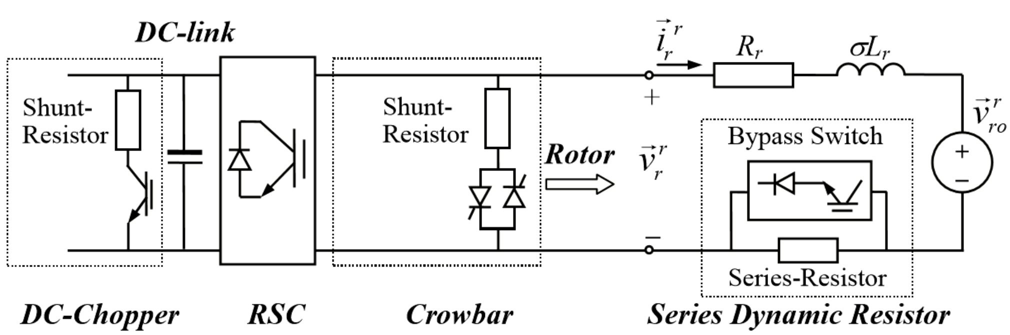

Fig. 3.4. Rotor equivalent circuit of DFIG with protection scheme

The crowbar protection system is used to have a protection of rotor side converter. Modern used crowbar system consists of three-phase series resistance which is controlled by the power electronics. When there is over-current on the rotor winding or over-voltage on the dc-link the crowbar protection is activated. There are some steps that are involved in the activation and deactivation of the protection system along with the circuit breaker:

- Disconnection of rotor windings from the RSC

- Introduction of three-phase resistances in series with the rotor winding
- Disconnection of crowbar from the rotor windings
- Resume of rotor side converter to rotor winding

If the voltage at the DC link or/and the current at the rotor windings are at a normal levels, the operation returns to its normal, however, if not, the activation of the crowbar system can be restarted (the second activation is undesirable). Considering more restrictive grid codes, the use of DC-Chopper system in the DC-link is also recommended to avoid the reinsertion of the crowbar system to enable the reestablishment of the terminal voltage control by the RSC

CHAPTER 4

Proposed Work Plan with Timelines

TIME / WORK	DISSERTATION-I	DISSERTATION-II	DISSERTATION-III
LITERATURE SURVEY	→		
MODELLING		→	→
METHODOLOGY		→	→
RESULT			→

CHAPTER 5

Summary

The DFIG system currently gained the attention in the field of wind power generation system. Since past 15 years academic as well industrial application has gain more attention in DFIG wind power system. Considering practical application of DFIG system has a technology for variable-speed wind energy production. In this thesis, the unbalance condition and symmetrical and unsymmetrical fault condition, characteristics under variable speed with practical applications and problems are summarised. With rotor side converter protection grid side performance can be improved. Although the new techniques give improved outcomes industry wise as well academic and this is the competitive option in terms of technical performance.

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