MODELLING AND CONTROL OF WIND-DRIVEN DFIG

A DISSERTATION

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STUDENT'S DECLARATION

I,Ruchika, 2K19/PSY/16, student of M.Tech, Power System, hereby declare that the project Dissertation titled "**Modelling and Control of Wind Driven DFIG"**which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of master of Technology is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

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SUPERVISOR CERTIFICATE

I hereby certify that the Project Dissertation titled**"Modeling and Control of Wind-driven DFIG",**which is submitted by **Ms. Ruchika**, Roll No.2K19/PSY/16,Department of Electrical Engineering, in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the students under my supervision.

To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Mr. Himanshu Singh
(Assistant Professor) Place:Delhi

Supervisor Date:03.05.2023

Department of Electrical Engineering

Delhi Technological University

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I am overwhelmed to expound my appreciation to everyone who backed me swirling these concepts, which are far more complex than they appear to be at first glance into something substantial.

To Mr. Himanshu Singh,Assistant Professor,“Department of Electrical Engineering, Delhi Technological University”, New Delhi, I would care to raise my unfeigned gratefulness for bestowing me thechance to invoke on the project titled “**Modelling and Control of Wind-driven DFIG”**and for counseling me throughout it with his steadfast assistance and support. Without their great advice, the project would not have been finished.As well as their willingness to respond to my questions about the work, I genuinely appreciate their encouragement throughout this time. Throughout the entire time, they served as a source of inspiration for me and assisted me in conducting extensive research, which allowed me to learn a great deal of brand-new information.

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No rung of exertion can be framed without the support and guidance of parents and friends. I would want to thank my parents for their underpinning and aid at bustling moments during this piece operation, backing me to gather a tract of facts, prepping papers, and mentoring me from moment to moment.

Ruchika

Date: 01.05.23 **(RUCHIKA)**

ABSTRACT

Wind energy stands out among other renewable coffers or energy sources (RESs), analogousto solar, wave, and geothermal energy due to its highest level of safety and low cost among all other types of renewable resources. There were no precise guidelines demonstrated to concatenate the wind dynamic networks to the grid or any other load in the early eras when sharing wind energy with the grids was relatively low and inconsequential. It was then advised to disconnect the wind turbine from the grid and any other connected power electronic converters in the event of any sudden abrupt disturbance or speed change in the system. However, DFIG is presently often times employed in wind turbines because it is protean and adaptive to the sudden or abrupt wind.

DFIG model is modeled in the dissertation, which includes a thorough examination of modeling, analysis, and control at operating speeds below, equal to, and above synchronous speed. Stator equations are expounded through a reference framework run by the stator flux, while the rotor equations are in a synchronously rotating reference frame. Wind turbine miniatures are also made with indirect maximum power extraction control.

Furthermore, the regulator of the GSC and RSC is set up so that the Network side converter Keeps up an unfaltering DC connect voltage and the RSC converter directs control.

The d axis the rotor current maintains the reactive power demand of the DFIG, while q-axis rotor current fulfill the reactive power demand. Similarly, the d-axis grid current maintains constant dc link voltage for wide variation of wind speed. The rotor-side and grid-side transducers are modeled separately to avoid erroneous results. The grid and rotor-side results from the rotor and stator circuits are shown to examine the energy exchange between the generator and the system during three (super synchronous, synchronous, and sub-synchronous) modes of operation.

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LIST OF ABBREVIATIONS

DFIG	Doubly-fed induction generator
A/D	AnalogtoDigital
GSC	grid side converter
RSC	rotor side converter
O/C	Overcurrent
ICT	In circuit Testing
WECS	wind energy conversion system
OTC	Optimum Torque Control
MPPT	maximum power point tracking
RMS	RootMeanSquare
VSCF	variable speed constant frequency
WT	wind turbine

CHAPTER- 1

INTRODUCTION

1.1 General:

The most affordable renewable energy source is wind energy. The generation of wind power has been inconsistent since it depends on the weather, despite the fact that it is a rapidly evolving renewable energy source in the current era. To acquire a consistent output from a wind system, energy storage is necessary. The world's emerging nations are reportedly concentrating on the application of renewable energy sources, apparently wind energy. The wind-driven DFIG is now a well-comprehended turbine system that is retained for inshore wind farms because of itshigh grounds.[1]- [2].

The DFIG is a generator that inducts current through a wound rotor while harnessingsequent converters between AC grids as well as rotor windings. The stator incontinentlyinputs power into the grid. The ensuing study proposes energy management and control of a DFIG, SC storage for hybrid energy, together with familial AC load that is compounded to the utility grid and exercised as a tailback source.

The measured model is inclusive of all of the system components. For the coordination of the flows of power among various sources of energy and load demand, there has been designing for the system of a strategy for the management of power. The usage of MATLAB/Simulink is done for the verification of system performance under different scenarios to carry out the studies of simulation.

The converter of AC/DC/AC which is bidirectional,commands a dc wurst voltage source which is quotidian and is to be conjugated to a rotor circuit. The RSC, DC-link, and GSC, the three unmediated parts, engender together to deliver sequential converters. Also, a DC-link provides disjointing between two AC flanks with nonidentical frequencies.

A GSC vector control scheme offers self-sustained control of the slip active, for uploading the voltage of the DC-link unceasing, as well as for authenticating sinusoidal supply currents. Reactive power has been superseded between the grid and GSC.

1.2 Evolution of DFIG:

According to its effectiveness in the power sector, the DFIG isa widely used wind turbine. In DFIG, the rotor circuit is controlled by a parallel inverter connected to the stator, which also draws additional power from the rotor under certain operating conditions. The revolving field synchronous speed produced by the rotor controls results in an output line frequency that can be either 50Hz or 60Hz. The control operates in such a thruway that the magnetic tractof the rotor transforms into synchronous speed when wind speed is tropical, resulting in a sub-synchronous working speed. A second rotating field exists in the rotor when the mechanical speed is sub-synchronous, and a negative rotating field exists when the mechanical speed is super-synchronous.

Gurney Flap Induction Generator (GF IG) wind turbines are another denotation for DFIG wind turbine controls. One rotor of an induction generator is hitched tothe grid from an AC/DC/AC conductor, while the statoris directly yoked tothe grid. Two voltage source converters fabricate this converter system. For DFIG systems, the rotor drive is to solelycontendactive and reactive power to rack up VAR correction. The converter used in the DFIG has two sides:Rotor and Grid Side Converter

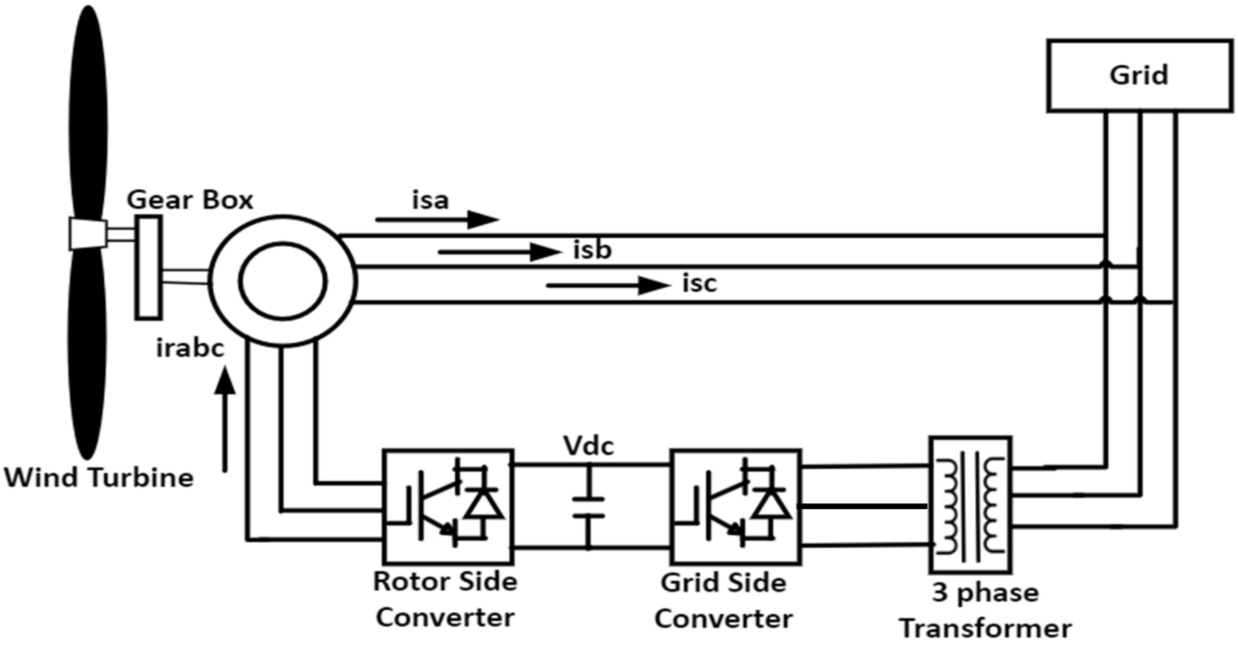

Fig1.1 Block Diagram representation of wind-driven DFIG

Signals from RSC and GSC are consigned to the voltage and flux reference frames, aggregately. A two-level controller manages both converters. The converter ac voltage authority is generated by the blistering inner current control, whereas the reference dq-frame currents are computed by slow outer control. The DFIG's active power affair and positive sequence terminal voltage arebridled by the RSC.

Because it can operate at various speeds, can control reactive power, and has lower converter ratings, DFIG has grown in popularity for wind power applications. Wind turbines typically have fixed turning speeds, however thanks to DFIG, they may operate at a range of speeds.

1.3 Wind Energy Conversion System(WECS):

Wind turbines catenated to double feed induction generators are the maiden choice for the wind farm to their unique advantages similar as speed control, demoted noise and stress, and coherent power and performance.

In WECS, a wind turbine's rotorordinarily has three blades. These blades are hookedwiththe rotor of the 3-phase wound rotor induction generator withthe gearbox to permit the phase difference between the two rotors. Approaching at a disparate speed indicates a difference in speed. Thus, the frequency contrast must be connected to the frequency circuit with a power transformer. The 3-phase stator windings are also catenated to the machine voltage of consequential back-to-back converters, or AC/DC/AC converters, RSC ("Rotor Side Converter") andGSC ("Grid Side Converter").

The capacitor acts as a steady source of DC voltage and is also used to connect the DC sides of GSC &RSC. The converter is also linked to the grid using the inductor line. This phenomenon, which is based on aerodynamic theory, occurs when the wind that is caught by wind turbine blades is turned into mechanical power.

The generator receives the mechanical power being eyed directly, transforms it into electrical power, and also sends the same towards the grid. There are two realizabledrags for the power inflow from the generator towards the grid: one goes directly via the "stator windings", and the other goes through the rotor windings and converter. The Synchronous,Sub-Synchronous, as well as Super-Synchronous modes of assignment all affect the behest of the flow of power. Power is aligned from a grid to the rotor windings via a converter during sub-synchronous operation. On the disparatefacet, in a super-synchronous mode of operation, the grid receives electricity from the rotor winding.

1.4 Power flow in wind-driven DFIG

It appears that to decompose the flow of power in the DFIG, the power supply from the stator & rotor side circuits to the DFIG must be decomposed or terminated. During pauses in operation, DFIG can run in two distinct modes, sub as well as super-synchronous, and kick in if the rotor speed is more or less synchronous. The three main sources of energy flow in the rotor are as follows:

1) electromagnetic energy passing through the air gap in the stator &rotor; This power is also understood as air gap power and is generally denoted by the letter Ps.

2) Pm is the prosaic abridgment for the mechanical power that is deeded between the stator and the rotor.

3) Rotor slip rings allow the rotor and load to exchange slip power (sometimes abbreviated as Pr).

The three rotor segments shown above can operate in sub and super-synchronous modes.

CHAPTER-2

LITERATUREREVIEW

2.1 INTRODUCTION

Multitudinous studies and pieces of work on DFIG systems utilized for converting wind energy are included in this Chapter. Review work is completed for many pivotal areas, including the DFIG in wind turbines andthe inflow of power during the various operation modes, including Synchronous, Sub-Synchronous& Super-Synchronous.

2.2 LITERATURE SURVEY

The model's power converters control the amount and direction of power flowing through the machine or system. The converter feeds electricity from the grid side to the rotor in the thesub-synchronous phase, and the rotor feeds energy to the grid side during the super synchronous phase. I used the programmers MATLAB SIMULINK and Microsoft Visio to produce my project, "Modeling and Control of wind-driven DFIG."

2.2.1Electrical Machines for WECS

In "Impact of increased penetration of DFIG-based wind turbine generators on transient and small signal stability of power systems," T. Harbor, and v vittal (2009) IEEE transcriptions of power system, volume. 24, number 3, pp. 1434–1440. In the study, the effects of installing more dfig-based “wind turbines” on the stability (transient as well as small signal) of large power systems are investigated. The results show that the adopted technique accurately pinpoints the benefits of greater DFIG penetration for small and transient stability in power systems.

Wind turbine modelingfor the grid linkingwith a doubly-fed induction generator, IEEE Transactions on Energy Conversion, vol. 21, no. 1, pp. 257-264, Y. Lei, A. Mullen, G. Light body, and R. Yacamini, 2006.

M-Gossa,M.Jemli,M.b.Mohamed and K.Jemli, “ DFIG in this turbine of the wind, in the modeling and the control for the power flow" in ICIT. For this work, the DFIG system for the conversion of wind energy has been studied. Firstly, d-q induction machine model of the wound rotor along with the reference frame of the rotor, further, the way for its implementation in the Simulink to simulate it fast. For controlling power flow among the stator of grid and dfigwhich is the rule of control synthesized with the use of PI controllers.

Wei Qiao along with LiyanQu[5] advised an idea for the storage of the SC energy is parallel linked with the dcdfiglink viaa converter of the dc to dc. The management of this process has been coupled in a way that storage of the energy supplies the power at the sub-simultaneous speed and it charges during the super-simultaneous speeds.

Almoataz Y. Abdelaziz, Ahmed M. Asim, Amr M. Ibrahim and Ahmed H. The article "Dynamic behavior of a DFIG based on a wind turbine during symmetrical voltage dips" published by Abdel Razek in EEE: An International Journal (ELELIJ) Volume 2, Number 2, May 2013, imposes various tests on TSOs. To build wind power, new grid requirements are necessary. These condition states that wind farmsteads must subsidize the power grid's control system, just like customary power plants, and concentrate on how the wind ranch behaves in the event of a grid disrangement. Due to the LVRT requirement, the isolation of the wind turbines during voltage drops is outlawed. In this research, the robustcomportment of a dfig-based on a wind turbine for 3-phase voltage dips, with or without the application of a crowbar ammunition device, is explored. The topic is supported by simulation results.

The 4th Conference ofEnergy, Power Engineering, and Electrical Drives provided a management study of the control and energy of a DFIG with hybrid energy storage of the SC, and a residential load of AC, connected with the utility grid and frequently used as a backup source. Bouharchouche1, E.M.Berkouk2, T. Ghennam1, and B. Tabbache1 presented their findings. Being complete for all aspects of the system, the scientific model. For system-coordinated power sequence between various energy sources and load demand, a general power management technique has been developed. For the purpose of evaluating the system's performance in various circumstances, simulation experiments have been conducted using MATLAB/Simulink.

Meera.g.s.n.a. Divya Scholar's paper "The Converter for the Control of the Rotor Side of the DFIG" is predicated on a wind energy transfiguration system presented in the International

Journal of Engineering Research and Technology (IJERT). In the latest ten epochs, the world's wind energy cubage has been increasing and it is the whirlwind growing renewable power technology. However,an imbalance in the energy generated via wind is influencing the energy changeover, and the knot can be solved only by applying wind turbines with malleable speed. In monthlies, the WECS-based DFIG is esteemed. Vigorous modeling of wind-driven dfig is feigned in MATLAB/Simulink, and the corollaries are sampled for a range of wind speeds. Management of active as well as reactive power generated with the legup of DFIG For the stator, a flux-acquainted stator vector control process is utilized in the rotor side converter.Comparison between power active with and without MPPT is tested in MATLAB/Simulink. The OTC MPPT approach helps orderthe optimal power of a track from a wind turbine.

Xunwei Yu and ZhenhuaJiang[6] advised an alike scheme except that the SC has been exchanged by a system of storage of the battery energy. The main aim of the system for the battery conversion is for having a regular DC link voltage so that the undulation of the voltage of the capacitor remains low. Also, a converter of the side stator could be taken into use for ordering the constant amount of real &reactive power for the grid.

AktarujjamanLedwich, Negnevitsky, Muttaqi, and Haque [7] gave an alike scheme with the system of storage of the battery energy but the fundamental aim of this system of storageis for maintaining a conversion that is smooth from anoperation mode, to the other.

It was suggested by Haihua Liu, Tongkuang Liu, Feng Zhao, Guanghe Li, Hongzhong Ma, and Lin Chen [8] that the fuel cell might be linked directly in resemblant to the DC-wurst capacitor. also, to contend the true and reactive power separately, the RSC and GSC were utilized.

Marinelli, Silvestro, and Morini [9] provided an idea for the integration of the DFIG and a system of energy storage for Lithium Ion. But they haven’t done any such integration of both to improve the general presentation.

Abolhassani, Enjeti, Toliyat, and Niazi, [10] were the first to propose a scheme to use the DFIG turbine generator of wind for the compensation of harmonics on a grid system of power. They advised using RSC of DFIG for compensation of harmonicand the real and the reactive supply of powervia the stator,[7].

remblay, Lagace and Chandra [11] use GSC for the injection of harmonics needed using the non-linear load. The injecting harmonics control through GSC includes the low pass filter for the removal of the principle features from the current of the grid and to order all of the harmonics needed by the nonlinear load.

2.2.2 Control of DFIG for WECS

Gaillard, Saadate, and Poure [12] gave the idea alike the preceding literature, except that there is a filter for tuning by itself, for extraction of the principle feature from grid currents, and for the injection of the harmonics to use RSC.

Yang, B., et al. (2016) explained nonlinear max power point trailing management and model decomposition of a dfig-based wind turbine in the Journal of “Electrical Power and Energy Systems” International. A wind turbine on the basis of a doubly-fed induction generator exhibits significant non-linearity resulting from the coupling of the dynamics of the dfig with the aerodynamics of the wind turbine and therefore has a wide and time-varying operating range. They probe a feedback linearization regulator grounded on the complex dfig wind turbine model; The system’s control goalis to maximize energy conversion.

M-Gossa, K.Jemli, "DFIG in the turbine of wind, modelling, and control of the flow of the power", presented DFIG for the conversion system of wind energy has been examined and published in IEEE International Conference on Industrial Technology. In disposal to possess faster simulations, it is first obligatory to builda d-q model of the machine of induction of the rotor for the wound in the frame forthe rotor. PI controllers are used to synthesize the enactment and control, which is applied to constrainthe power flow between the stator for DFlG and the grid.

2014's 16th “International Electronics &Motion Regulation Conference and Exposition” featured a paper by Gang Yao, Lidan Zhou, Jiawei Chen, Huajun Yu, and Xin Wang that introduced a platform that was fully open for DFIG experiments based on a conversation system for wind energy. The basics of the DFIG are covered at the outset of the study, followed by tactics for controlling the VSCF (“Variable-Speed-Constant-Frequency”), the grid connection, and the tracking of the max power point.The impact of the control approach was seen in the MATLAB/Simulink environment. Finally, a fully open platform for the experiment was created using the PLC and TMS320F28335. The DSP programming employed the DFIG control techniques. The results of the trials validated the logic and efficacy of the control mechanisms and demonstrated platform stability.

"Progress of Wind Turbines and DFIGs During Voltage Surge," IEEE Transactions on Energy Conversion, Vol.I. Posted by IEEE Student Member John Morren in June 2005, No. 2. The accompanying paper identifies solutions that increase the likelihood that wind turbines using DFIG generators will stay linked with the grid during a grid nonfeasance. The purpose of the circuit is to limit the rotor elevation current to protect the inverter and to give this current an expedient step by connecting several resistors to the rotor winding. System failure can be avoided without disconnecting the turbine from the grid by using such resistors. After the generator & converter are linked together at the same time, the fault is generated before and after generation. After the fault is corrected, standard operations can continue uninterrupted. Another important aspect is the injection of reactive power into the grid during long-lasting voltage dips to maintain the voltage. An operation arrangement has subsided fix in place, which leads back to normal work. However, there’s a big leak, if the operation doesn’t take action.

The wind turbines'short-circuit current with DFIG was published by Johan Morren and Sjoerd WH de Haan in IEEE Transactions on Conversion of the Energy (Volume: 22, Issue: 1, March 2007). The wind turbines'contribution to short-circuit current has received little attention. Such a paper is considered when using a DFIG to control the “short-circuit” behavior and, in particular, the “short-circuit current” of the turbines. The electronic converter connected to the rotor windings of the asynchronous generator is often protected with a crowbar in these wind turbines. First, an extreme short-circuit current value is selected for standard asynchronous machines.The variationsbetween a crowbar-protected “DFIG” and a typical induction generator were selected and estimatemethods for excessive short circuit current of a DFIG were chosen. The solutions produced in this manner have been contrasted with those that came from time domain simulations. These variations are even fewer than 15%, roughly.

M.B. Mohamed, K. jemli, M-gossip, "DFIG, modeling and control of power flow in wind turbines", in IEEE; ICIT. In this work, DFIG is studied for WECS. First, the d-q model of the wound rotor for the asynchronous machine in the rotor reference frame, then the use of Simulink for a fast simulation. The DFlG describes a control law designed with PI controllers to controlthe current flow between the stator and grid.

Wei Qiao and Liyan Qu [5] introduced the concept of a SC energy storage device linkedin parallel to the DC link of a DFIG with a bi-directional DC to DC converter. This control method was developed to simultaneously store energy for the power supply and charge at super-fast speeds.

Ahmed H. Abdel Razek, Amr M. Ibrahim, Almoataz Y. Abdelaziz, Ahmed M. Asim Dynamic behavior of DFIG based on wind turbines under symmetrical voltage and new responsibilities for TSOs. Published in “Electrical and Electronics Engineering: International Journal” (ELELIJ) Volume 2, May 2, 2013. The new system must meet the requirements for wind turbines. These requirements are similar to conventional power plants that are concentrated in wind farms in the event of power outages, most include farms wind that contributes to the electrical control system. Due to the need for low-voltage operation capability (LVRT), the wind turbine is not isolated during voltage dips. The DFIG’sdynamic behavior is subject to 3 - phase input voltage.

In the 4th International Conference on “Power Engineering, Energy and Electrical Drives”, Bouharchouche1, E.M. Berkouk1, T.Ghennam1, and B. Tabbache1 presented the control as well as the management of the energy of a DFIG with the Battery-SC energy storage of hybrid, and a residential load of AC, which is connected with utility grid used as a backup resource. The Scientific model has beencomprehensive for everysubstance of the system. A general strategy for the management of powerhasbeen designed for a system for the coordination of the flows of powerbetween different xresources of the power and the demand for the load. Simulation tests have been conducted with MATLAB/Simulink to determine the system performance in various scenarios.

In her article "Rotor Side Converter Control of the DFIG that is based on the Conversion System of Wind Energy" which was published in IJERT, Meera G. S. N. A Divya PG Scholar explains how over the past ten years, the capacity of the world's wind energy has grown quickly and has become the technology with the fastest rate of growth for renewable energy. However, the imbalances in wind energy are greatly affecting the conversion of the, and this problem can be resolved by using different wind turbine speeds. The WECS-based DFIG has been receiving a lot of attention lately. MATLAB / Simulink is used to simulate the dynamic modeling of the wind turbine by DFIG, and the results are observed at different wind speeds. To control the reactive/activepower of the stator generated by DFIG, a stator current with vector control is operated in the rotor side converter. The OTC MPPT method has also been used to examine the optimum energy output of wind turbines. A similar comparison can be made between stator active power without MPPT analysis in MATLAB/Simulink.

Similar ideas were put out by Xunwei Yu and Zhenhua Jiang [6], with the exception that the SC is replaced by a system of storage for the battery energy. This battery conversion system's primary goal is to maintain a constant DC connection voltage, so capacitor voltage undulation is minimal. Similarly, the stator side inverter could be utilized to provide real and constant reactive power to the grid.

Aktarujjaman,Muttaqi, Haque,Ledwich, and Negnevitsky [7]advised for an alike scheme which has a system for the storage of the battery energy. A sophisticated transition from one operating mode to another is the unmediated intent of the storehouse network.

The concept was developed by Haihua Liu, Lin Chen, Feng Zhao, Hongzhong Ma, Tongkuang Liu, and Guanghe Li [8]. It includes a cell that allows the fuel to be parallel-connected directly with the DC-link capacitor. Therefore, GSC and RSC have each been utilized to control actual and reactive power separately.

A roadmap for the DFIG and a lithium-ion energy repository system integration was proposed by Marinelli, Silvestro, and Morini [9]. However, they haven't combined the two to enhance the overall presentation.

Abolhassani, Toliat, Niazi, and Enjeti [10] suggested the use of dfig wind turbine generators for harmonic feedback in the power system. Their work proposed to use DFIG RSC for true and reactive stator supply with harmonic compensation. [7]

The GSC is used by Tremblay, Lagace, and Chandra [11] to input the harmonics required by nonlinear loads. The low-pass filter is utilized to removethe main features of the line current while injecting the harmonic control through the GSC, and a nonlinear load is used to arrange all the required harmonics.

Poure, Gaillard, and Saadate [12] are used to propose an idea that is alike the preceding literature except that it has afilterto tune itselffor the extraction of the principle features from currents of the grid and for the injection of harmonics to use RSC.

M-Gossa, K. Jemli, "DFIG, Modeling and Power Flow Control in Wind Turbines," published in “IEEE International Conference on Industrial Technology”, describes DFIG for wind energy conversion systems. studied. The tool's d-q model is the first to be used in Simulink to control and more rapidly simulate the wound rotor in the rotor “reference frame”. A control law with a PI controller is created to control the current flow between the grid and DFlG stator.

Gang Yao; Xin Wang; Jiawei Chen; Huajun Yu; LidanZhouin 2014, the 16th International “Power Electronics and Motion Control Conference and Exposition” provided the paper to introduce a full-open platform of experiments for the DFIG, that ison the basis of theconversation system of the energy produced by the wind. The study has been started from the working fundamentals of DFIG, then the strategies to control the variable-speed-constant-frequency (VSCF) as well as the gird-connection and the MPPT(“Maximum Power Point Tracking”). The influence of strategies of control was observed in the MATAB/Simulink surrounding. At last, a platform that is full-open of experiments was developed that is based on thePLC and theTMS320F28335. The strategies of control of the DFIG have been applied with the help of DSP programming. The conclusions of the experiments certified that the validation aswell as theefficient strategies of control showed the stability of the platform.

IEEE Student member Sjoerd W. H. de Haan and AnohanMorren, "Wind Turbine Switching with DFIG for Volt Tube," in IEEE Transactions on Energy Conversion. 20, no. June 2, 2005. In this work, a solution was developed to enable the use of DFIG generators for grid connection in the case of grid faults in wind turbines. The specification of the system is to keep the high current of the rotor low for the safety of the converter by providing a current loop through the resistors attached to the rotor windings. Thanks to the resistor, you can bypass the grid fault without decoupling the turbine from the grid. By catenating the generator to the inverter, it helps maintain continuity during & after the fault, and continuous operation could continue even after the fault was remedied. Another function is to be suitable to give reactive power during prolonged absorption to grease voltage reclamation. A management plan is made to manage the return to normal work. If the administration does not take concrete action, there is a big leak.

A brief combination of DFIG and wind turbines was published by Sjoerd W. H. de Haan and AnohanMorren in “IEEE Transactions on Energy Conversion” (Volume22, issue: March 2007). The low current benefaction of the wind turbine has not been reckoned. This reverie investigates the short-circuit geste of wind turbines fitted with DFIGs, especially short-circuits.Wind turbines ordinarily have a cowl panel to shield the power electronic converter linked with the induction generator’srotor windings.First, the paramount valuation for standard induction machines short-circuit current is culled. The disputations between a crowbar-forfended DFIG and a prescriptive induction generator have been commended, and comparative formulae for the DFIG generator's furthermost short-circuit current have been demonstrated. The results developed in this way are then contrasted with the results of the time domain simulations. lesser than 15% separates the two in stints of disagreements.

Francisco K. A. Lima, Pedro Rodríguez, Member, IEEE, Alvaro Luna, Student Member, IEEE, FredeBlaabjerg, Fellow, IEEE, and Edson H. Watana, Senior Member, IEEE, "Rotor Voltage Dynamics in DFIGs During Grid Faults" In IEEE TRANSACTIONS ON ELECTRONICS, 25, January 1, 2010, presented a new strategy for RSC control of DFIG-based wind turbines, which helps to enhancelow voltage operation. With a change to the conventional solution based on the connection of the grid circuit. This method of operation allows the inverter to be connected to the generator, allowing it to inject into the grid when there is a fault according to the new code for the set. analysis of the dynamic way of the rotor voltage is also established for examining the voltage at the rotor terminals is necessary to implement a control strategy to stay within the limits. The results were collected to verify the simulation of the control system using EMTDC/PSCAD and experimental tests on a scale prototype.

CHAPTER-3

MODELLING OF WECS AND DFIG

3.1Wind Turbine Modelling Equations

Wind turbines are used to extract the energy. This is then it is converted into mechanical power. The following algebraic connection of mechanical power & wind speed is:

$$P_m = \frac{1}{2} * C_p * \rho * \pi * R^2 * V^3{}_{wind}$$

Where,

ρ : the density of air ($\rho = 1.225\ kg/m^3$)

R:wind turbine's radius

V_{wind} : wind speed

$C\ _p$:Power coefficientis a dimensionless quantity that describes how effectively the wind turbine converts the kinetic energy extracted from the wind into "mechanical energy".

The mathematical estimations of Cp are [1]:

$$C_p(\lambda, \beta) = c_1 \left(\frac{c_2}{\lambda_1} - c_1\beta - c_4 \right) e^{\frac{c_5}{\lambda_i}} + c_6\, \lambda \qquad (1)$$

The constants $c_1 to\ c_6$ mainly depend on the manufacturer and alsothe type of wind turbine.

$$\lambda = \frac{\Omega_{turb} R}{V_{wind}}$$

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08} - \frac{0.0035}{\beta^3 + 1} \qquad (2)$$

3.2 DFIG Modelling Equations

Since the simulation of the DFIG model corresponds to this frame, the DFIG model shown is the stationary rotating frame dq0.The DFIG model's transient solution is probable due to the conversion from the abs to dq0 using which the differential equations having variations in the time that has been transferred into the differential equations having constant inductances,

For the boundary between the mechanical system of the grid and the wind turbine, where the wind turbine is connected, the electrical system of the wind turbine is becoming increasingly noticeable. Induction machines are typically used to transform mechanical power into electrical power. Compared to asynchronous generators, induction generators with squirrel cages are more widely employed because of their simplicity, ease of control, and low cost [2]. To extract excess power from the wind potential, we must put an AC-AC converter between the generator stator and also between the utility set. However, these converters, which must be properly sized to adjust the generator speed to wind conditions, are expensive. In the below Fig. Stator and coil are connected directly.

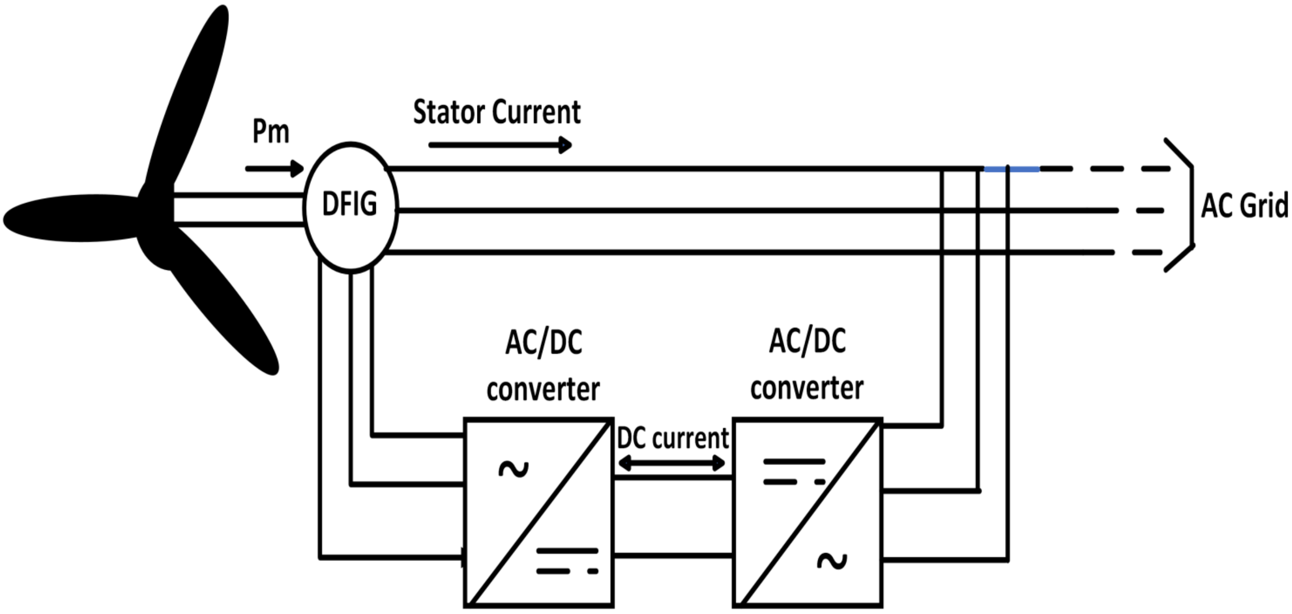

Fig3.1.DFIG System's block diagram

3.2.1Stator side equation in Stator flux-oriented reference frame

Three-phase grid voltages are applied to powerthe grid-side converter. Voltages va, vb, andvc

couldbe represented as follows, assuming a symmetrical grid:

$$v_a = V_s \sin\left(\omega_g t + \varphi_g\right)$$

$$v_b = V_s \sin\left(\omega_g t + \frac{2\pi}{3} + \varphi_g\right)$$

$$v_c = V_s \sin\left(\omega_g t - \frac{2\pi}{3} + \varphi_g\right)$$

Where φ_g is the phase of the voltage v_a, ω_g is the electric frequency of the grid and V_s is the RMS stator voltage.

An equivalent model of DFIG that uses the simultaneously rotating reference frames (qd-frame) is presented in equations (1) and (2).

$$V_{ds} = R_s . i_{ds} + \frac{d}{dt}\phi_{ds} - \omega_e \phi_{qs} \qquad (3)$$

$$V_{qs} = R_s . i_{qs} + \frac{d}{dt}\phi_{qs} - \omega_e \phi_{ds} \qquad (4)$$

$$V_{dr} = R_r . i_{dr} + \frac{d}{dt}\phi_{dr} - (\omega_e - \omega)\phi_{qr} \qquad (5)$$

$$V_{qr} = R_r . i_{qr} + \frac{d}{dt}\phi_{qr} - (\omega_e - \omega)\phi_{dr} \qquad (6)$$

3.2.2Rotor side equation in Stator flux-oriented reference frame

The quantities v_{ar},v_{br} and v_{cr} are the RMS rotor voltages, which can be shown as :

$$v_{ar} = V_r \sin\left(\omega_r t + \varphi_{gr}\right)$$

$$v_{br} = V_r \sin\left(\omega_r t + \frac{2\pi}{3} + \varphi_{gr}\right)$$

$$v_{cr} = V_r \sin\left(\omega_r t - \frac{2\pi}{3} + \varphi_{gr}\right)$$

Where φ_{gr} is the phase of the voltage $v_{ar}$and V_r is the RMS rotor voltage.

The Stator as well as the rotor fluxes are representedas :

$$\phi_{ds} = L_s i_{ds} + M i_{dr} \qquad (7)$$

$$\phi_{qs} = L_s i_{qs} + M i_{qr} \qquad (8)$$

$$\phi_{dr} = L_r i_{dr} + M i_{ds} \qquad (9)$$

$$\phi_{qr} = L_r i_{qr} + M i_{qs} \qquad (10)$$

In these equations, R_s, R_r, $L_s and\ L_r$, indicates resistances as well as inductances of stator &rotor windings, respectively, and M presents mutual inductance.

$V_{ds}, V_{qs}, V_{dr}, V_{qr}, i_{ds}, i_{qs}, i_{dr}, i_{qr}, \phi_{ds}, \phi_{qs}, \phi_{dr}\ and\phi_{qr}$ are the components of d &q of thestator and the rotor voltages, current, and flux, whileω in electrical terms is the rotor speed and $\omega_e$is the reference's synchronous rotation's angular velocity. The electromagnetic torque, which is electromagnetic is expressed in the form [3]:

$$\tau_e = P * \frac{M}{L_r}(\phi_{dr} * I_{qs} - \phi_{qr} * I_{ds}) \tag{11}$$

Where P: No. of Pole Pairs.

The active and reactive powers at the stator also rotor side is defined as :

$$P_s = \frac{3}{2}\left(V_{ds}i_{ds} + V_{qs}i_{qs}\right) \tag{12}$$

$$Q_s = \frac{3}{2}\left(V_{qs}i_{ds} - V_{ds}i_{qs}\right) \tag{13}$$

$$P_r = \frac{3}{2}\left(V_{dr}i_{dr} + V_{qr}i_{qr}\right) \tag{14}$$

$$Q_r = \frac{3}{2}\left(V_{qr}i_{dr} + V_{dr}i_{qr}\right) \tag{15}$$

CHAPTER-4

CONTROL OF DFIG

4.1Grid Side Converter (GSC) Control

The goal of GSC is to achieve a constant voltage in the DC connection between successive converters. To attainthis, a scheme of vector control is utilized to provide independent control of activeas well as reactive power flows between the grid and GSC. The axis DC is applied to control the DC link voltage DC, while the axis quadrature current is utilized to bridge the reactive power. The cornerstone of the technique used is the d-q hypothesis or source frame position, which is utilized to solve the parameter interpretation challenge over time with the AC machines.This is done to convert stator variables into a fixed reference frame that is simultaneously rotating.Using transformations, Here we use Park's Transformation, one can eliminate the inductances having the issue of time variations occurring because of a working electric circuit which is relative, and the electric circuit having the issue of variation in the magnetic reluctances.

The change of three to 2-phase axis in the stationary position is presented as :

$$\begin{bmatrix} V_{qs}^{s} \\ V_{ds}^{s} \\ V_{0s}^{s} \end{bmatrix} = \begin{bmatrix} cos\theta & \cos(\theta - 120) & \cos(\theta + 120) \\ sin\Delta\theta & \sin(\theta - 120) & sin(\theta + 120) \\ 0.5 & 0.5 & 0.5 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad (16)$$

Conversion of the 2-phase axis in the stationary position to the 2-phase simultaneous axis in rotations is given by :

$$V_{qs} = V_{qs}^{s} cos\theta_e - V_{ds}^{s} sin\theta_e \qquad (17)$$

$$V_{ds} = V_{qs}^{s} sin\theta_e + V_{ds}^{s} cos\theta_e \qquad (18)$$

The GSC voltage in the d-q substance is achieved by a typical configuration of the strategy control, which is as follows:

$$V_q = Ri_q + L\frac{di_q}{dt} + \omega_e Li_d + v_{qi} \qquad (19)$$

$$V_d = Ri_d + L\frac{di_q}{dt} - \omega_e Li_d + v_{di} \qquad (20)$$

Apply Laplace transforms on the aforementioned 2equations :

$$V_q = (R + sL)i_q + \omega_e Li_d + v_{qi} \qquad (21)$$

$$V_d = (R + sL)i_d - \omega_e Li_q + v_{di} \qquad (22)$$

Considering :

$$V_q' = (R + sL)i_q \qquad (23)$$

$$V_d' = (R + sL)i_d \qquad (24)$$

Calculations for the angular positions of the voltage supply are done as :$\theta_e = \int \omega_e dt = \tan^{-1}\frac{v_\beta}{v_\alpha}$

Here v_α and v_β are the stator-voltage components.

The control scheme uses the current control loops for i_d and $i_q$with the DC link voltage error requirement derived from DC with a regular controller for PI. The factor of the shift on the inductor supply side is determined by the demand. The current control loop system is given by

$$F(S) = \frac{i_q}{v_q'} = \frac{i_d}{v_d'} = \frac{1}{R + sL}$$

consider$V_q(s) = 0$, then the reference voltage values $V_{q_ref}$and V_{d_ref} is obtained by :

$$V_{q\_ref} = -v_q' - \omega_e Li_d + v_q \qquad (25)$$

$$V_{d\_ref} = -v_d + \omega_e Li_d + v_d \qquad (26)$$

The values of $V_{q_ref}$and$V_{d_ref}$are the reference values of the input tothe PWM converter used to obtain the DC Voltage level along withthe power factor requirement of the output.

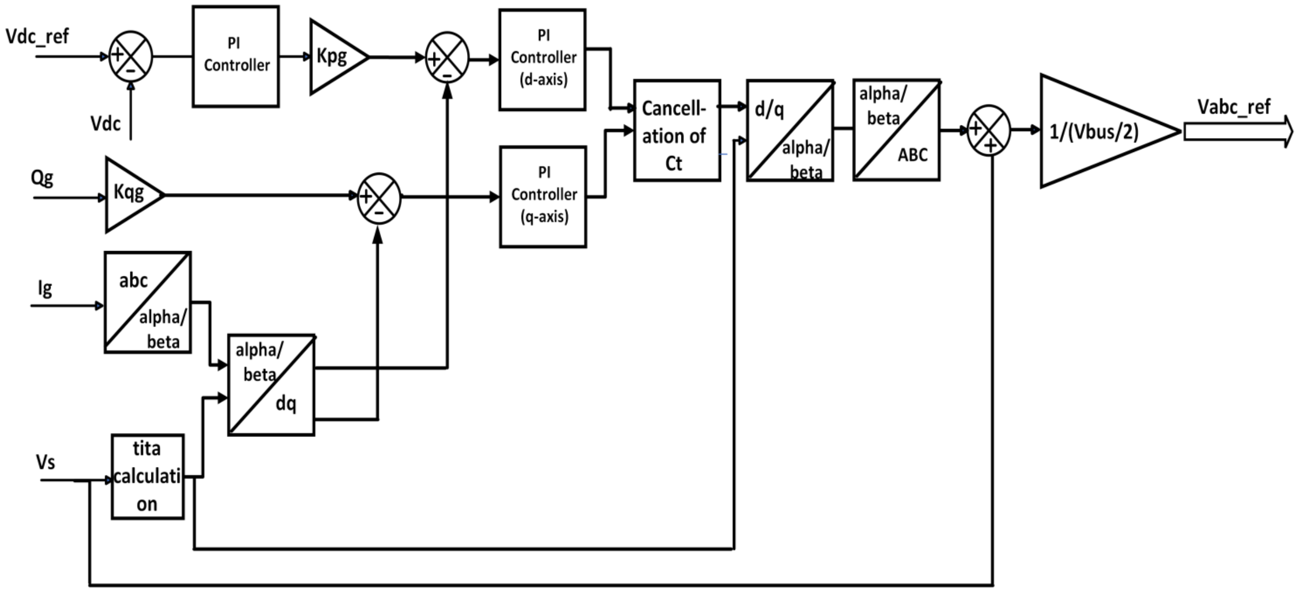

Fig 4.1 Control of GSC

4.2 Rotor Side Converter (RSC) Control

A vector control system is usedfor the RSC for active control of the reactive power and the stator. The reactive power is controlled with the DC of the axis & active power is controlled with the current of the quadrature axis [10]. The side rotor of the inverter is subjected to the stator flux vector control [11]. The rotation of the direct axis controls the reactive power, whereas the quadrature axis controls the “reactive power”.

The rotor side converter control equations,

$$V_{dr} = R_r i_{dr} + \sigma L_r \frac{di_{dr}}{dt} - \omega_{sl}\sigma L_r i_{qr} \tag{27}$$

$$V_{rr} = R_r i_{qr} + \sigma L_r \frac{di_{qr}}{dt} - \omega_{sl}(\sigma L_r i_{dr} + L_o i_{ms}) \tag{29}$$

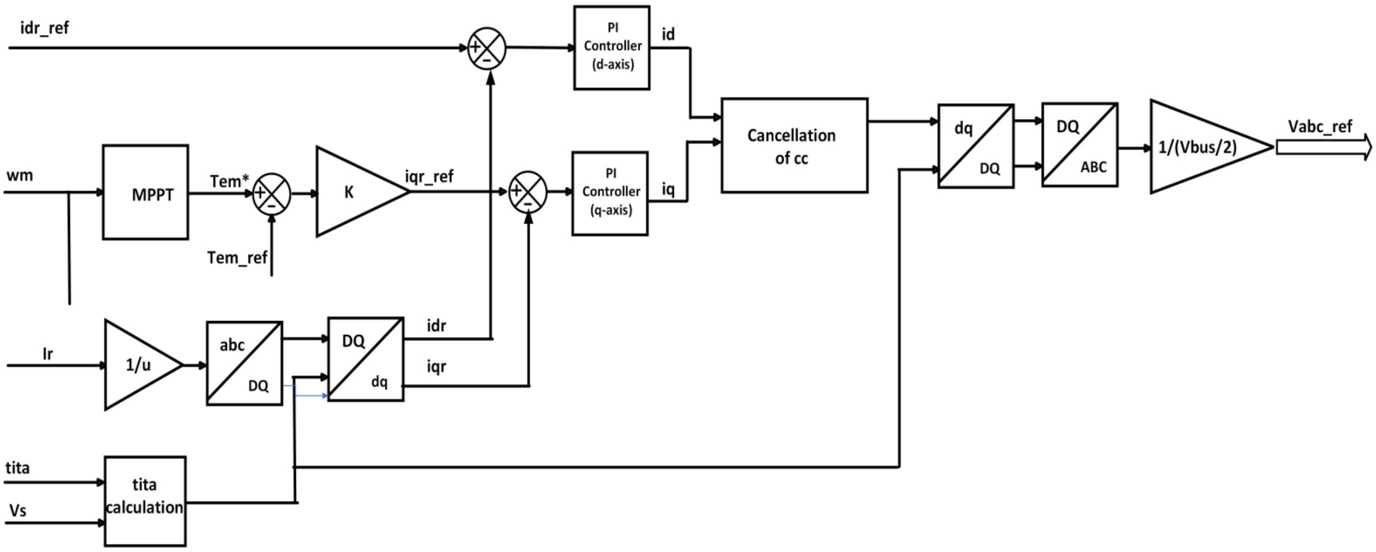

Fig 4.2Rotor Side Converter Control

CHAPTER-5

RESULTS

5.1 INTRODUCTION

The doubly-fed induction generator was applied for its variable speed profiles. The bidirectional converter, which is also linkedto the mains, supplies the rotor, whereas the the stator is directly linked to it.

The following list represents the DFIG's primary characteristics:

- - The primary objective of the inverter is to compensate for the discrepancy between the rotor speed and the coexisting speed by means of a push-off control.
- (-30% to +20%) Limited Operating Speed Range
- The representative features adheredto in the modeling are as follows :
  - For control of generators, power converters, active and reactive power, and grid code support, use vector control or direct torque control (DTC).
  - Rated Power: 500 to 2500 kVAs
  - Rated Voltage: 690 V, +10% to -15%

5.2Wind Turbine Characteristics

Here, MATLAB/Simulink software is used to interface theWECS.It is depending on DFIG (“Doubly Fed Induction Motor”) with the grid system. The frequency valuein use is 50 Hz. Snubber circuits, which are coupled to limit or reduce voltage transients in the system, are essentially what universal bridge circuits are.

Here in Fig 5.1, The characteristics of the $C_p(\lambda)$ are clearly shown. In the first graph, it is shownhow Ct varies with respect to Lambda, where Ct is the Shear Coefficient and Lambda is Speed Ratio.

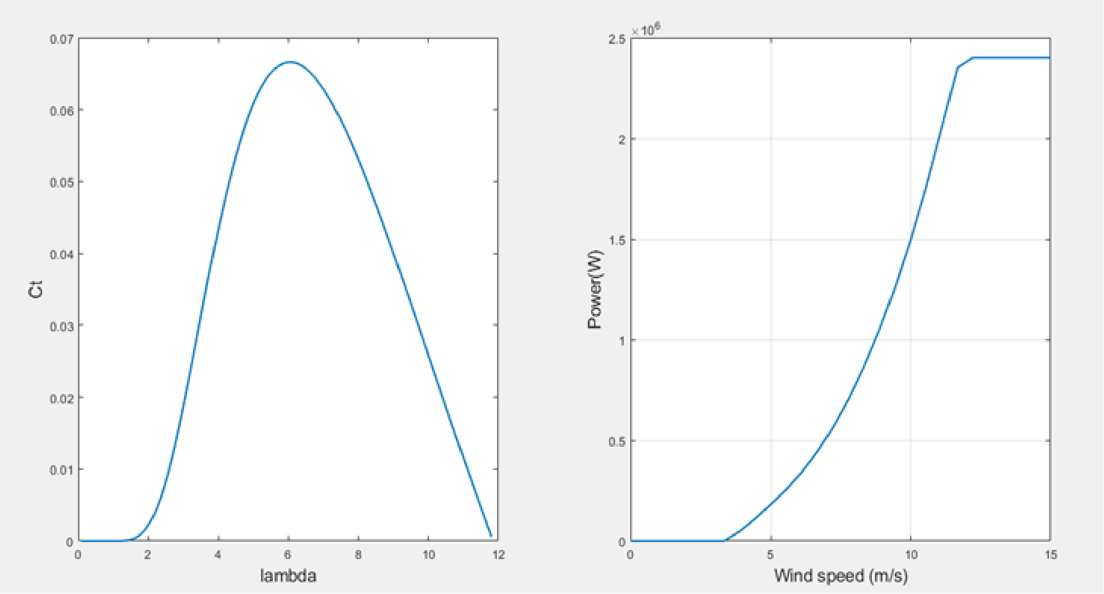

Fig:5.1:Characteristics of the $C_p(\lambda)$

The definition of both terms is as follows :

Thrust Coefficient(Ct): One of the most substantialdelegates affecting the rendition of wind turbines is this quantum. Damping portions are needed to regard for power losses in wind granges, wind speed reductions, and power affair reductions. The wake effect on wind turbines is the accretive effect on the quantum of wind energy produced in the wind ranch.

Speed Ratio or Tip Speed Ratio(λ): This factor is one of the extremely valuable parameters for wind turbine designing. It is essentially a correlationbetween the wind speed and blade tip speed of wind turbines.

$$\text{TSR}(\lambda) = \frac{\text{Tip Speed of the Blade of the wind turbine}}{\text{Wind Speed}}$$

If the TSR value is low, it means that the wind turbine rotor is slow, and the maximum amount of wind flows directly through the gap or space between the turbine blades.

5.3 Simulation Results:

5.3.1 Control of Dynamics at different Speeds:

One of the most unmatched uses for DFIG is in variable-speed wind turbines, so in this application, we operated the wind-driven DFIG at several speed ranges in subsynchronous, synchronous, and supersynchronous modes. The following figures display the three-phase voltages and currents on the Stator and Rotor sides. The fact that the stator side voltage and current remain consistent during all three modes of operation merely illustrates that the grid side impact of switching the wind-driven DFIG from one mode to another was minimal, awarding higher scores to the system's control system performance.

Similar to how the synchronous mode of operation results in the rotor circuit switching to a DC circuit, the sub-synchronous mode of operation has the phase sequence (abc) at a positive slip frequency. The voltages and currents in the rotor circuit can be seen in Fig. 5.5 as dc values supplied by the dc source. The voltage and current on the rotor side are supplied back into the AC system in the super-synchronous mode but with a modified phase sequence (acb) and a negative slip frequency, which signals a shift in the direction of power flow.

The Rotor side and Grid side converter characteristics for the Sub-Synchronous, Synchronous, and Super-Synchronous modes of operation are shown in the following topic from Fig. 5.2 to 5.7. Rotor side converter characteristics are presented in Figs. 5.2, 5.3, and 5.4, while grid-side converter characteristics are shown in Figs. 5.5, 5.6, and 5.7. The wind speed variations are done in a way that at t=0 to t=7 sec; the speed is taken as 8.0 m/s and the system is working under sub-synchronous mode and at t=7 sec, the speed is changed from 8.0 m/s to 9.5 m/sec and system is in super-synchronous mode till t=15 sec. After t=15 sec, the speed is again changed to 8 m/s and the system again runs in the sub-syhchronous mode of operation and for these speed values, the rotor side and grid side characteristics are plotted for above mentioned three modes of operation.

5.3.2 rotor side converter characteristics

5.3.2.1Sub-Synchronous Mode

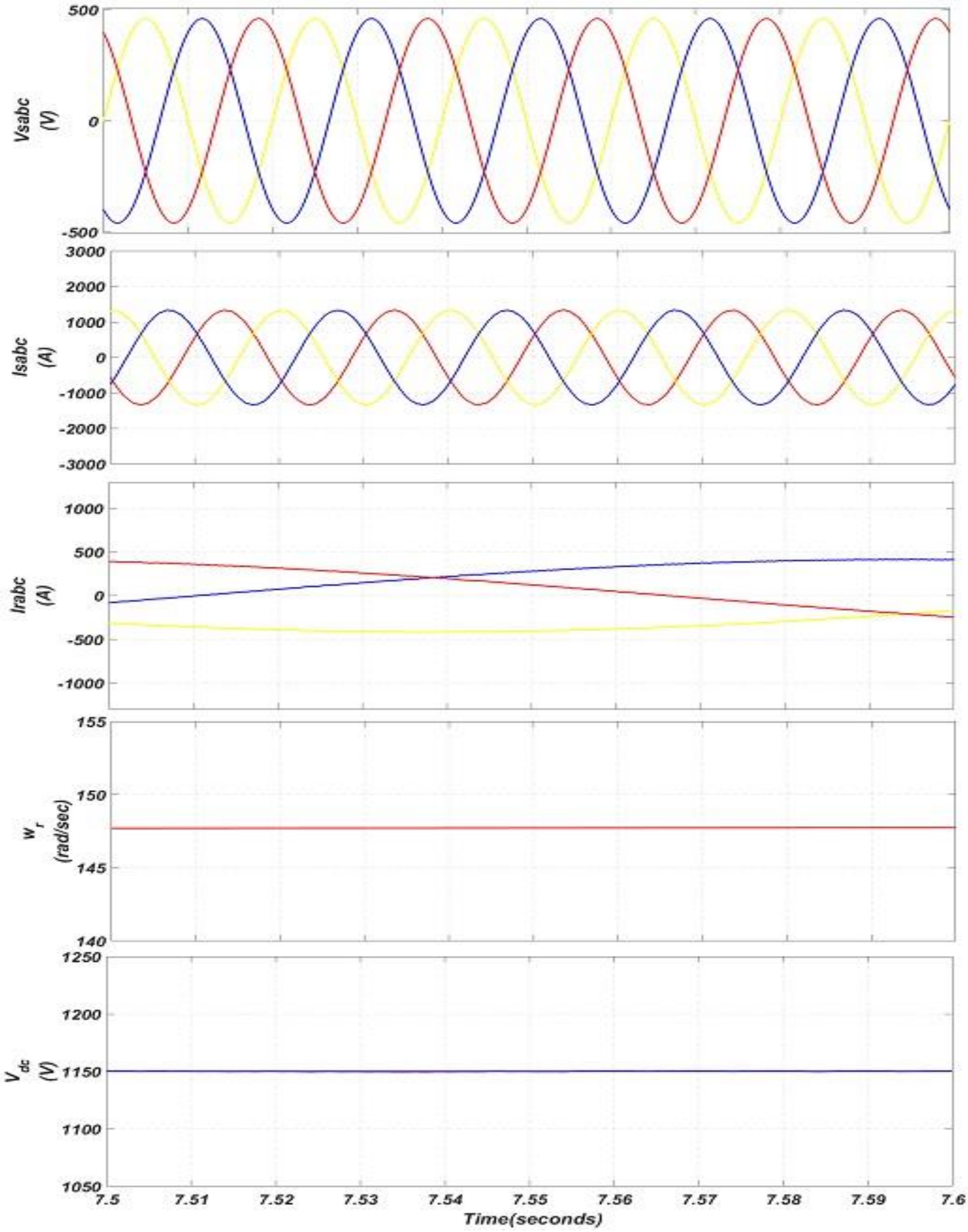

Fig:5.2: (RSC) Sub-Synchronous Operation Characteristics with time

5.3.2.2 SynchronousMode

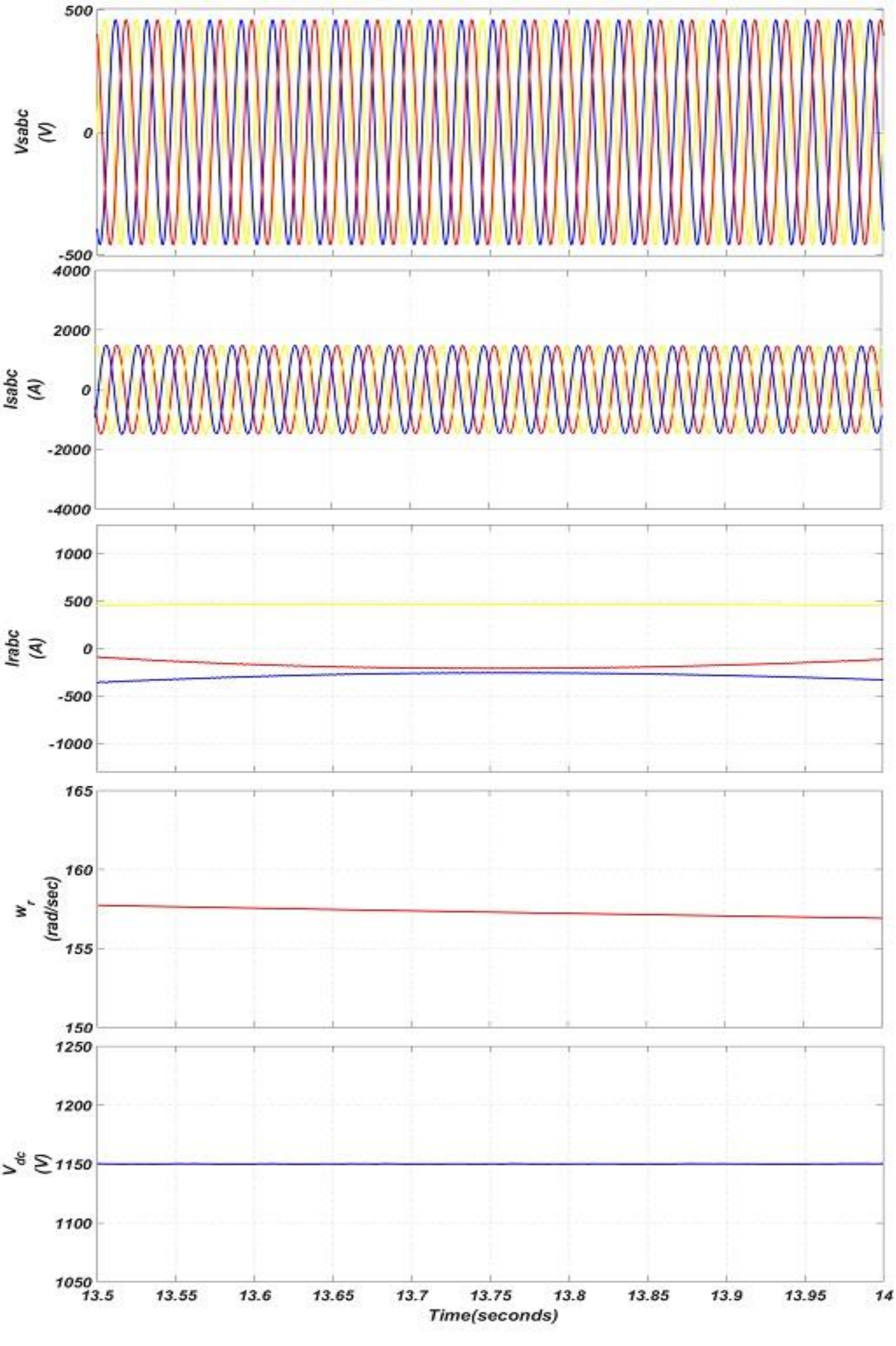

Fig:5.3: (RSC) Synchronous Operation Characteristics with time

5.3.2.3 Super-synchronous Mode

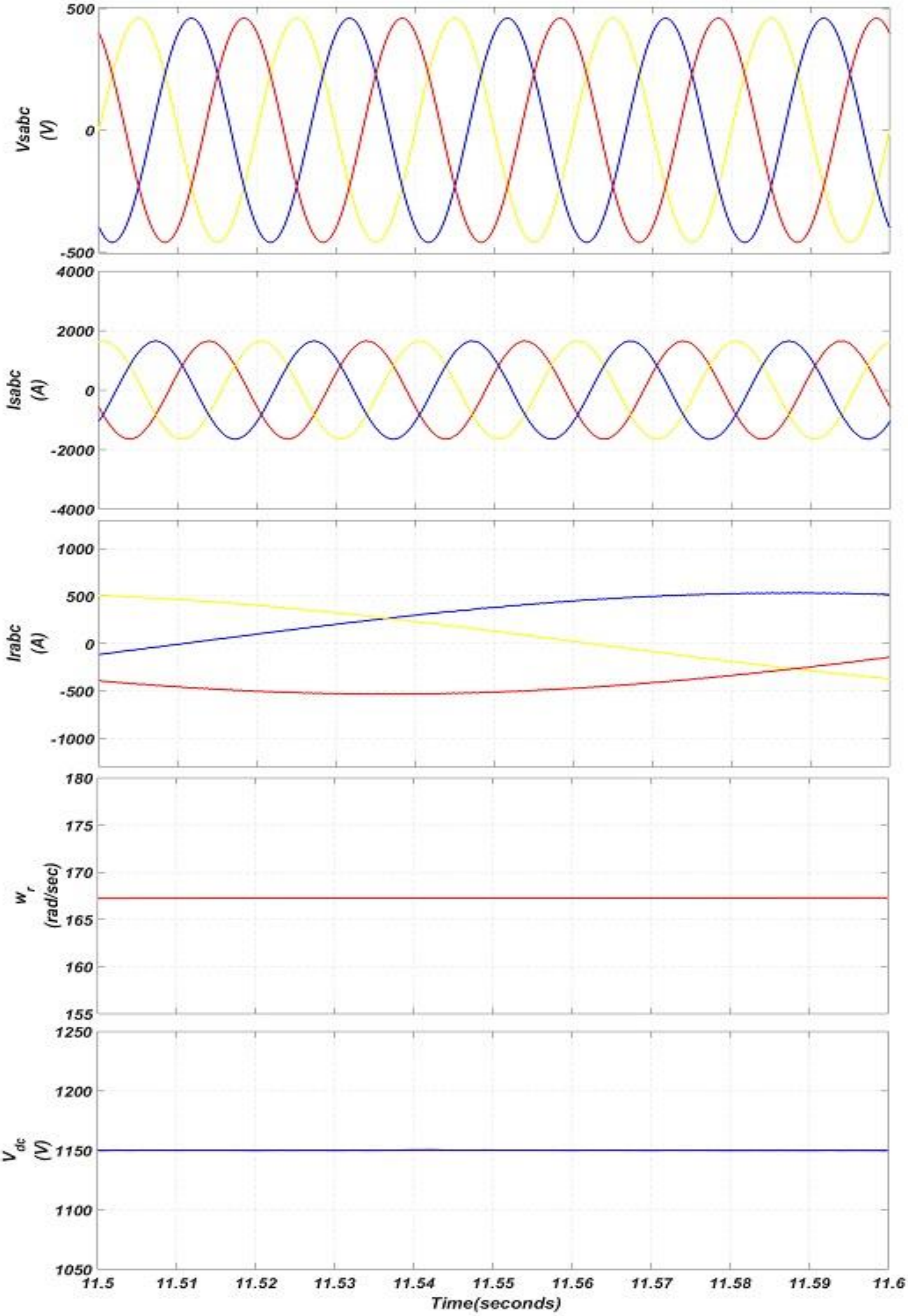

Fig:5.4: (RSC) Super-Synchronous Operation Characteristics with time

5.3.3 Grid Side Converter Characteristics

5.3.3.1Sub-Synchronous Mode

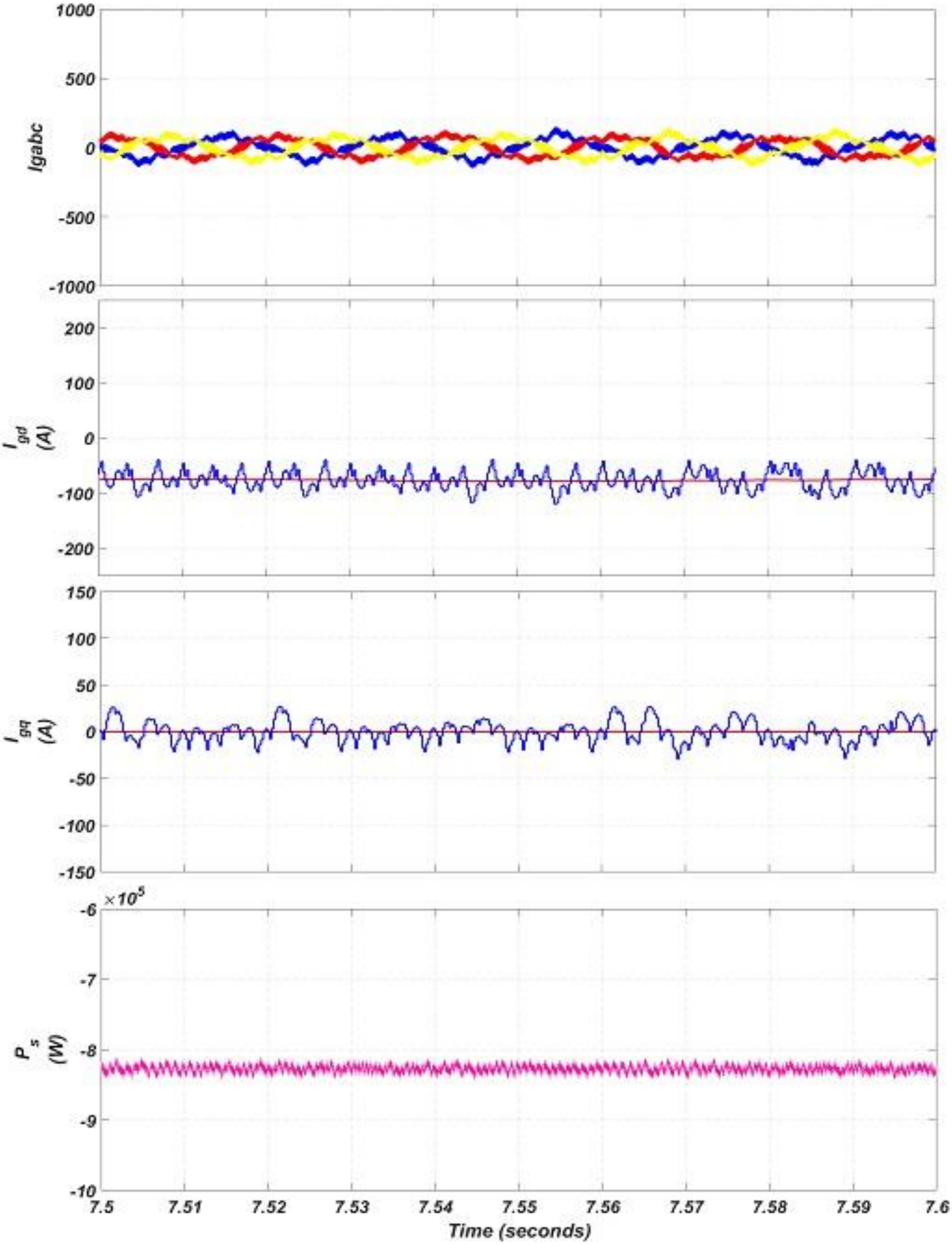

Fig:5.5:(GSC) Sub-Synchronous Operation Characteristics with time

5.3.3.2 SynchronousMode

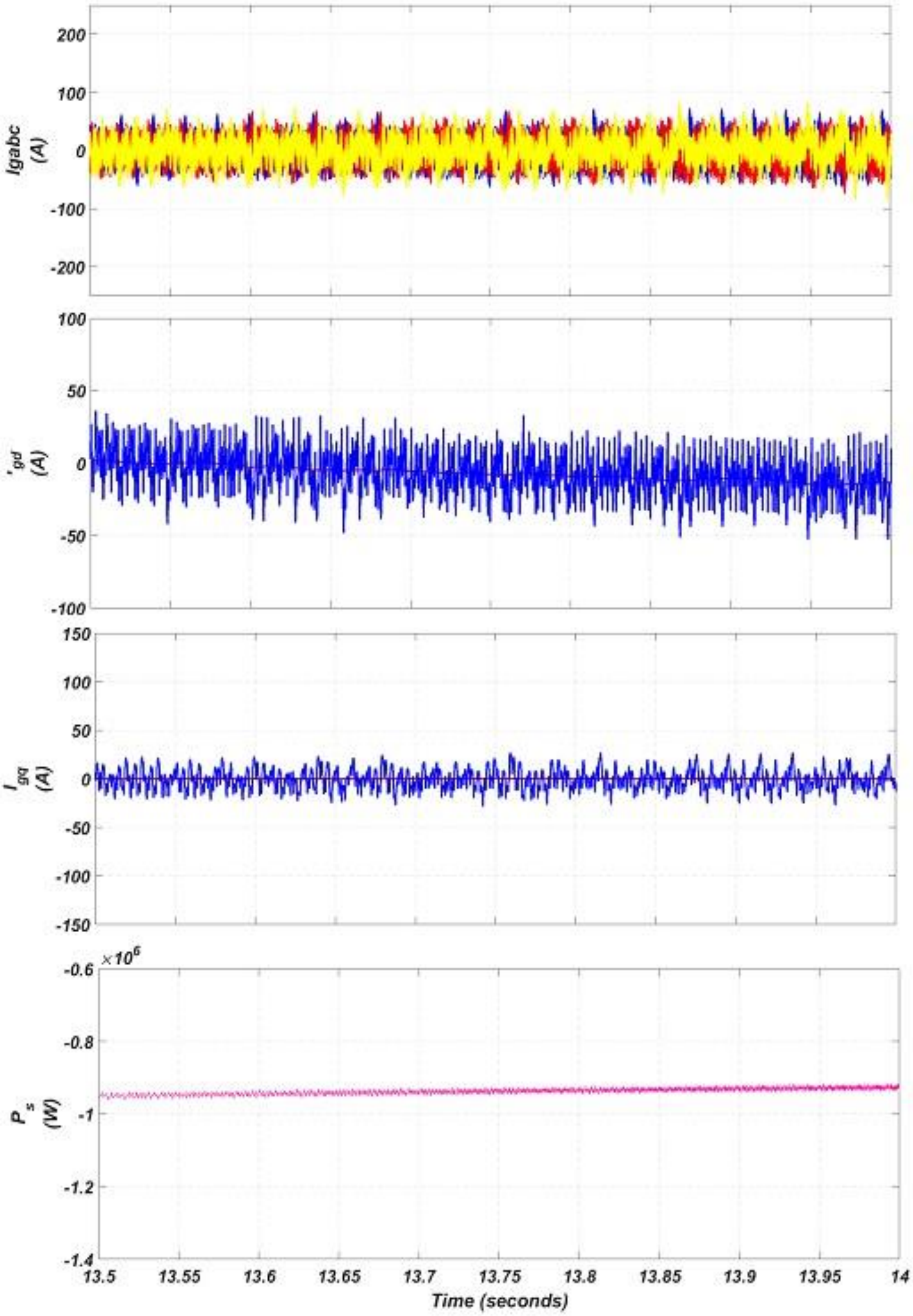

Fig:5.6:(GSC) Synchronous Operation Characteristics with time

5.3.3.3Super-synchronous Mode

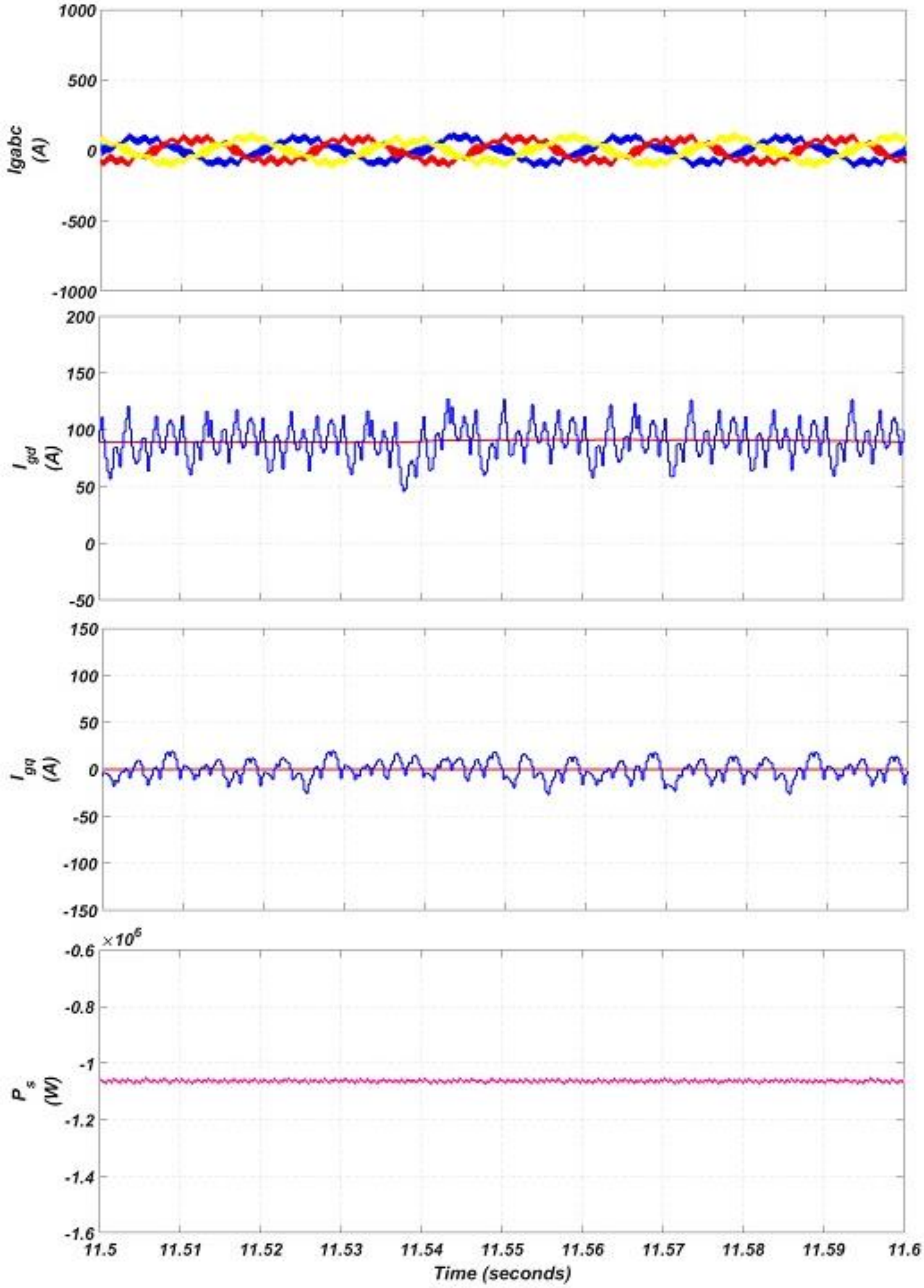

Fig:5.7:(GSC) Super-Synchronous Operation Characteristics with time

CHAPTER-6

CONCLUSIONS AND FUTURE SCOPE OF WORK

6.1 Conclusion

A wind-driven DFIG system is designed and analyzed in this thesis in terms of voltage, current, and electrical conductivity between the grid and the wind turbine rotor. These three methods are then presented with dynamic modeling and performance characteristics. There are three types of workflows: sub-synchronous workflows, synchronous workflows, and super-synchronous workflows.The different parts of the system are modeledincluding :

1. The dynamic of the mechanical system and wind turbine
2. wind turbine modeling
3. grid side converter modeling
4. rotor side converter modeling
5. Generator
6. Power Exchanges between active rotor power (Pr)andactive stator power (Ps).
7. The equivalent circuit equations are used in the modeling to ascertain the operational characteristics of the machine.
8. MPPTtechnique is used for variable speed operation.

Performance characteristics are recorded for the three operating modes –synchronous,sub-synchronous as well as super-synchronous.

6.2 FUTURE SCOPE OF WORK

The topics which would possibly be of future researcher's interest in variable speed wind-driven DFIG model and its power control and management are as follows :

1. Dynamic modeling and control of wind farms consist of multiple wind turbines and their compatibility with each other in case of unequal wind distribution.

2. Various faults i.e. phase to ground, phase to phase and three-phase faults can be introduced on the grid side, and then the system behavior can be analyzed.

3. Examining the self-governance system of wind turbine systems during faults.

4. When the GSC and RSC are unable to supply enough reactive power due to fault situations, use more efficient and effective converters to generate additional reactive power in the system.

CHAPTER-7

REFERENCES

[1] Electrical and Electronics Engineering: An International Journal (ELELIJ), Vol. 2, No. 2, May 2013, "Dynamic Behaviour of DFIG based wind turbines during symmetrical voltage dips," Almoataz Y. Abdelaziz, Amr M. Ibrahim, Ahmed M. Asim, and Ahmed H. Abdel Razek.

[2] W. Qiao and R. G. Harley, “Grid connection requirements and solutions for DFIG wind turbines,” in Proc. IEEE Energy Conf., Atlanta, GA, Nov. 17–18, 2008, pp. 1–8.

[3] "Constant Power Control of DFIG Wind Turbines With Supercapacit capacitor Ener or Energy Storage," by IEEE Member Liyan Qu and Wei Qiao, appeared in IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 47, NO. 1, January/February 2011.

[4] Wind energy delivery issues: Transmission planning and competitive power market operation, IEEE Power Energy Mag., vol. 3, no. 6, pp. 47–56, Nov./Dec. 2005. R. Piwko, D. Osborn, R. Gramlich, G. Jordan, D. Hawkins, and K. Porter.

[5] "Energy storage and its use with intermittent renewable energy," IEEE Trans. Energy Convers., vol. 19, no. 2, pp. 441–448 (June 2004). J. P. Barton and D. G. Infield.

[6] IJCSMC, Volume 5, Issue 8, August 2016, Pages 123–130, Mallala Harshavardhan and K. Rajesh, "Modelling and Simulation of Grid Side Control of DFIG Using Fuzzy and PI."

[7] J. Power Electron., vol. 9, no. 5, pp. 677–685, September 2009. G.B. Chung and J.H. Choi, "Application of fuzzy PI control algorithm as stator power controller of double-fed induction machine in wind power generation systems."

[8] Reactive power regulation of a wind farm made up of doubly fed induction generators, (I) and (II), IEEE Porto Power Tech Conference, 2001. A. Tapia, G. Tapia, J. X. Ostolaza, J. R. Saenz, R. Criado, and J. L. Berasategui.

[9] N. S. Chouhan's 2010 Master's thesis at Missouri University was titled "Double-fed induction generator with integrated energy storage system for smoothing of output power."

[10] Modelling and control for wind energy generation: Gonzalo Abad, Jesus Lopez, Miguel A. Rodriguez, Luis Marrayo, and Grzegorz Iwanski, 2011.

[11] The authors of "Power Electronics for Renewable Energy Systems, Transportation and Industrial Application" are Haitham Abu-Rub, Mariusz Malinowski, and Kamal Al-Haddad.

[12] The article "The Dynamic Behaviour of DFIG which is based on the Turbines of the Wind during the voltage dips that are symmetrical" by Almoataz Y. Abdelaziz, Ahmed M. Asim, Amr M. Ibrahim, and Ahmed H. Abdel Razek, published in the EEE: An International Journal (ELELIJ) Vol 2, No 2, May 2013, imposes various tests on TSOs.

[13] "Ridethrough of the wind turbines with the DFIG during a Voltage Dip" was published in IEEE Transactions on Energy Conversion, Vol. 20, No. 2 in June 2005 by John Morren, an IEEE Student Member.

[14] The Short-Circuit Current of the Turbines for the Wind with the DFIG was published by Johan Morren and Sjoerd W. H. de Haan in IEEE Transactions on Conversion of the Energy (Volume: 22, Issue: 1, March 2007).

[15] The Ride Through of the Turbine of Wind with DFIG During a Dip for the Voltage was published by Sjoerd W. H. de Haan and Johan Morren, who are Student Members of IEEE, in IEEE Transactions on Energy Conversion, Vol. 20, No. 2, June 2005.

[16] The Short-Circuit Current of the Wind Turbines with the DFIG was published by Sjoerd W. H. de Haan and Johan Morren in the IEEE Transactions on the Conversion of the Energy (Volume: 22, Issue: 1, March 2007).

[17] "Rotor Voltage Dynamics in DFIG during the Grid Faults" was published by Francisco K. A. Lima, Pedro Rodriguez, Alvaro Luna, FredeBlaabjerg, Fellow, and Edson H. Watana, Senior Member, IEEE in the IEEE TRANSACTIONS ON POWER ELECTRONICS, VOL. 25, NO. 1, JANUARY 2010.

[18] S. Rahman, "Going Green: The Growth of Renewable Energy", IEEE Power and Energy Magazine, Vol. 99, No. 6, Nov./Dec. 2003, pp. 16-17.

[19] International Renewable Energy Agency, "Renewable Power Generation Costs in 2012: An Overview", A. Z. Amin, 2013.

[20] The second edition of Wind Energy Explained Theory, Design, and Application by J. F. Manwell, J. G. McGowan, and A. L. Rogers was published in 2009 by John Wiley & Sons Ltd.

[21] A review of the state-of-the-art in power electronics for wind turbines was published by C. Zhe, J. M. Guerrero, and F. Blaabjerg in IEEE Transactions on Power Electronics, Vol. 24, No. 8, in August 2009.

[22] IEEE Transactions on Energy Conversion, Vol. 5, No. 2, pp. 272-278, June 1990. C. S. Demoulias and P. S. Dokopoulos, "Transient behaviour and self-excitation of wind-driven induction generator after its disconnection from the power grid."

[23] A Single-Phase SelfExcited Induction Generator for Lighting Loads in Remote Areas, B. Singh, R. B. Saxena, S. S. Murthy, and B. P. Singh, International Journal on Electricity Engineering Education, Vol. 25, pp. 269–275, 1988

[24] "Transient behaviour and self-excitation of wind-driven induction generator after its disconnection from the power grid," IEEE Transactions on Energy Conversion, Vol. 5, No. 2, June 1990, pp. 272-278. C. S. Demoulias and P. S. Dokopoulos.

[25] IEEE Transactions on Energy Conversion, Vol. 14, No. 3, pp. 333-339, Sept. 1999. L. Refoufi, B. A. T. Al Zahawi, and A. G. Jack, "Analysis and Modelling of the Steady State Behaviour of the Static Kramer Induction Generator.".

[26] "Voltage Stability of Isolated Self Excited Induction Generator (SEIG) for Variable Speed Applications using Matlab/Simulink," International Journal of Engineering and Advanced Technology (IJEAT), Vol. 1, Issue-3, pp. 2249-8958, February 2012; K. K. Raj, E. Swati, and Ch. Ravindra/

[27] An analysis, modelling, and control of doubly-fed induction generators for wind turbines was the subject of A. Petersson's 2005 doctoral dissertation at Chalmers University of Technology in Sweden.

[28] IEEE Power and Energy Society General Meeting Conversion and Delivery of Electrical Energy in the 21st Century, 20-24 July 2008, pp. 1-6. X. Yu, Z. Jiang, and Y. Zhan, "Control of Doubly-Fed Induction Generators for Distributed Wind Power Generation."

[29] Comparison of Reduced Order Doubly Fed Induction Generator Models for Nonlinear Analysis, K. Elkington and M. Ghandhari, IEEE Electrical Power & Energy Conference, pp. 1-6, October 2009.

[30] "Wind Speed Estimation Based Sensorless Output Maximisation Control for a Wind Turbine Driving a DFIG," IEEE Transactions on Power Electronics, Vol. 23, No. 3, pp. 1156-1169, May 2008; W. Qiao, W. Zhou, J. M. Aller, and R. G. Harley

[31] Three-phase doubly fed induction generators: an overview, M. Tazil, V. Kumar, R. C. Bansal, S. Kong, Z. Y. Dong, W. Freitas, and H. D. Mathur, IET Electric Power Applications, Vol. 4, No. 2, pp. 75-89, Feb. 2010.

[32] "Direct Power Control of Doubly-FedInduction-Generator-Based Wind Turbines Under Unbalanced Grid Voltage," IEEE Transactions on Power Electronics, Vol. 25, No. 2, Feb. 2010, pp. 442-452. G. Abad, M. Rodrguez, G. Iwanskiand, and J. Poza.

[33] IEEE Transactions on Sustainable Energy, Vol. 2, No. 3, July 2011, pp. 288–299; E. Tremblay, S. Atayde, and A. Chandra, "Comparative Study of Control Strategies for the Doubly Fed Induction Generator in Wind Energy Conversion Systems: A DSP-Based Implementation Approach."

[34] "Double-Fed Induction Machine: Converter Optimisation and Field Oriented Control without Position Sensor," IEE Proceedings Electric Power Applications, Vol. 145, No. 4, pp. 360-368, Jul. 1998. L. Morel, H. Godfroid, A. Mirzaian, and J. M. Kauffmann.

[35] "MRAS Observers for Sensorless Control of Doubly-Fed Induction Generators," IEEE Transactions on Power Electronics, Vol. 23, No. 3, May 2008, pp. 1075–1084. R. Cárdenas, R. Pea, J. Clare, G. Asher, and J. Proboste.

[36] "Energetic Macroscopic Representation and Inversion Based Control Illustrated on a Wind-Energy-Conversion System Using Hardware-in the Loop Simulation," A. B. Xavier and S. Betty, IEEE Transactions on Industrial Electronics, Vol. 56, No. 12, Dec. 2009, pp. 4826–4835.

[37] Maximum Power Point Tracking Based on Sensorless Wind Speed Using SVR by G. Ahmed and A. Kalil is published in Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19–21, 2010, Paper ID 264, pp. 678–682.

[38] "Sensorless Maximum Power Point Tracking in Multi-Type Wind Energy Conversion Systems," Proceedings of the 48th IEEE Conference on Decision and Control, 2009, held in conjunction with the 2009 28th Chinese Control Conference. L. Fan, Z. Miao, and X. Wang. CDC/CCC 2009, 15-18 Dec. 2009, pp. 6823-6828

[39] A Fault Tolerant Doubly Fed Induction Generator Wind Turbine Using a Parallel Grid Side Rectifier and Series Grid Side Converter, P. S. Flannery and G. Venkataramanan, IEEE Transactions on Power Electronics, Vol. 23, No. 3, May 2008, pp. 1126–1135.

[40] L. Fan, Z. Miao, X. Wang, "Sensorless Maximum Power Point Tracking in Multi-Type Wind Energy Conversion Systems", Proceedings of the 48th IEEE Conference on Decision and Control, 2009 held jointly with the 2009 28th Chinese Control Conference. CDC/CCC 2009, pp. 6823-6828, 15-18 Dec. 2009

[41] "Fault Ride Through of DFIG Wind Turbines During Symmetrical Voltage Dip with Crowbar or Stator Current Feedback Solution", Energy Conversion Congress and Exposition (ECCE), 2010 IEEE, pp. 2771–2777, 12–16 September 2010.

[42] Modelling and Experimental Verification of Grid Interaction of a DFIG Wind Turbine, IEEE Transactions on Energy Conversion, Vol. 20, No. 4, Dec. 2005, pp. 878-886. A. Petersson, T. Thiringer, L. Harnefors, and T. Petru.

[43] A Fast Method To Evaluate Annual Energy Production of Different Off-Shore Wind Farm Configurations Connected to a VSC-HVDC Line Transmission Including Evaluation of a New Variable Speed Wind Turbine Concept Based on RCC-WRIG, J. V. Barreras and F. V. Sánchez, Msc. Thesis, Aalborg University, Institute of Energy Technology, 2009

[44] Speed Sensorless Control of DFIG Based MRAS Observer, International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, Paper ID 210, pp. 476-481, December 2010. A. A. Naassani, A. Ghazal, A. Joukhadar, and A. El Shafei.

[45] "DFIG Control Performance Under Fault Conditions For Offshore Wind Applications," 18th International Conference and Exhibition on Electricity Distribution, 2005, Cired 2005, pp. 1–5, 6–9 June 2005, by G. Pannell, D. Atkinson, R. Kemsley, L. Holdsworth, P. Taylor, and O. Moja.

[46] An MRAS Observer for Sensorless DFIM Drives with Direct Estimation of the Torque and Flux Rotor Current Components by F. C. Dezza, G. Foglia, M. F. Iacchetti, and R. Perini was published in IEEE Transactions on Power Electronics, Vol. 27, No. 5, May 2012, pp. 2576-2584.

[47] Wind Farms Fault Ride Through Using DFIG with New Protection Scheme, IEEE Transactions on Sustainable Energy, Vol. 3, No. 2, April 2012, pp. 242-254. K. E. Okedu, S. M. Muyeen, R. Takahashi, and J. Tamura

[48] Ride Through of Wind Turbines With Doubly Fed Induction Generator Under Symmetrical Voltage Dips, E. Guba, E. Olea, J. Ruiz, and L. Marroyo, IEEE Transactions on Industrial Electronics, Vol. 56, No. 10, Oct. 2009, pp. 4246–4254.

[49] Crowbar System in Doubly Fed Induction Wind Generators, by M. B. C. Salles, K. Hameyer, J. R. Cardoso, A. P. Grilo, and C. Rahmann, Energies, Vol. 3, No. 4, February 2010, pp. 738–753.

CHAPTER-8

APPENDIX

```
   close all;
   clear all;
   clc;



   f=50; where f is the frequency
  Ps=2e6; where Ps is the stator power.
  n=1500; where n is the rotor speed
 Vs = 690; where Vs is the stator voltage
  Is = 1760; where Is is the stator current
 Tem = 12732; Where Tem is the electromechanical torque

 P=2;
 u=1/3;

Vr=2070; where Vr is the rotor voltage
smax=1/3; where smax is the maximum state of charge
Vr_stator=Vr*smax*u;where Vr is the rotor side voltage with stator frame reference
Rs=2.6e-3;
Ls=Lm+Lsi; where Ls :total stator side inductance
Lr=Lm+Lsi;  where Lr : total inductance of the rotor
Vbus=1150;


%Vs=690*sqrt(2/3);
J=127; Inertia Constant
D=1e-3;Turbine coefficient

Fsw=4e3; Stator winding force
Ts=1/fsw/50; Torque on stator side

tau_i=(sigma*Lr)/Rr; where tau is Internal Torque
tau_n=0.05/4; where tau_n is the torque produced by turbine speed
wni=100*(1/tau_i); where wni is Wind turbine speed
wnn=1/tau_n;wnn is the wind velocity

kp_id = ( 2 * wni * sigma * Lr ) - Rr; where kp_id and kp_iq are the coefficientsPI
kp_iq = kp_id;
ki_id = ( wni ^ 2) * sigma * Lr; where ki_id and ki_iq are the coefficients of PI
ki_iq=ki_id;
kp_n=(2*wnn*J)/p;
ki_n = ((wnn^2)*J)/p;
```

```
 N=100; where N is the gear ratio
 Radio=42;where radio is the interference factor of the turbine system
 ro=1.225; turbine resistance



beta=0; This is a beta field
ind2=1;

       for

lambda=0.10:0.010:11.80

lambda (ind2)=(1./((1./(lambda-0.02.*beta)+(0.003./(beta^3+1)))));
Cp(ind2)=0.72.*(15./lambdai(ind2)-0.579.*beta-0.002.*beta^2.139
-13.199).* (Exp(-18.39./ lambda (ind2)));Ct(ind2)=Cp(ind2)/lambda;
Ind2=ind2+1;
end
tab_lambda=[0.10:0.010:11.80];



Cp_max=0.439;
lambda_opt=7.199;
Copt=((0.50 *ro*pi*(Radio^5)*Cp_max)/(lambda_opt^3));



P = 1.0e+06 *[0,0,0,0,0,0,0.04719,0.1098,0.181499,0.25689,0.34179, ...
 0.4436,0.7046,0.867,1.052,1.2616,1.498,1.761,2.053,...
 2.35,2.40,2.402,2.402,2.40,2.40, 2.40];

V = [0.0000,0.555,1.11,1.666,2.222,2.778,3.333,3.889,4.4444,...
  5.00,5.5,6.11,6.67,7.22,7.78,8.333,8.89,9.44,...
 10.00,10.56,11.111,11.667,12.2222,12.7778,14.33,12.889,...
 13.444,14.999];

figures
subplot(1,2,1)
plot(tb_lambda,Ct,'line-width',1.5)
xlabel('lambda','font-size',14)
ylabel('Ct','font-size',14)
subplot(1,2,2)
plot(V,P,'linewidth',1.5)
grid
xlabel('Wind speed (m/s)','font-size',14)
ylabel('Power(W)','font-size,14)


Cbus=80e-3;
Rg=20e-6; where Rg is the grid resistance
```

```
 Lg=400e-6;where Lg is the grid inductance

Kpg=1 / (1.5*Vs*sqrt(2/3));Kpg is the proportional factor of the GSC.
Kqg=-Kpg;

tau_ig=Lg/Rg;
wnig=60*2*pi;
kp_idg=(2*wnig*Lg)-Rg;
kp_iqg=kp_idg;
ki_idg=(wnig^2)*Lg;
ki_iqg=ki_idg;

kp_v=-10000;
ki_v=-3000000;
```