



The fast growth of wind generation has led to concern about the effect of wind power on the transient stability of the electric grid. New studies must be performed in order to evaluate the behaviour of the wind farms after severe faults and improve the design of the wind farms in an efficient and economical way. Under such circumstances, the most demanding requisite for wind farm is the Fault Ride-Through (FRT) capability. Wind farms connected to high voltage transmission system must stay connected when a voltage dip occurs in the grid, otherwise, the sudden disconnection of great amount of wind power may contribute to the voltage dip, with terrible consequences. Therefore, the dynamic and transient analyses of wind generators are necessary. This book proposes some methods with suitable control strategies for wind power application that helps wind farms to be connected during grid disturbances, achieving the grid code provisions in both steady and transient conditions. The results in this book can be significant in understanding the transient stability phenomena of fixed and variable speed wind turbines and also in designing of wind farms based on transient stability requirements.

Kenneth Eloghene Okeadu

Low Voltage Ride Through Enhancement of Grid Connected Wind Farms

Augmentation of Variable Speed Wind Turbines
Fault Ride Through (FRT) Capability



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Victor Flores Mendes



Low Voltage Ride Through Enhancement Of Grid Connected Wind Farms Augmentation Of Variable Speed Wind Turbines Fault Ride Through FRT Capability:

Ride-Through Fault Capability of Doubly-Fed Induction Wind Generators Victor Flores Mendes, 2016-01-08 Due to the continuing growth of the installed power capacity of wind farms worldwide the grid codes define specific requirements to the connection of wind turbines to the grid One of these requirements is the ride through fault capability RTFC that is the equipment capability of continuing operating during voltage sags This book presents the analysis of the behavior of the doubly fed induction generator technology DFIG during balanced and unbalanced voltage sag and proposes novel control strategies to improve the RTFC The system behavior analysis and the strategies validation are performed using mathematical models in time and frequency domains simulation results with a Simulink Matlab model 2MW and experimental results in two scaled test benches 4kW and 25kW The limitations for the operation of the strategies are also analyzed The main objectives of this work are to point the system weaknesses and to contribute to the study of low voltage ride through strategies LVRT of the DFIG technology

Fault Ride-through Capability of Doubly-fed Induction Generators Based Wind Turbines Abobkr Hamdia Abobkr, 2013 ABSTRACT Due to growing concerns over climate change more and more countries are looking to renewable energy sources to generate electricity Therefore wind turbines are increasing in popularity along with doubly fed induction machines DFIGs used in generation mode Current grids codes require DFIGs to provide voltage support during a grid fault The fault ride through FRT capability of DFIGs is the focus of this thesis in which modifications to the DFIG controller have been proposed to improve the FRT capability The static synchronous compensator STATCOM controller has been applied with proposed method to study its influence on the voltage at the point of common coupling PCC The proposed method was also compared with other FRT capability improvement methods including the conventional crowbar method The simulation of the dynamic behaviour of DFIG based wind turbines during grid fault is simulated using MATLAB Simulink The results obtained clearly demonstrate the efficacy of the proposed method

Integration of Large Wind Farms to Weak Power Grids Kamyab Givaki, 2017 Power grids are changing significantly with the introduction of large amounts of renewable energy especially wind into the system Integration of wind energy into the grid is challenging as firstly it increases penetration stresses when compared to conventional generation as the wind is intermittent and fluctuates in power output Secondly most of the wind farms are located in offshore or rural areas which have good wind conditions The grid in these regions is not normally strong Most of the modern variable speed wind turbines use voltage source converters VSCs for grid integration However integrating VSCs to weak power grids will cause instability when a large amount of active power is transferred to the grid In this thesis the integration of wind farms to very weak power grids is investigated A multiple input multiple output MIMO model of the grid side VSC of a wind turbine is developed in the frequency domain in which the d axis of the synchronous reference frame SRF is aligned with the grid voltage Then this model has been used as the basis for

modelling the multiple parallel converters in the frequency domain In this thesis to improve the stability of the very weak grid connected of VSCs a control method based on the d and q axis current error is introduced This controller compensates the output angle of the phase locked loop PLL and the voltage amplitude of the converter Using this controller full rated active power transfer and fault ride through are achieved under very weak grid connection Furthermore a stabiliser controller based on virtual impedance is proposed in this thesis to achieve stable operation of a very weak grid connected VSC This stabilising control method enables the VSC to operate at full power and to ride through faults under very weak grid conditions Based on this principle an external device is proposed that can be utilised and connected to a weak point of the grid to allow a large amount of VSC interfaced power generation e g wind power to be connected to the grid without introducing stability issues

Transient Stability Improvement of DFIG Based Variable Speed Wind Turbine Generator System Using DC Resistive Fault Current Limiter Md Maruf Hossain, 2016 Presently the doubly fed induction generator DFIG is the most popular technology to harness the wind power due to its ability to adapt to variable wind speed and to capture more wind energy However the DFIG based variable speed wind generator is vulnerable to faults as the stator of the DFIG is directly connected to the grid Both symmetrical and asymmetrical faults may cause the DFIG face high mechanical stress which may lead to mechanical damage According to the grid code the transient stability enhancement of the DFIG system is very important Though the DFIG has a salient feature of the fault ride through capability this is not sufficient to preserve the regulations of the grid code at all situations In this dissertation in order to enhance the transient stability of the DFIG based variable speed wind generation system first the performance of the different types of internal controlled devices such as crowbar DC chopper and parallel capacitor with the DC link of DFIG system has been investigated From the analysis it is established that the internal controlled devices cannot maintain the grid code during all types of network faults This testifies the importance of the application of the auxiliary devices to enhance the transient stability of the DFIG based wind generator system An investigation has been made to explore a device which could provide the best performance in terms of transient stability enhancement for a grid connected DFIG system during faults Ultimately a DC resistive superconducting fault current limiter SFCL is proposed because of its best performance The DC resistive SFCL reduces the system power losses during stable operation of the network with improved system efficiency in comparison with the conventional SFCL One of the salient features of using the SFCL is that it does not require any controller and immune to any sort of cyber threat or vulnerability To verify the transient stability performance of the DFIG based wind generator system with the proposed DC resistive SFCL both the symmetrical and asymmetrical faults are considered The performance of the DC resistive SFCL is compared to that of the series dynamic braking resistor SDBR and the conventional SFCL Simulations are carried out by using the Matlab Simulink software Simulation results clearly indicate that the proposed DC resistive SFCL shows the best performance to enhance the transient stability of the DFIG based wind generator system

Advanced Distributed Wind Turbine Controls Series: Part 3-Wind Energy in Grid-Connected Deployments; Microgrids, Infrastructure Resilience, and Advanced Controls Launchpad (MIRACL). ,2022 In recent years the technical ability and requirement for distributed wind turbines to provide grid support services beyond maximum energy production has increased Ancillary services leveraged through advance controls of a wind turbine support grid reliability and resilience One ancillary service that is significant to a grid connected wind turbine deployment is fault ride through FRT in response to the voltage and frequency events in the power system As part of the Microgrids Infrastructure Resilience and Advanced Controls Launchpad MIRACL this paper demonstrates through desktop simulations the wind turbine s FRT capabilities to support stable grid operation We establish that the wind turbine models exceed FRT performance requirements stipulated in IEEE 1547 2018 regarding interconnection and interoperability of distributed energy resources Utilizing a standalone CART2 600 kW wind turbine connected to the NREL s Flatirons Campus grid we study voltage and frequency FRT utilizing various test cases One of the test cases under study is a Category III voltage fault defined in IEEE 1547 2018 and derived from CA Rule 21 Some distributed wind turbines were unable to connect to the grid following the Rule 21 enforcement in California Even if this is not a general requirement elsewhere the grid codes might evolve in this direction This study illustrates how a distributed wind turbine can provide some of these FRT services and enable a pathway toward a higher contribution of renewable energy in a distribution grid

Fault Ride-Through Capacity Enhancement of Fixed Speed Wind Generator by A Modified Bridge-type Fault Current Limiter Gilmanur Rashid,2014 Fault Ride Through FRT is a common requirement to abide by grid code all over the world In this work to enhance the fault ride through capability of a fixed speed wind generator system a modified configuration of Bridge Type Fault Current Limiter BFCL is proposed To check the effectiveness of the proposed BFCL its performance is compared with that of the Series Dynamic Braking Resistor SDBR A harmonic performance improvement by the proposed method is also analyzed Three line to ground 3LG line to line LL and single line to ground 1LG faults were applied to one of the double circuit transmission lines connected to the wind generator system Simulations were carried out using Matlab Simulink software Simulation results show that the proposed BFCL is very effective device to achieve the FRT and suppress fault current that eliminates the need for circuit breaker replacement Also the BFCL improves the harmonic performance and helps follow harmonic grid code Moreover it was found that the BFCL works better than the SDBR and has some distinct advantages over the SDBR

Ride-through Capability Predictions for Wind Power Plants in the ERCOT Network National Renewable Energy Laboratory (U.S.),Electric Reliability Council of Texas,2005

Clemson University Wind Turbine Drivetrain Test Facility ,2016 In November of 2009 Clemson University was awarded a competitive grant from the U S Department of Energy to design build and operate a facility for full scale highly accelerated mechanical testing of next generation wind turbine drivetrain technologies The primary goal of the project was to design construct commission and operate a state of the art sustainable facility that permits full scale highly

accelerated testing of advanced drivetrain systems for large wind turbines. The secondary goal was to meet the objectives of the American Recovery and Reinvestment Act of 2009 especially in job creation and provide a positive impact on economically distressed areas in the United States and preservation and economic recovery in an expeditious manner. The project was executed according to a managed cooperative agreement with the Department of Energy and was an extraordinary success. The resultant new facility is located in North Charleston SC providing easy transportation access by rail road or ship and operates on an open access model such that it is available to the U S Wind Industry for research analysis and evaluation activities. The 72 m by 97 m facility features two mechanical dynamometer test bays for evaluating the torque and blade dynamic forces experienced by the rotors of wind turbine drivetrains. The dynamometers are rated at 7.5 MW and 15 MW of low speed shaft power and are configured as independent test areas capable of simultaneous operation. All six degrees of freedom three linear and three rotational for blade and rotor dynamics are replicated through the combination of a drive motor speed reduction gearbox and a controllable hydraulic load application unit LAU. This new LAU setup readily supports accelerated lifetime mechanical testing and load analysis for the entire drivetrain system of the nacelle and easily simulates a wide variety of realistic operating scenarios in a controlled laboratory environment. The development of these two dynamometer test rigs is the first significant achievement for the project. These test rigs embody a new manner of test due to the system configuration and completely new design with a free floating loading hub in the LAU. This project provided the catalyst for the advancement to this new test rig configuration that has been adopted by every significant wind turbine test rig constructed since the inception of this project. There are currently two different vendors supplying these new systems. Catalyzing this new design is the second major success of the project. With the increased market penetration of wind energy over the past decade many regions and countries have developed specific electrical grid specifications and performance codes for large wind farms to ensure operational reliability and stability. These grid codes provide requirements for interconnection with the grid during low or high voltage phenomena typically encountered during and after system fault events. Given the installed infrastructure of the Wind Turbine Drivetrain Testing Facility WTDTF a natural expansion of facility capability was to include the necessary equipment for performing fault ride through evaluations of wind turbines to the Low Voltage Ride Through LVRT codes. Once the decision was made to expand the scope of the original grant into fault ride through testing it was clear that there are several markets not just wind which could benefit from this type of test and that simple fault ride through testing could be extended into a broader scope of electrical testing capabilities. It was at this point that Clemson University was awarded a second grant to build a 15 MW Hardware In the Loop HIL Grid Simulator in order to establish world class electrical testing capabilities to compliment the mechanical testing at the WTDTF. This third significant achievement resulted in the 15 MW HIL Grid Simulator as the corner stone of the Duke Energy eGRID Center and is collocated with t

Novel Sensorless Generator Control and Grid Fault Ride-through Strategies for Variable-speed Wind

Turbines and Implementation on a New Real-time Simulation Platform Sheng Yang,2010 **Advanced Fault Ride Through Control of DFIG Based Wind Turbines Including Grid Connection Via VSC-HVDC** Christian Feltes,2012 Impact of Past, Present, and Future Wind Turbine Technologies on Transmission System Operation and Performance Michael R. Behnke,2006 *Fault Ride-through Control Paradigms for DFIG-based Wind Turbines* Mohammad Javad Morshed,2018
Low Voltage Ride Through (LVRT) Solution For Wind Farm Using STATCOM Pravin Phutane,2016-04-08

Controllable Grid Interface for Testing Ancillary Service Controls and Fault Performance of Utility-Scale Wind Power Generation: Preprint ,2017 The rapid expansion of wind power has led many transmission system operators to demand modern wind power plants to comply with strict interconnection requirements Such requirements involve various aspects of wind power plant operation including fault ride through and power quality performance as well as the provision of ancillary services to enhance grid reliability During recent years the National Renewable Energy Laboratory NREL of the U S Department of Energy has developed a new groundbreaking testing apparatus and methodology to test and demonstrate many existing and future advanced controls for wind generation and other renewable generation technologies on the multimewatt scale and medium voltage levels This paper describes the capabilities and control features of NREL s 7 MVA power electronic grid simulator also called a controllable grid interface or CGI that enables testing many active and reactive power control features of modern wind turbine generators including inertial response primary and secondary frequency responses and voltage regulation under a controlled medium voltage grid environment In particular this paper focuses on the specifics of testing the balanced and unbalanced fault ride through characteristics of wind turbine generators under simulated strong and weak medium voltage grid conditions In addition this paper provides insights on the power hardware in the loop feature implemented in the CGI to emulate in real time the conditions that might exist in various types of electric power systems under normal operations and or contingency scenarios Using actual test examples and simulation results this paper describes the value of CGI as an ultimate modeling validation tool for all types of grid friendly controls by wind generation **Grid Fault Ride Through for Wind Turbine Doubly-fed Induction Generators** Graham Steven Pannell,University of Newcastle upon Tyne. School of Electrical, Electronic & Computer Engineering,2008 NWTC Controllable Grid Interface (Fact Sheet) ,2012 NREL s Controllable Grid Interface tests wind turbines off line from the grid verifies compliance with standards and provides grid operators with the performance information they need for a fraction of the time and cost it would take to test the turbine in the field To understand the behavior of wind turbines during grid disturbances manufacturers and utility grid operators need to perform a series of tests and accurate transient simulation studies The latest edition of the IEC 61400 21 standard describes methods for such tests that include low voltage ride through LVRT active power set point control ramp rate limitations and reactive power capability tests The IEC methods are being widely adopted on both national and international levels by wind turbine manufacturers certification authorities and

utilities Utility operators also need to estimate how much power wind turbines might be able provide to help regulate grid frequency during situations when they need additional energy quickly and after design modifications or changes are made to control software manufacturers may be required to retest their turbines But testing wind turbines in the field can be a lengthy and expensive process often requiring manufacturers and utility operators to send equipment and personnel to remote locations for long periods of time NREL s National Wind Technology Center NWTC has developed a new Controllable Grid Interface CGI test system that can significantly reduce the time and cost required to conduct these tests The CGI is first test facility in the United States that has fault simulation capabilities and allows manufacturers and system operators to conduct the tests required for certification in a controlled laboratory environment It is the only system in the world that is fully integrated with two dynamometers and has the capacity to extend that integration to turbines in the field and to a matrix of electronic and mechanical storage devices all of which are located within close proximity on the same site NREL s 7.5 MVA CGI tests wind turbines off line from the grid verifies compliance with standards and provides grid operators with the performance information they need for a fraction of the time and cost it would take to test the turbine in the field The system combines hardware and real time control software and is designed to operate with the NWTC s 2.5 MW dynamometer as well as the center s new 5 MW dynamometer test facilities It is designed to work with four types of wind turbines photovoltaic systems and energy storage inverters Results from the dynamometer tests can also be used to fine tune and validate the dynamic models used in integration studies and help industry improve turbine performance and develop test standards for renewable technologies and energy storage

Fault Ride-through of Wind Farms Using Series Dynamic Braking Resistors
Andrew Causebrook, University of Newcastle upon Tyne. School of Electrical, Electronic and Computer Engineering, 2008

Variable-speed Wind Power Plant Operating with Reserve Power Capability Mohit Singh, 2013 As the level of wind penetration increases wind turbine technology must move from merely generating power from wind to taking a role in supporting the bulk power system Wind turbines should have the capability to provide inertial response and primary frequency governor response Wind turbine generators with this capability can support the frequency stability of the grid To provide governor response wind turbines should be able to generate less power than the available wind power and hold the rest in reserves ready to be accessed as needed In this paper we explore several ways to control wind turbine output to enable reserve holding capability The focus of this paper is on doubly fed induction generator also known as Type 3 and full converter also known as Type 4 wind turbines

Wind Power Plant Enhancement with a Fault-current Limiter :. E. Muljadi, 2011

Variable-speed Wind Power Plant Operating with Reserve Power Capability :. Mohit Singh, 2013

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