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MODELING, ANALYSIS AND OPERATION OF WIND DRIVEN DFIG UNDER UNBALANCE NETWORK VOLTAGE CONDITIONS: A REVIEW

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ABSTRACT

This paper investigates the operation of wind driven DFIG under unbalance Voltage or unsymmetrical fault condition. According to grid codes world wide the wind driven DFIG are required to supply reactive power during and after the fault. It has been observed that the conventional vector control method used for control of DFIG does not work well during fault conditions. To reduce the oscillations in electromagnetic torque and Stator Active power and to maintain constant DC link Voltage a new control strategy has to be presented. Sequential decomposition of positive and negative sequence currents and controlling it with PI plus proportional Resonant controller is adopted both on Rotor side and grid side converter .The paper presents a development in methodologies for controlling wind driven DFIG during fault ride conditions. In recent year improved control strategy using different Artificial Intelligence based controllers are used to control the RSC and GSC without sequence decomposition.

Key Words: Wind turbines, Rotor side converter, Doubly fed induction generator, Low-voltage ride-through

INTRODUCTION

Over the last few years, doubly fed induction generators (DFIGs) have dominated the largest world market share of wind turbines (WTs), as an alternative concept to conventional variable speed generators. A DFIG consists of a wound rotor induction generator with its stator windings directly connected to the grid and its rotor windings connected to the grid via an arrangement of two ac/dc back-to-back converters. As the converters are sized for only the one third of the rated power of the turbine, this topology accomplishes a cost-effective, decoupled control of the active and reactive power. However, DFIGs present a major drawback concerning their operation during grid faults. The voltage drop at the stator windings, due to grid faults, results in a sudden change in the stator flux of the DFIG, which finally leads to an over current to the rotor windings, due to the magnetic coupling. This over current may cause severe damage to the semiconductors of the rotor side converter and large fluctuations of the dc-link voltage. When DFIGs started being used in WTs, the penetration of WTs to the power system was relatively low, so their control concerning faults focused on the protection of the DFIGs themselves and no special actions were taken in order to provide the DFIGs with the capability of contributing to network support. Under this concept, in order to protect the generator, its rotor windings were protected with a crowbar circuit. This device consists of a bank of resistors, which is connected to the rotor windings through power electronic devices. When a fault is detected, the rotor windings are connected to the crowbar resistors, whereas the rotor-side converter is temporary disabled. Thus, the short-circuit current flows through the crowbar instead of the rotor-side converter. With this solution, the machine is effectively protected, but due to the fact that the blocking of the rotor-side converter leads to the partial loss of power control during the crowbar action, large transients are generated after the fault, which may lead to the disconnection of the machines from the grid. In addition, during the activation of the crowbar, the DFIG is converted to a conventional squirrel-cage induction generator, absorbing a large amount of reactive power from the grid. Nowadays, due to the fact that WTs represent a significant part of the total generation in electrical systems, system operators worldwide have revised their grid codes (GCs), making the requirements concerning the fault ride-through (FRT) capability of WTs more stringent. The majority of the GCs require that the WTs should provide low voltage ride-through (LVRT) capability for grid faults resulting in a 85% voltage drop or even more. This means that they should stay connected to the grid during and after

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grid faults, contributing to the system stability. Moreover, they should supply reactive power to the grid in order to support the voltage recovery. This requirement cannot be fulfilled by DFIGs protected with a conventional crowbar circuit, as they cannot generate reactive power during the activation of the crowbar. For this reason, researchers started addressing the issue of the FRT of the DFIGs from several other points of view. For instance, proposes an improved version of the crowbar circuit, eliminating the duration of the crowbar action. Reference investigates the application of a STATCOM to achieve the uninterrupted operation of a wind turbine equipped with a DFIG during grid faults. In a control strategy using a series grid-side converter is proposed. Although these last two arrangements are promising in some cases, the complexity and the additional cost impair their applicability. Other papers propose some methods for FRT without any auxiliary external devices . They show that if the DFIG controllers are suitably designed, it is possible to limit the rotor over current. Xiang et al. in propose a control strategy that orients the rotor current to counteract the dc and negative sequence components of stator flux linkage. Experimental results show that under certain circumstances, the rotor current is limited; therefore, the use of the crowbar can be avoided. However, this method has high dependence on the estimation of stator flux linkage and the exact knowledge of the parameters of the DFIG. In is proposed a flux linkage tracking-based control strategy, to suppress the fault rotor current. Its control objective is to keep the rotor flux linkage close to the stator flux linkage instead of maintaining a certain value accurately. In this way, there is no need to decouple the dc and negative sequence components, which means the control scheme does not depend on the exact knowledge of the system parameters. Although the proposed control method is promising, the paper could have studied a bigger voltage dip for the case of the three-phase fault, as it is imposed by international grid codes. In , Hu et al. propose the use of a virtual resistance in combination with demagnetization control to limit the rotor side over currents. This method manages to enlarge the control range in relation to the control method proposed in, but the drawbacks that were met in still cannot be avoided. The study described in suggests that a properly designed fuzzy controller (FC) presents a better performance in presence of variations of parameters and external disturbances than a traditional proportional integral (PI) controller. Comparative results between the two controllers showed that the FC manages to limit the generator currents during the fault, avoiding the use of the crowbars. However, it would be interesting to see which would be the response of this control system and what changes should possibly be done, for the case where the DFIG would be connected to a weaker bus, instead of an infinite bus. Reference proposes a control strategy based on genetic algorithms (GA) for the acquisition of the optimal gains of the PI controllers to the rotor-side converter of the DFIG. The GA fitness function is defined with the objective to reduce the over-current in the rotor circuit, in order to maintain the converter in operation during the fault period. Simulation results show that, in some cases, if the GA gain adjustment is used, the use of the crowbar protection-scheme can be avoided. However, in this work, no analytical information is given about the electrical grid connected to the DFIG. In addition, it is tested for a small voltage dip in relation to the voltage dip described in most grid codes. Papers propose some methods for FRT without any auxiliary external hardware for the case of asymmetrical grid faults. Based on the experience gained from the studies published so far, this paper tries to extend the concept of the protection of the DFIG without the use of additional hardware, in more demanding situations, such as the connection of a relatively weak electrical system with the DFIG in the case of a fault resulting in a bigger voltage dip, as it is required from the GCs. The proposed control scheme contributes to the optimal coordination of the two converters, aiming to attenuate the disturbances to the system caused by the fault and ensure system stability. In order to encounter the difficulties met due to the uncertainties of the system modeling and considering the nonlinearity of the system, the controllers were designed based on fuzzy logic (FL) and GAs, which are more efficient in such cases. By this concept, the over currents at the rotor windings and the dc side over voltages are effectively eliminated. In addition, the FRT requirement concerning the reactive power supply is fulfilled. In this point, it would be necessary to point out that many previous papers have tested their proposed systems using small scale test equipment that had a rotor voltage rating far too high, when compared with the megawatt range WT generators that have stator to rotor winding turns ratio around 2.5 to 3.

LITERATURE REVIEW

Year 2007

Wang, Lu Xu develops the dynamic model and control scheme for DFIG to improve the performance and Stability under unbalanced grid conditions. The modeling is done using both positive and negative sequence components using Stator Voltage orientation. Here the control Strategy for active, reactive powers and electromagnetic torque oscillations during unbalanced system network is presented. The system control is based on a positive sequence controller which controls average active and reactive Power and a negative sequence controller which minimizes torque or power oscillations. The proposed scheme works well under unbalance Voltage network.

Hu, He, Heng presents a unified positive and negative sequence dual dq dynamic model of wind turbine driven DFIG under unbalanced grid Voltage conditions using PWM Voltage source Converter(VSC).The modified control design for the grid side converter in the Stationary αß frames diminishes the amplitude of DC link Voltage ripples twice the grid frequency. On the rotor side converter two control strategies using PI controller improves the fault ride capability of the DFIG based wind power generation system during unbalanced network supply. A rotor current control scheme based on positive and negative synchronously rotating reference frame was proposed to provide precise control of rotor current.

Xu and Wang present an analysis and control of DFIG based wind generation system under unbalanced network conditions. The system is modeled in positive and negative synchronous reference frame. It shows that conventional vector control of DFIG without considering network unbalance results in excessive oscillations on Stator active and reactive Power and electromagnetic torque and stator and rotor currents even with a small Stator Voltage unbalance. A rotor current control strategy based on positive and negative (dq) reference frames is used to provide precise control of rotor positive and negative sequence currents. On account of negative rotor current influence converter voltage /power ratings is increased. Here in this paper an effective control strategy is presented.

Yusuf Yasa, Evren Isen Yilmaz Sozer , Erkan Mese, Hilmi Gurleyen in their Paper presents detailed analysis of doubly fed induction generator (DFIG) wind turbine electrical components during normal and unbalanced fault condition. Wind turbine components are individually modeled and then combined in a simulation process which is called coupled simulation. The coupled simulation results show that grid frequency oscillation occurs on q and d axis currents under one phase-ground fault condition. Experimental study has been done to show the effects of fault on rotor currents.

Year 2008

Hu, He in their paper presented a new concept and mathematical model of instantaneous active & reactive Power at different locations of VSC. To avoid the use of band trap or notched filter for decomposing the positive and negative sequence dq component of current and voltage a new scheme with multi frequency proportional resonant controller in the stationary αß frame is employed to improve the steady state and dynamic response under generalized unbalanced operation condition. The proposed control scheme is the stationary reference frame provides sufficiently steady state tracing capability for ac current and better transient response in compensation for wide range unbalanced operation conditions. By reducing oscillating terms or harmonics from DC link Voltage and stator powers the ratings of the capacitor and converters can be kept low.

He Hu et al presents the analysis and modeling of DFIG based wind power generation system under unbalanced network voltage conditions. During unsymmetrical fault there is existence of negative sequence currents and Voltages. For this the system parameter gets disturbed. Here a new current control scheme consisting of Proportional Integral (PI) controller plus resonant compensator is presented which is in rotating reference frame and is able to provide an enhance current control for both rotor and grid side converters without decomposition of positive and negative sequence currents. Under unbalance or low stator voltage conditions the operation of wind driven DFIG must be taken care of by simultaneously removing the fluctuations in electromagnetic torque and output active power. For the RSC the main concern is to focus on limited voltage magnitude supplied with different modulation technique and for the GSC the most important issue is to maintain dc link Voltage constant.

Year 2009

He Hu presented a control strategy involving a proportional resonant controller tuned at grid frequency & implemented in the stator stationary reference frame without involving decomposition of the positive and negative sequence currents. The oscillation in electromagnetic torque, Stator active power, double the grid frequency is eliminated. Three selective control targets for GSC is developed to reduce the pulsations in stator active power. RSC is controlled to control the oscillations of the electromagnetic torque.

Wang Xu Hu He et al presented a proportional integral plus multi frequency resonant current controller for grid connected voltage source converter under unbalance voltage conditions. The control scheme is implemented on positively synchronously rotating reference frame and composed of PI plus MFRC tuned at frequency of 2ws and 6ws respectively. The scheme works well under unbalance Voltage conditions by reducing active power oscillations and 5^{th}, 7^{th} order current harmonics elimination during supply voltage imbalances

Yi Zhou, Paul Bauer, Jan A. Ferreira, Jan Pierik provides the benefits of variable speed operation cost-effectively, and can control its active and reactive power independently. Crowbar protection is often adopted to protect the rotor-side voltage source converter (VSC) from transient over current during grid voltage dip. But under unbalanced grid voltage condition, the severe problems are not the transient over current, but the electric torque pulsation and dc voltage ripple in the back-to-back VSCs. This paper develops dynamic models which investigates the behavior of DFIG during unbalanced grid voltage condition, and proposes new controllers in separated positive and negative sequence. Methods to separate positive and negative sequence components in real time are also developed, and their responses to unsymmetrical voltage dip are compared. It is seen that the "signal delay cancellation" is much faster than the "low-pass filter," and is chosen in this study. Equations of instantaneous active p and reactive power q, and voltage equations of DFIG and grid VSC in positive dq and negative dq sequence are derived.

Jesús López, , Eugenio Gubía, , Eneko Olea, Josu Ruiz, and Luis Marroyo This paper deals with the grid fault ride-through capability of doubly fed induction generators. These machines are very sensitive to grid disturbances. To prevent the damages that voltage dips can cause on the converter, most machines are equipped nowadays with a crowbar that short circuits the rotor. However, during the crowbar activation, the rotor converter must be disconnected, hence the power generated with the turbine is no longer controlled. In doing so, the crowbar impedes the wind turbine from carrying out the voltage stabilization required by most new grid codes. This paper proposes a novel control strategy that notably reduces the crowbar activation time. As a result, the control of the turbine might shortly be resumed and the turbine can furthermore supply a reactive power fulfilling the newest grid regulations.

Year 2010

Van-Tung Phan and Hong-Hee Lee An enhanced control strategy for variable-speed unbalanced stand-alone doubly-fed induction generator-based wind energy conversion systems is proposed in this paper. The control scheme is applied to the rotor-side converter to eliminate stator voltage imbalance. The proposed current controller is developed based on the proportional-resonant regulator, which is implemented in the stator stationary reference frame. The resonant controller is tuned at the stator synchronous frequency to achieve zero steady-state errors in rotor currents without decomposing the positive and negative sequence components. The computational complexity of the proposed control algorithm is greatly simplified, and control performance is significantly improved. An enhanced control scheme using the PR controller for unbalanced stand-alone DFIG systems was investigated in this paper. The proposed current controller was implemented in the stator stationary reference frame for controlling positive and negative sequence components without the sequential decomposition of the measured rotor currents. Consequently, the desired control target, i.e., eliminating the negative sequence components in unbalanced stator voltages, was well achieved with the proposed control method. Comparative results between the proposed and the conventional PI controllers indicated the ability of the former to perform a more precise and adequate control of proposed Strategy

Francisco K. A. Lima, Alvaro Luna, Pedro Rodriguez, Edson H. Watanabe, and Frede Blaabjerg, This paper presents a new control strategy for the rotor-side converter (RSC) of wind turbines (WTs) based on doubly fed induction generators (DFIG) that intends to improve its low-voltage ride through capability. The main objective of this work is to design an algorithm that would enable the system to control the initial over-currents that appear in the generator during voltage sags, which can damage the RSC, without tripping it. As a difference with classical solutions, based on the installation of crowbar circuits, this operation mode permits to keep the inverter connected to the generator, something that would permit the injection of power to the grid during the fault, as the new grid codes demand. This strategy is based on using the measured stator current values as the set point for the rotor current controller during the fault. As it has been demonstrated, in this way, it is possible to synthesize a current in the stator in opposition to the currents generated during the fault, preventing thus the stator/rotor windings from suffering over-currents, with no need of using crowbar circuits.

Year 2011

Xueqin Zheng Donghui Guo (2011) With the increasing of wind penetration in power systems, new grid codes require distributed energy resources to ride through temporary low voltage event and at the same time injecting reactive current into the grid. The purpose of this paper is to optimize control strategy and enhance the performances of the doubly fed induction generator wind power system by using the combination of double-vector-PWM control and the active crowbar in series with the stator windings. This control strategy can notably reduce the stator and rotor over-current and keep the dc bus voltage stable, which prevent the damages that voltage dips cause on the converter and power system. This paper dealt with low voltage ride through capability improvement in DFIG wind power system. An efficient control strategy was proposed. The proposed strategy is a combination of double-vector-PWM control strategy and active crowbars which are series with the stator windings for a DFIG system. The principles of the system operation and control strategy were described. The system performances during three-phase grid voltage dip was studied. The analysis and simulations results showed that the system can ride through under such a fault satisfactorily by maintaining the stability of the wind farm AC network and dc bus voltage, the output active and reactive power. The rotor and stator currents can considerably reduce at the instant of occurring and clearing the fault.

Sheng Hu, Xinchun Lin, Yong Kang, and Xudong Zou This paper presents a control strategy to improve the low-voltage ride-through capability of a doubly fed induction generator (DFIG); since the stator of a DFIG is directly connected to a grid, this sort of machine is very sensitive to grid disturbance. Grid voltage sag causes over-currents and over-voltages in rotor windings, which can damage the rotor-side converter (RSC). In order to protect the RSC, a classical solution based on installation of the so-called crowbar is adopted; however, as the DFIG absorbs reactive power from the grid, this type of solution deteriorates grid voltage sags and cannot meet the requirements of a new grid code. An improved control strategy which uses virtual resistance to limit rotor side over-currents is proposed in this paper, which can make a crowbar inactive and supply reactive power to fulfill the latest grid code requirement during voltage sags.

Year 2012

Mokryani, Siano et al presents a fuzzy logic based controller to increase fault ride through capability of variable speed wind turbine equipped with DFIG. The controller is designed in order to compensate Voltage ups and downs by regulating the active and reactive power generated by DFIG. Here the oscillations of stator active and reactive power are compensated simply by tunning the fuzzy controller without using any filter circuits.

V. Suresh, D. J. V Prasad presents a mathematical model of a doubly fed induction generator (DFIG) in the positive synchronous reference frame under distorted grid voltage conditions with the help of fuzzy logic controller. The oscillations of the DFIG's electromagnetic torque and the instantaneous stator active and r active powers are fully described when the grid voltage is harmonically distorted. Four alternative control targets are proposed to improve the system responses during grid harmonic distortions. A new rotor current control scheme implemented in the positive synchronous reference frame is developed. The control scheme consists Fuzzy logic controller and a resonant controller consequently, the fundamental and the fifth- and seventh-order components of rotor currents are directly regulated by the Fuzzy–R controller without sequential-component decompositions.

Yan Yan , Meng Wang , Zhan-Feng Song and Chang-Liang Xia presents a novel control strategy is proposed in this paper for the rotor side converter (RSC) of doubly-fed induction generator (DFIG)-based wind power generation systems. It is supposed to enhance the low-voltage ride-through (LVRT) capability of DFIGs during great-level grid voltage dips. The strategy consists of a proportional-resonant (PR) controller and auxiliary PR controllers. The auxiliary controllers compensate the output voltage of the RSC in case of grid faults, thus limiting the rotor inrush current of DFIG and meeting the requirements of LVRT. Sequential-component decompositions of current are not required in the control system to improve the response of system. Since the resonant compensator is a double-side integrator, the auxiliary controllers can be simplified through coordinate transformation. With limited RSC voltage ratings, the rotor fault currents of specified frequencies are eliminated to a great extent. The controller performs well, even when the angular frequency detection is not accurate. Simulations have been presented under symmetric and asymmetric grid fault conditions to confirm the analysis and verify the proposed control method.

Year 2013

Zarei, Asaei et al presented a new control method for rotor side converter (RSC) and grid side converter (GSC) of doubly fed induction generator (DFIG) is proposed. A combined vector control and direct power control for RSC and direct current control for GSC have been introduced. The RSC directly controls the stator d-q axis currents (rotating at synchronous speed ws) by applying an optimal voltage vector from a switching table. Under the unbalanced and distorted grid voltage conditions, the new control strategy injects a pure sinusoidal and balanced stator and GSC currents without any need of extracting the negative sequence and 5th and 7th voltage harmonics. Only a modified phase locked loop (PLL) to extract the positive sequence of the fundamental phase angle, is added to this situation.

Zaijun Wu , Chanxia Zhu and Minqiang Hu presents an improved control strategy for both the rotor side converter (RSC) and grid side converter (GSC) of a doubly fed induction generator (DFIG)-based wind turbine (WT) system to enhance the low voltage ride through (LVRT) capability. Within the proposed control strategy, the RSC control introduces transient feed-forward compensation terms to mitigate the high frequency harmonic components and reduce the surge in the rotor currents. The proposed GSC control scheme also introduces a compensation term reflecting the instantaneous variation of the output power of the rotor side converter with consideration of the instantaneous power of grid filter impendence to keep the dc-link voltage nearly constant during the grid faults. To provide precise control, non-ideal proportional resonant (PR) controllers for both the RSC and GSC current regulation are employed to further improve dynamic performance. Further DC link Voltage equation is modified by modifying the rotor power equation in terms of grid side parameter.

Xinyan Zhang, Xuan Cao, Weiqing Wang, Chao Yun presents in their paper the rotor short current of doubly-fed induction generator (DFIG) was limited by introducing a rotor side protection circuit. Second, the voltage of DC bus was limited by a DC energy absorb circuit. Third, STATCOM was used to increase the low level voltages of the wind farm. Simulation under MATLAB was studied and the corresponding results were given and discussed. The methods proposed in this paper can limit the rotor short current and the DC voltage of the DFIG WT to some degree, but the voltage support to the power system during the fault largely depend on the installation place of STATCOM. New FRT needs not only the WTs keep on grid but also can provide voltage support or generator reactive power to the power system.

Shuai Xiao, Geng YangHonglin Zhou, and Hua Geng, In For doubly fed induction generator (DFIG)-based wind energy conversion systems (WECSs), large electromotive force will be induced in the rotor circuit during grid faults. Without proper protection scheme, the rotor side of DFIG will suffer from over-currents, which may even destroy the rotor-side converter (RSC). To mitigate this problem, a new flux-linkage tracking-based low-voltage ride-through (LVRT) control strategy is proposed to suppress the short-circuit rotor current. Under the proposed control strategy, the rotor flux linkage is controlled to track a reduced fraction of the changing stator flux linkage by switching the control algorithm of RSC during grid faults.

Year 2014

Theodoros D. Vrionis, Xanthi I. Koutiva, and Nicholas. A. Vovos proposes a new computational intelligence- based control strategy, to enhance the low voltage ride-through capability of grid-connected wind turbines (WTs) with doubly fed induction generators (DFIGs). Grid codes world-wide require that WTs should supply reactive power to the grid during and after the fault, in order to support the grid voltage. The conventional crowbar-based systems that were initially applied in order to protect the rotor-side converter at the occurrence of grid faults, do not fulfill this requirement, as during the connection of the crowbar, the DFIG behaves as a squirrel cage machine, absorbing reactive power from the grid. This drawback led to the design of control systems that eliminate or even avoid the use of the crowbar. In order to conform to the above-mentioned requirement, this paper proposes a coordinated control strategy of the DFIG converters during a grid fault, managing to ride-through the fault without the use of any auxiliary hardware. The coordination of the two controllers is achieved via a fuzzy controller which is properly tuned using genetic algorithms. using the proposed control system, the DFIG can successfully ride-through the fault, even in the case where the WT feeds a relatively weak ac grid. The over-currents at the rotor windings and the dc side over-voltages are effectively eliminated and the DFIG can continuously supply the electrical system with reactive power during and after the fault, contributing to the support of the ac voltage.

PROPOSED METHODOLOGY

Tuning of Fuzzy Controller is big issue. The Controller is either tuned with the aid of neural network (ANFIS) or Genetic Algorithm. A neural network based controller can be used in place of a Fuzzy Controller for protection of DFIG under fault condition. A back propagation method is used to develop an algorithm to make Stator Active and Stator Voltage controller on the rotor side converter and a DC link Voltage controller in the Grid side converter. Artificial neural network (ANN) consists of highly interconnected simple processing units designed in a way to model how human brain performs a particular task. It is essentially a mathematical model of a non-linear statistical data modeling tool and is a powerful and simple algorithm to approximate nonlinear functions or to solve problems where the input-output relationship is neither well defined nor easily computable. Generally, the procedure of ANN includes 3 steps: model selection, training and learning algorithm, and evaluation. The historical data can be collected by running the model tuned with Conventional PI controller and Resonant Controller used for controlling DFIG under unbalance network conditions. The data collected by running the simulation can be used to train a two-layer feed-forward ANN in which the first layer has one input i.e the error between the reference Value and the actual value. TANSIG and PURELIN are transfer functions of ANN in common use.

CONCLUSION

This paper proposes a control strategy to improve the LVRT capability of grid connected DFIG WTs without the need of any auxiliary hardware. Various methods used in various papers has been studied from past to present. With the increase in the field of Artificial intelligence techniques. ,it is seen that the AI based controllers provides a better control of DFIG under unbalance system network providing reactive power to grid under fault conditions also. The over-currents at the rotor windings and the dc side over voltages are effectively eliminated and the DFIG can continuously supply the electrical system with reactive power during and after the fault, contributing to the support of the ac voltage. The controller based on intelligent techniques can successfully ride the DFIG through the fault, decrease oscillations in Stator active power and electromagnetic torque and keeps DC link Voltage constant even in the case where the WT feeds a relatively weak ac grid.

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