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Fault Ride-Through Techniques of Wind Turbine State of Art: A Review

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Abstract : Today, renewable sources for the generation of electricity is becoming more popular due to depleting fossil fuels. Solar and wind energy is the world's fastest growing source of renewable energy also grid integration of wind power is growing in leaps and bounds and India is one of them. The cost of producing one kilowatt hour of electrical energy from the wind power is the cheapest. All this has become possible because of recent developments in electrical, mechanical, power electronics, materials and other fields which have wide range of applications in renewable energy technology. Wind power, at the one end is very much useful source of energy same time when it is connected to the electric grid creates some quality issues like voltage sag, swell, harmonics etc. Wind power plants are much affected by faults which occur in each and every power plant. In this article a comparative study has been carried out for different fault ride-through techniques.

Keywords: Renewable Energy, Fault ride-Through Technique, Crowbar, Blade-pitch angle control, STATCOM

Introduction

The Renewable energy is a form of energy which is obtained from naturally from tides, wave, sunlight, wind, ocean and geothermal heat. It is used in following important areas such as generation of electricity, heating and cooling of water and air, transportation, and rural (off-grid) energy services. Renewable energy sources exist around the world, in discriminate to other energy sources, which are situated in a limited number of areas. Rapid expand and utilization of renewable energy may reduce the rate of climate change and affect the world in economic measure.

1.1 Renewable energy in India

India is a vast country. Its energy requirement is increasing day by day and depleting coal make to switch towards renewables. Based on Renewable Energy Policy Network of 21 century (REN21's) 2017 report, renewables contributed 17.7% to total Indian energy consumption. Renewable sources for electricity are targeted to increase heavily by 2022 this includes more than doubling of large wind power capacity. These large targets, if achieved timely, would place India amongst the world

leaders in renewable energy sector. Overall installed capacity of India is 329.4 GW and renewables contribute 57.472 GW as of 14 June 2017. Contribution of wind and solar is nearly 61% and 19% respectively. MNRE has sets its targets to produce renewable electricity from 43 GW in April 2016 to 175 GW by 2022. This includes 100 GW from solar power, 60 GW from wind power. These ambitious targets would make India one of the leading green energy producers and surpassing many developed countries in the world. Wind power generation capacity in India has significantly increased in recent years making total installed capacity of 32.72 GW (October 2017). This is the fourth largest installed wind power capacity in the world. Due to increment of wind power the tariff of wind power has dipped a record low of ₹2.64 (4.1¢ US) per kWh (without any subsidies) during the auctions for wind power projects in October 2017. Before that the tariff was Rs.3.42/kWh in August 2017. Following tables shows the Fuel wise Generation Installed Capacity in India and Installed capacity of renewable energy source in India.

Table 1.1 Fuel wise Generation Installed Capacity in India

Fuel	Installed Capacity	% Share in
THERMAL	219,490	66.7%
Coal	193,467	58.8%
Gas	25,185	7.6%
Diesel	838	0.3%
HYDRO	44,653	13.6%
NUCLEAR	6,780	2.1%
RES	58,303	17.7%
TOTAL	329,226	

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Table 1.2 Installed capacity of renewable energy source (31 August 2017)

Energy source	Power(GW)	Percentage
Wind energy	32GW	56%
Solar energy	13GW	22%
Biomass energy	8GW	14%
Small hydro energy	4GW	8%

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1.2 Issues Associated with Wind Energy

The wind penetration levels in India has increased dramatically in the recent years. This increase, affect the performance of the power system due to its integration and operation. A moderate share does not create any problem. Increasing capacity may create many problems therefore new regulations for grid connection of WPPs become necessary for stability of power system. These new regulation creates issues which are: 1) Interface issue and 2) Operational issue. Interface issues are short circuit power control, active and reactive power control and voltage control. The operational issues are Power system stability, frequency control, short and long term balancing, impact on transmission and distribution and economic dispatch. Power system stability affects by the faults occurring in the system and seeks more attention. Different faults occurring in power system also affects grid stability where the penetration of wind power is large. Hence

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transmission and distribution operators decided to form new grid codes addressing these issues. Thus, it was required to analyze fault ride through behavior of DFIG wind turbine under the influence of new grid code. Modern large-scale wind turbines, typically 1 MW and larger, are normally required to include systems that allow them to operate through such an event, and thereby "ride through" the voltage dip. Depending on the application the device may, during and after the dip, be required to:

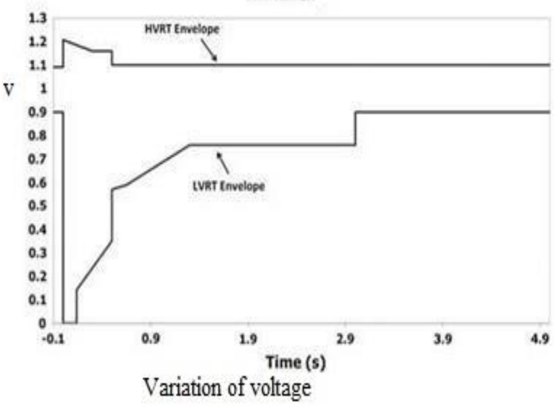
- Disconnected temporarily from the grid and but reconnect and continue operation after the dip, stay disconnected until manually reconnected
- stay operational and not disconnect from the grid and support the grid with reactive power (Fault Ride-Through)

2. Fault ride through

Fault ride through (FRT) is the capability of WT generators to stay connected in the network for short periods of lower voltage (voltage dip). It is needed at distribution level to prevent a short circuit which causes loss of generation. Some critical loads such as computer systems and industrial processes are handled by an uninterruptible power supply (UPS) or capacitor bank to supply make-up power during interruption of supply in a similar manner.

2.1 Fault Ride-Through Requirement of Wind Turbine Systems

Expanding wind power creates some new problems to power system. The power system with large scale wind power will involve problems in steady state operation and in contingency condition. FRT keep the WTs to stay connected to grid during faults so that stability to the power transmission system is maintained. The most common fault in the power system is voltage drop and its lowest depth can be zero. The stator of DFIG is directly connected to the grid, while its three-phase rotor windings are coupled to the grid through a back-to-back converter. Very high rotor current may lead to the damage of rotor side converter and the DC bus over-voltage. During the fault, a large fault current flows through the stator of DFIG because it is directly connected to the grid. Since the rotor and stator are magnetically coupled and the flux is conservative this disturbance must affect the rotor of DFIG making the rotor current very high and an overcurrent may flow through the rotor side converter. Owing to this WTs must have capability to support voltage by providing reactive power to the grid and this is done riding-through the fault. Following figure shows the voltage supporting capability of WTs.



Variation of voltage

Fig 1.1 variation of voltage in FRT (http://energyprofessionalsymposium.com/img/1237/image023_2.jpg

New grid codes ensures that during FRT following conditions must meet. During a voltage drop, turbines remain connected for specific time duration before being allowed to disconnect. Wind power plants must regulate their active power output to ensure a stable frequency in the system and reactive power capability to maintain the reactive power balance and the power factor in the desired range.

3. Strategies

FRT approaches can be divided into two main categories:

1. *Passive Methods* these methods use additional equipment: such as crowbar methods, energy capacitor system (ECS) and energy storage system (ESS), blade pitch angle control.

2. *Active Methods* These methods use appropriate converter control.

1. Passive methods

A) Blade pitch angle control: It is one of the most widely used techniques to regulate the output power of a wind turbine. This method is based on the variation in the input power to the turbine as the pitch angle of the blades is changed. Pitch angle of blade is varied by hydraulic actuators.

B) Crowbar methods: This is the classical method to fulfill FRT requirements. It has ability to protect the generator and the converter as well during the faults. Dangerous effects of fault are minimized by crowbar protections systems. Crowbar avoid the disconnection of the doubly fed induction wind generators from the network during faults.

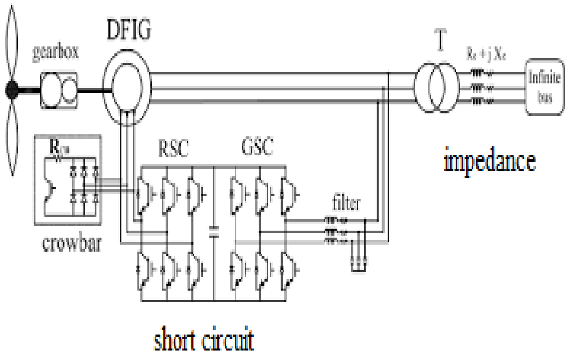


Fig 2.1 Crowbar [9]

Faults at terminal of DFIG induced the high current and increased the DC-link voltage of the converter, to protect from this severe condition crowbar protection system is used. Conventional crowbar, series crowbar and a new protection method named the outer crowbar are main types of crowbar system.

In conventional crowbar technique, when a short circuit occurred the RSC is disabled and bypassed, at the same time external resistors are coupled via the slip rings of the rotor windings in place of the converter.

The series crowbar, three resistors which are parallel with bidirectional static switches are connected in series with stator winding. During short circuit at the DFIG terminals these switches are triggered otherwise switches are not triggered.

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Outer crowbar is quite similar to series crowbar but difference in series crowbar and series outer crowbar is that the outer crow bar is connected in series with the DFIG instead of the stator winding.

C) Energy capacitor system: This method is similar to some extent to crowbar configuration, except that this method protects the converter from overvoltage and can dissipate energy without effecting the rotor currents.

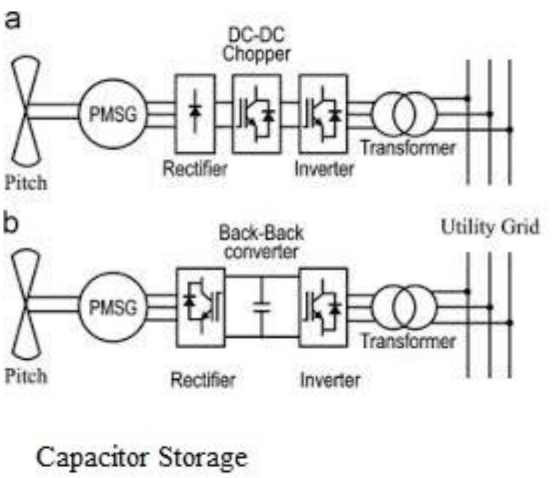

Fig 2.2 Energy capacitor (https://ars.els-cdn.com/content/image/1-s2.0-S0378779613002174 gr1.jpg)

D) Energy storage system: This method controls the generator during the fault. The battery stores energy in the electrochemical form, and is the most widely used for energy storage in a variety of application.

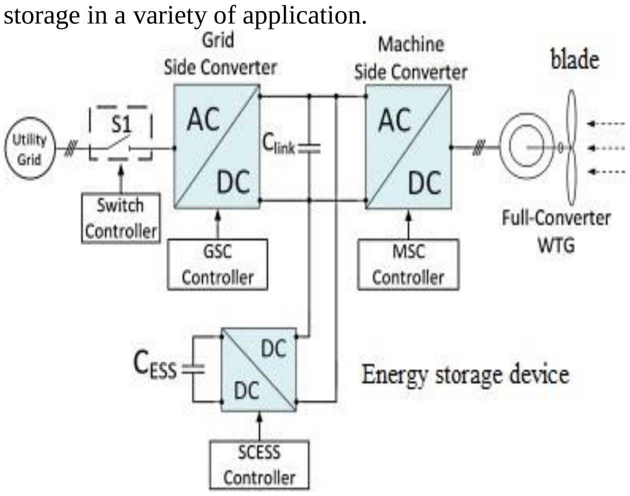

Fig 2.3 Energy storage (https://ars.els-cdn.com/content/image/1-s2.0-S0960148116302981-gr15.jpg)

2. Active Methods

It is a combination between hardware modifications (e.g., crowbar) and control strategies.

A feed-forward transient current control scheme is used for the rotor side converter (RSC) of a DFIG with crowbar protection. Another method uses a parallel grid side rectifier (PGSR) with a series grid side converter (SGSC). All these methods require additional devices which leads to extra costs and increases system complexity. So, it would be better to eliminate these devices. With these considerations, the implementation of classical flux-oriented vector control techniques (PI controllers) has been proven to work well to fulfill the grid code requirements. But, this kind of control could be easily saturated when dealing with substantial sag and it is sensitive to the generator parameters and other phenomena such as disturbances and unmodeled dynamics. These above classical control techniques suffers from the drawback that is their linear nature due to which robustness is lacking.

A robust nonlinear controller based on the sliding mode, an LVRT scheme for a PMSG-based WT based on the feedback linearization theory and a susceptance control strategy are some non- linear control strategies are also proposed for FRT of wind turbines.

3. New approaches

STATCOM and DVR are the new devices to provide FRT of WTs.

Static synchronous compensator (STATCOM) is a Flexible AC Transmission Systems (FACTS) device. It is a power electronic based synchronous var compensator that generates three-phase reactive power in synchronism with the transmission line voltage. It is connected to it by a coupling transformer. STATCOM consist of a three-phase inverter using Gate Turn-off Thyristors. It acts as a sink or a source of reactive power (inductor/capacitor). By varying the amplitude of the converter voltage with respect to the system bus voltage, STATCOM can continuously exchange power through the flow of a controlled current. The power exchange between STATCOM and rest of the system is purely reactive although an insignificant amount of active power is supplied by the grid to compensate for converter losses. This reactive power support enables the STATCOM improve the voltage profile of the system and reduce voltage fluctuation in event of grid disturbance.

Dynamic Voltage Restorer (DVR) is a series connected device, which corrects the voltage dip and restore the load voltage in case of a voltage dip. Basic DVR topology is illustrated in Fig 3.1. Dynamic Voltage Restorer (DVR) is applied to compensate for voltage sags and swells and expected to respond fast (less than 1/4 cycle) and thus employs PWM converters using IGBT devices.

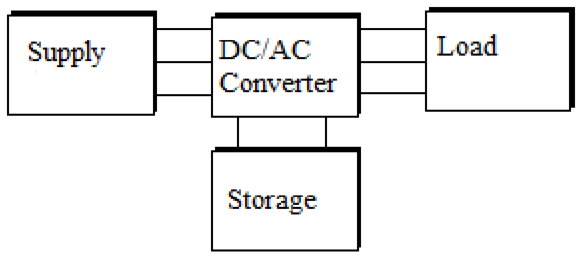

Figure 3.1 Basic DVR Topology

4. Comparison

Faults are the severe problem faced by wind turbines connected to grid. Due to fault in the system power is lost so fault ride-through provides the alternative power to distribution network. So many FRT techniques are proposed for this. All the methods of FRT have some advantages and disadvantages associated with them. Passive methods are easy to implement, cost effective, have best controllability of active and reactive power also improve voltage profile. They also suffers some disadvantages like large response time and have reduced peak generating capacity, also absorbs large amount of reactive power from the grid this will degrade the grid voltage. In some methods additional energy storing elements are required which further increases the cost of the system. Due to additional cost and complexity in passive methods, active methods using PI controller are proposed. These methods saturated easily when they deal with sags. Some linear controllers are also there but they are not robust. Besides this some new techniques are under development and testing. These are STSTCOM and DVR method. They provide active and reactive power to the system during fault when it is required during faults.

5. Conclusion

LVRT is found to be the biggest challenge facing by wind turbine farms; in particular those using DFIGs. This type of generator is very sensitive to grid disturbance, in particular voltage sags. To overcome this sensitivity, several FRT techniques have been proposed. These strategies have been examined and advantages and disadvantages of each one have been discussed. The use of additional hardware can be avoided if the rotor-side converter is able to counter the grid disturbance effects. Therefore, particular attention has been drawn to nonlinear control strategies. Some new techniques are also developed in recent years. FRT techniques are very costly and industries doesn't disclose their researches due to competitive market. Therefore, future researches should be focused on the development of DFIG robust and cheaper strategies for the solution of FRT problem.

Reference

i. *Marwa Ezzat, Mohamed Benbouzid, Sm Muyeen, Lennart Harnefors. Low-Voltage Ride-Through Techniques for DFIG-Based Wind Turbines: State-of-the-Art Review and Future Trends. IEEE IECON 2013, Nov 2013, Vienne, Austria. pp.7681-7686, 2013.*

ii. *Xinyan Zhang1, Xuan Cao2, Weiqing Wang1, Chao Yun1 Fault Ride-Through Study of Wind Turbines Journal of Power and Energy Engineering, 2013, 1, 25-29*

iii. *Supercapacitor energy storage system for fault ride-through of a DFIG wind generation system A.H.M.A. Rahim a,⇑, E.P. Nowicki b a Department of Electrical Engineering, King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabiab Department of Electrica & Computer Engineering, University of Calgary, Calgary, AB,Canada*

iv. *Ms.Ch.laxmi, Ms.K.Sree Latha, 3Dr.Himani 1Asst.prof(EEE) GNITC,Hyderabad 2Assoc.Prof(EEE) GNITC, Hyderabad 3Prof & HOD(EEE) Aurora's Engg ,Bhongir*

v. *Improving the low voltage ride through capability of wind generator system using crowbar and Battery Energy storage system. International Journal of Engineering Science Invention ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726*

vi. *Supercapacitor energy storage based-UPQC to enhance ride-through capability of wind turbine generators Gangatharan SIVASANKAR, Velu SURESH KUMAR Department of Electrical and Electronics Engineering, Thiagarajar College of Engineering, Madurai, India, Turk J Elec Eng & Comp Sci (2015) 23: 1867 { 1881*

vii. *Montazeri, Miad Mohaghegh, "Improved Low Voltage Ride Through Capability of Wind Farm using STATCOM" (2011). Theses and dissertations. Paper 1407.*

viii. *C. Jauch, P. Sorensen, I. Norheim and C. Rasmussen, "Simulation of the Impact of Wind Power on the Tran- sient Fault Behavior of the Nordic Power System," Elec- tric Power System Research, Vol. 77, 2007, pp. 135-144.*

ix. *S. J. Hu, J. L. Li and H. H. Xu, "Analysis on the Low-Voltage-Ride-Through Capability of Direct-Drive Perma- nent Magnetic Generator Wind Turbines," Automation of Electric Power Systems, Vol. 31, No. 17, 2007, pp. 73-77.*

x. *https://www.researchgate.net/profile/Sadegh_Ghani_Varzaneh/publication/281627313/figure/fig1/AS:287010901250058@1445440139828/Figure-1-Schematic-diagram-for-DFIG-accompanied-with-conventional-crowbar-protection.png.*

xi. *Meegahapola LG, Littler T, Flynn D. Decoupled-DFIG fault ride-throughstrategy for enhanced stability performance during grid faults. IEEE Trans Sustain Energy 2010;1:152–62.*

xii. *Ahsanul Alam M, Rahim AHMA, Abido MA. Supercapacitor based energy storage system for effective eault ride through of wind generation system. In:IEEE international symposium on industrial electronics (ISIE-2010), Bari, Italy July, 2010.*

xiii. *X. Dawei, R. Li, P. J. Tavner, and S. Yang, "Control of a doubly fed induction generator in a wind turbine during grid fault ride-through," IEEE Transactions on Energy Conversion, vol. 21, pp. 652-662, 2006.*

xiv. *E. Koutroulis, D. Kolokotsa, and G. Stravrakakis,"Optimal design and economic evaluation of a batteryenergy storage system for the maximization of the energygenerated by wind farms in isolated electric grids," WindEngineering, vol. 33, pp. 55-81, 2009.*

xv. *V. Akhmatov, "Analysis of dynamic behavior of electric power system with large amount of wind turbine", Ph.D. thesis, Orsted DTU, pp. 26–28,30, 31, 2003.*

xvi. *S. M. Muyeen, R. Takahashi, T. Murata, and J. Tamura, "Integration of an energy capacitor system with a variablespeed wind generator," IEEE Trans. Energy Convers., vol. 24, no. 3, pp. 740-749, Sep. 2009.*

xvii. *K. H. Kim, Y. C. Jeung, D. C. Lee, and H. G. Kim, "LVRT scheme of PMSG wind power systems based on feedback linearization," IEEE Trans. Power Electron., vol. 27, no. 5, pp. 2376-2384, May 2012.*

xviii. *D. W. Xiang, S. C. Yang and L. Ran, "Magnet Excitation Control Strategy of DFIG on Grid Operation during Power System Symmetric Fault," Proceedings of the CSEE, Vol. 26, No. 3, 2006, pp. 164-169.*

xix. *D. Campos-Gaona, E. Moreno-Goytia and O. Anaya-Lara, "Fault Ride-Through Improvement of DFIG-WT by Inte- grating a Two-Degrees-of-Freedom Internal Model Con- trol," IEEE Transactions on Industrial Electronics, Vol. 60, No. 3, 2013, pp. 1133-1145.*

xx. *F. Díaz-González, A. Sumper, O. Gomis-Bellmunt and R. Villafáfila- Robles, "A review of energy storage technologies for wind power applications," Renewable and Sustainable Energy Reviews, vol. 16, n°4,pp. 2154-2171, May 2012.*

xxi. *D. Ramirez, S. Martinez, C. Carrero and C.A. Platero, "Improvements in the grid connection of renewable generators with full power converters,"Renewable Energy, vol. 43, pp. 90-100, July 2012.*