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FAULT-CURRENT LIMITER (FCL) APPLICATION IN A WIND POWER PLANT

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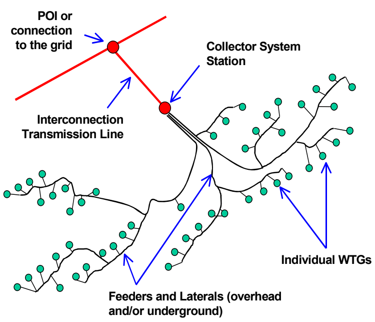
Introduction and Objectives

In the years to come, there will be more and more wind power plants (WPPs) connected to the electrical grid. With the scenario of 20% wind penetration by 2030, the WPP's operation should be well planned. The power system switchgear and power system protection for WPPs should be carefully designed to be compatible with the operation of conventional synchronous generators connected to the same grid.



Typical layout of wind power plant

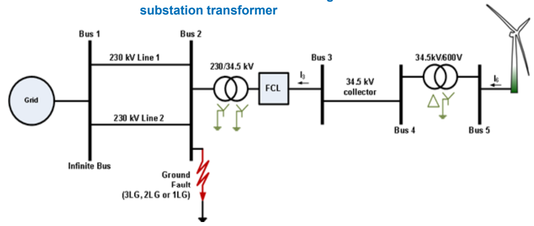
As shown in above, a WPP consists of many (hundreds) of wind turbine generators (WTGs). Currently, available WTG sizes are between 1 MW and 5 MW. The WTG is connected at a low voltage level (e.g. 600 Volt), and a pad-mounted transformer is connected to step up the voltage to 34.5 kV.

Several turbines are strung together and connected in a daisy chain fashion. The collector system is connected to the substation transformer where the voltage is stepped up to higher voltage (e.g., 230 kV) and the power is transmitted over long distance. Thus, a 300-MW wind power plant may consist of 300 turbines connected to the grid.

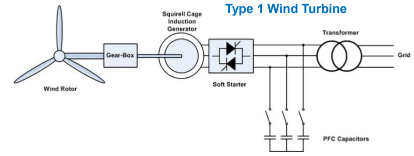
In this analysis, the fault-current limiter (FCL) is proposed to be installed at the collector side (34.5 kV) of the substation transformer. Thus, the FCL will be able to protect the entire WPP.

Modeling Approach

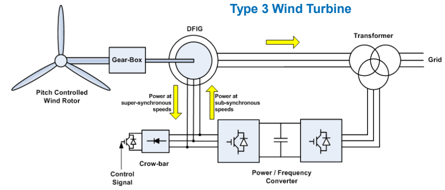
FCL is installed at the low voltage side of 34.5-kV substation transformer



Type 1 Wind Turbine

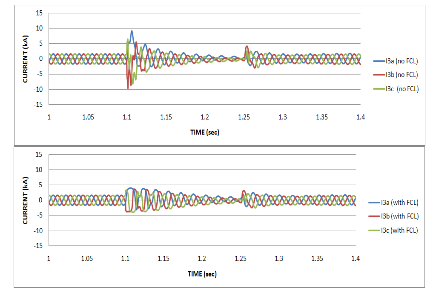


Type 3 Wind Turbine

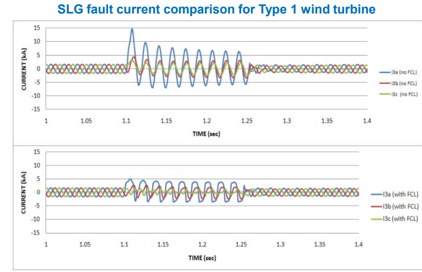


Results

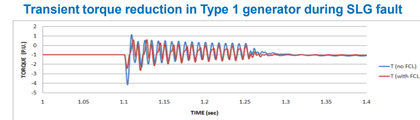
3LG fault current comparison for Type 1 wind turbine



SLG fault current comparison for Type 1 wind turbine



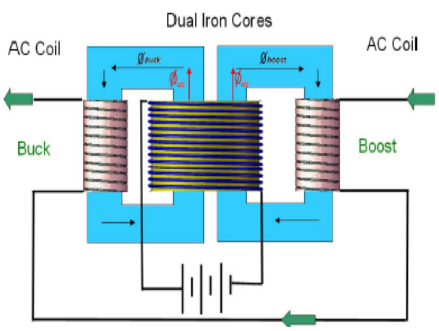
Transient torque reduction in Type 1 generator during SLG fault



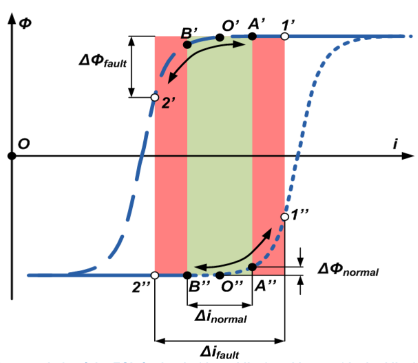
3LG = 3 lines to ground, **SLF** = single line fault, **LL** = line-to-line fault, **LLG** = line-to-line-to ground fault.

Fault-Current Limiter

The saturable core FCL consists of a set of coils wound around one or more ferromagnetic cores. A high-temperature superconducting (HTS) magnet is coupled to the core region in such a way that the DC magnetization force can saturate the magnetic material. Each AC phase consists of two coils connected in series and wound around two core regions. Under normal operating conditions, the operating point on the *Φ-I* curve is always in the saturated region due to the DC bias.



Dual iron-core FCL



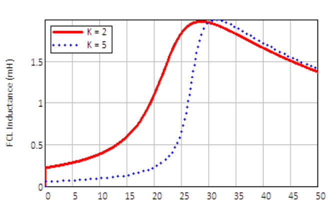
Φ-I characteristic of the FCL for buck (dotted line) and boost (dashed line) coils

Linkage magnetic field:

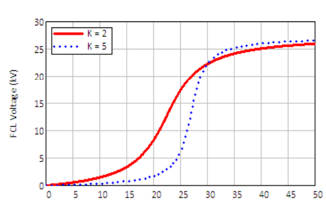
$$B(i_{ac}) = \frac{-2B_{sat}}{1+\tan^{-1}(K\pi - \frac{\pi}{2})}[1+\tan^{-1}(K\frac{\pi}{I_{\max}}(I_{\max}-i_{ac})-\frac{\pi}{2}]+2B_{sat}$$

Effective inductance: $\tilde{L} = n_{ac} A_{core} \frac{\partial B(i_{ac})}{\partial i_{ac}}$

Back EMF across the FCL: $V = \tilde{L}\frac{\partial i}{\partial t}$



Differential inductance for different operating currents



Approximate voltage drop for different operating currents

Conclusions

Reduction ratio of short-circuit current (SCC) and transient torques with and without FCLs for three wind turbine types

	Type 1		Type 2		Type 3	
	SCC	Torque	SCC	Torque	SCC	Torque
3LG fault	0.44	0.63	0.5	0.62	0.99	0.99
SLF fault	0.33	0.55	0.34	0.55	0.75	0.71
LL fault	0.47	0.66	0.38	0.63	0.71	0.77
LLG fault	0.33	0.66	0.36	0.65	0.70	0.67

FCLs can effectively reduce the SCC for the Type I wind turbine generator. It is also shown that for single line-to-ground and other types of unsymmetrical faults, the FCL behaves like an equalizer such that not only a reduction in the positive, negative, and zero sequence currents is achieved, but also the timing of the reduction is very beneficial. The most significant reduction of those sequence currents occurs during the transient (at the few cycles in the beginning of the faults), thus, as a result, the transient torque is reduced very significantly.

The SCC contribution for different types of WTGs is tabulated as the ratio of SCC for a WPP with FCLs to the SCC for a WPP without FCLs. A table showing the reduction in transient torque for different faults and different WTGs is also tabulated in the same fashion. As shown in the table above, there is significant improvement in the SCC and the transient torque reductions for a WPP with FCLs.

The designs of the FCL for different types of WTGs must be designed specific to the WTG technology because the nature of the SCC contribution is unique for each type of WTG.

References

1. U.S. Department of Energy – Energy Efficiency and Renewable Energy, "20% Wind Energy by 2030 – Increasing Wind Energy's Contribution to U.S. Electricity Supply," May, 2008.
2. J. Charles Smith, Michael R. Milligan, Edgar A. DeMeo and Brian Parsons, "Utility wind Integration and operating impact state of the art," *IEEE Trans. Power Systems*, vol. 22, pp. 900-908, Aug. 2007.
3. Moriconi, F., Koshnick, N., De La Rosa, F. and Singh, A., "Modeling and Test Validation of a 15 kV 24 MVA Superconducting Fault Current Limiter", in *Proc. of IEEE/PES Transmission and Distribution Conference*, New Orleans, USA, April 2010.
4. WECC Modeling and Validation Work Group, "WECC Wind Power Plant Power Flow Modeling Guide Prepared." May 2008.
5. Short-circuit currents in three-phase AC systems–Part 0: Calculation of currents, IEC Standard 60909-0, July 2001.
6. IEEE Application Guide for AC High-Voltage Circuit Breakers Rated on a Symmetrical Current Basis, IEEE Standard C37.10-2000, Sept. 2000.
7. J. Moren, S.W.H. de Haan, "Short-Circuit Current of Wind Turbines with Doubly Fed Induction Generator," IEEE Transactions on Energy Conversion, Vol. 22, No. 1, March 2007.
8. IEEE PES Wind Plant Collector System Design Working Group, "Power Transformer Application for Wind Plant Substation," Proceedings of the 2009 IEEE Power and Energy Society General Meeting.
9. V. Gevorgian, E. Muljadi, " Wind Power Plant Short-Circuit Current Contribution for Different Fault and Wind Turbine Topologies", Presented at the 9th International Workshop on Large Scale of Wind Power into Power Systems, Quebec City, Quebec, Canada, July 18-19, 2010
10. E. Muljadi, R. Schiferl, and T.A. Lipo, "Unsymmetrical Triggering of Phase Back Controller for Unbalanced Operation of Induction Machine", IEEE Transactions on Industry Applications, Vol. IA-21, No. 4, May/June 1985, pp. 669- 677
11. J. Oyama, F. Profumo, E. Muljadi and T.A. Lipo, " Design and Performance of a Digitally Based Voltage Controller for Correcting Phase Unbalance in Induction Machines." IEEE Transactions on Industry Applications Vol. 26, No. 3, May/June 1990, pp. 425-433.
12. E. Muljadi, T.Batan, D.Yildirim, C.P. Butterfield, "Understanding the Unbalanced-Voltage Problem in Wind Turbine Generation," IEEE-Industry Applications Society Annual Conference, October 3-7, 1999 in Phoenix, Arizona.

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