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A Novel Approach for Fault Detection and its Analysis For Grid Connected Doubly Fed Induction Generators

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Abstract: Because of the intermittent nature of wind, its integration to the power system is still promising under fault condition with respect to power quality and stability. For the large penetration of wind energy, this study using an embedded time-frequency localization features in wavelet, provides deep insight to the character of transient signals for a proposed test system comprising 1 thermal plant and 3 DFIG-based wind plants. The test system results are analyzed onto the wavelet format for accurate detection and better resolution of the characters of transients. This is found that the presence of lower frequency bandwidth signals and larger magnitude wavelet coefficients are the root cause information for the stability and quality.

Key words: DFIG, fault, wavelet, time-frequency, frequency bandwidth and transients

INTRODUCTION

Wind generation is one of the mature and cost effective resources among different renewable energy technologies (Srivastava and Chauhan, 2006). The increasing wide spread use of wind generation on power system networks imposes the requirement that wind farms should be able to contribute to the network support and operation as do conventional generating stations based on synchronous generators (Bhadra *et al*., 2005).

For the large penetration of wind energy, an internationally recognized tool wavelet transform approach is proposed for the condition monitoring of the test system, comprises 1 thermal plant and 3 DFIG-based wind plants. This study explains, a novel approach i.e., wavelet for fault detection and its analysis.

As analyzed from theory point of view, the wavelet can be formulated via a family of basis functions such that the signals can be described in a localized time and frequency format. Hence, by employing the long windows at low frequency and short windows at high frequencies, the wavelet transform will be capable of comprehending the time and frequency information simultaneously. For those transients in time-varying signals, they would be supervised more effectively, thereby encouraging the application of such method to enhance the detection capabilities.

In area of DFIG-based wind energy, limited numbers of wavelet-based research papers are available (Douglas *et al*., 2005) made a comparative analysis of the approaches, MCSA, EPVA and DWT to detect the interturn fault in Doubly-Fed Induction Generator (DFIG). CWT-based approach is proposed in (Chin-Shun Tsai *et al*., 2006) for the enhancement of damage detection of wind turbine blades. Wavelet-based ARMA model is presented in CAO Lei and Ran (2008) for the short-term wind speed forecasting. But, the affect of fault on the integrated system with respect to stability is not yet addressed, which is utmost important for large penetration of wind energy. In this connection, this study comes out with proposal of fault detection and its effect on the stability of the integrated system through novel wavelet technique.

MATERIALS AND METHODS

Doubly-fed induction generator: Power captured by the wind turbine is converted into electrical power by DFIG- based wind farm is shown in the Fig. 1. The generator assures efficient power production at variable speed. The speed variability is made possible by directionally dependent transfer of slip power via converters. In sub synchronous speed the stator of DIFG feeds all the generating electrical power to the grid and additional makes slip/rotor power Pr available which is fed from converter to the rotor via slip rings. However, in the super synchronous mode total power consists of the components fed by stator of DFIG plus rotor power Pr, which is fed from the rotor to grid via converter. The control system generates pitch angle and the voltage

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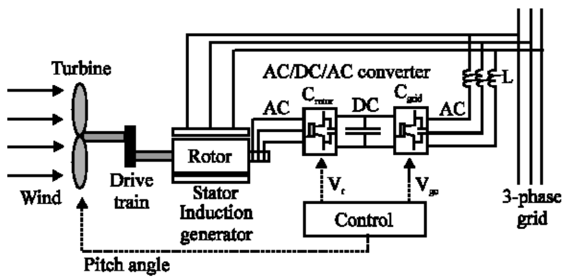

Fig. 1: Doubly-fed induction generating system

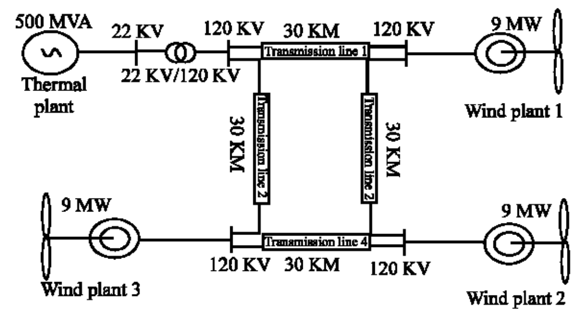

Fig. 2: Test system

command signal Vr and Vgc for C_{rotor} and C_{grid}, respectively in order to decouple the active and reactive power, C_{rotor} and C_{grid} have the capability for generating power and could be used to control the flat voltage at grid.

Overview of the test system: To demonstrate the results, a test system, shown in Fig. 2 is selected based on (Changling Luo and Boon-Teck, 2006). Total 27 MW DFIG-Based wind farms are integrated to 500 MVA thermal power plants through 120 KM ring distribution feeder. Three Wind Power, each 9 MW at 575V and 1 Thermal Power Plant at 22 KV are stepped up to Grid voltage of 120 KV through a step-up Transformer, 600 MVA, 22 KV/120 KV (delta-star). After integration, Total Harmonic Distortions (THD) is measured and eliminated (3rd and 5th order) by three phase harmonic filter having quality factor 20.

Fault is created near the wind power plant 2 for the duration 1.66 ms. A capacitor of 0.6 F is connected in between the rotor side converter and grid side converter. DC link voltage is made almost 1200 V for bidirectional power flow in the rotor of DFIG. Slew rate of wind speed are different for the different wind farms.

Wavelet analysis: The ability to provide variable time-frequency resolution is hallmarks of wavelet transform (Rghuveer *et al*., 2005; (http://www/engineering.rowam.edu/polikar/WAVELETS/WTtutoria/.htm). Wavelet transform is relatively new mathematical technique, which is used to analyze signal in nature. It is becoming the focus point of much science and is fondly delighted tool by scientists. It plays a very important role in signal and information processing.

Discrete Wavelet Transform (DWT): The wavelet transformation is a process of determining how well a series of wavelet functions represent the signal being analyzed. The goodness of fitting of the function to the signal is described by the wavelet coefficients. The result is a bank of coefficients associated with 2 independent variables, dilation and translation. Translation typically represents time, while scale is a way of viewing the frequency content. Larger scale corresponds to lower frequency meaning thereby better resolution. The most efficient and compact form of the wavelet analysis is accomplished by the decomposing a signal into a subset of translated and dilated parent wavelets, where these various scales and shifts in the parent wavelet are related based on powers of two.

Full representation of signal can be achieved using a vector coefficients the same length as the original signal.

The forward wavelet transform determines the wavelet coefficients $C_{a,b}$ of b wavelet at each level a. For the signal f (n),

$$C_{a,b} = \Sigma f(n) \Psi_{a,b}(n)$$

Continuous Wavelet Transform (CWT): The DWT is most efficient and compact; its power of two relationships in scale fixes its frequency resolution. Often it is required to differentiate between smaller frequency bands than DWT allows. This is possible by using scales that are more closely spaced together than the power of 2 relationships and is the basis for Continuous Wavelet Transform.

For a signal f (t), CWT determines the coefficients as:

$$C_{a,b} = \int f(t)\psi(a,b,t)dt$$

Here, a and b represent the dilation and translation. The number of coefficients necessary to describe the signal may be larger than the signal strength, as the wavelet over samples the signals as the CWT over samples the signal.

In this study, the wavelet coefficients is used to provide the scalogram, which describes the signal energy on time-scale domain. This facilitates identification of time varying energy flux spectral evolution and transient bursts not readily discernible usingtime or frequency domain method.

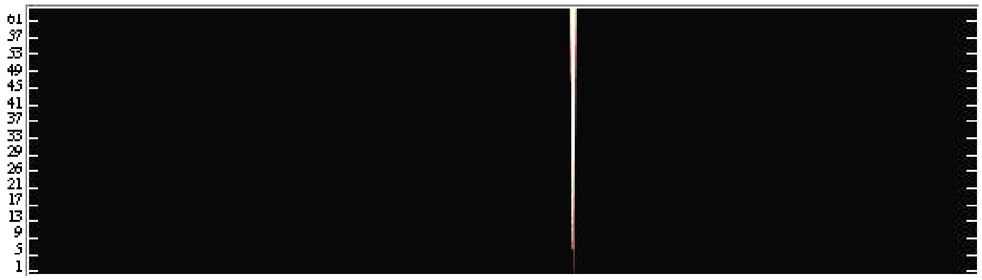

Fig. 3: Fault detection

RESULTS AND DISCUSSION

Dubieties wavelet is applied in one dimensional CWT for scalogram which reveals much information about the nature of non-stationary processes that was hidden. Scalogram is useful for the diagnosis of special events in the structural behavior. Any change in frequency content e.g., initiation of stiffness degradation can easily be identified by the scalogram.

Scalogram is a plot of coefficients on time-scale plane. Each point on this plane represents wavelet coefficients. The wavelet coefficients are well suited for analyzing non-stationary events such as transient and evolutionary phenomena. There are 2^i coefficients to describe the energy at the ith frequency band, for i = 0, 1, 2......, M-1 where, the signal consists of 2^M data points. The coefficients in a particular band represent the energy at that interval equally spaced over the duration of the signal. When, the squared coefficients are plotted on a time-scale grid, the transfer of energy from one band to next would be observed along the time scale. This is called the scalogram. In this study, the signal consists 10286 data points whereas, the coefficients generated at the 8 levels are 10323. This happens because the CWT over samples the signal and so wavelet coefficients contains partial redundancies of information. Line-Ground fault occurs on the ring distribution feeder near by the wind plant 2 is clearly detected, can be seen in Fig. 3. Discrete Wavelet Transform (DWT) is used to decompose the fault signal at d1 (low frequency) level for intensifying the high frequency oscillations present at the instant of fault. Decomposition at low frequency (d1) level is having better resolution is observed in Fig. 4. These oscillations are divided in frequencies bandwidth, the scalogram format to extract the root cause information. There are 8 energy bands except Fig. 3 and 4. Horizontal axis represents time whereas vertical axis, scale increasing from bottom to top. Higher scale corresponds to low frequency. Volume bounded by the surface decreases from upper frequency to lower frequency band. Therefore, the energy strength of the faulty signal decreases towards

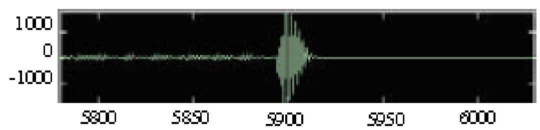

Fig. 4: Presence of oscillations at the time of fault

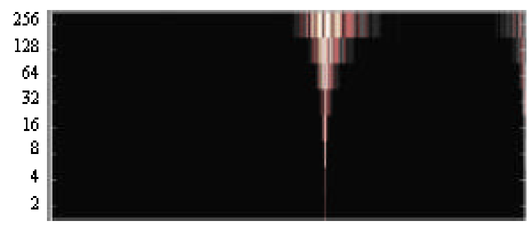

Fig. 5: Scalogram of wind plant 1 at the time of fault

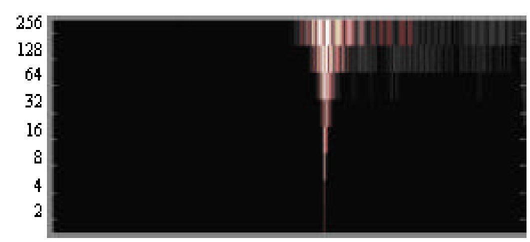

Fig. 6: Scalogram of wind plant 2 at the time of fault

lower frequency i.e., higher frequency bandwidth. This is clearly observed in Fig. 5-7 for the wind plant 1, wind plant 2 and wind plant 3, respectively. Transfer of energy for a particular band is also clearly seen, but its resolution is more in the upper frequency band i.e., low frequency bandwidth. This is how the wavelet is superior to Fourier Transform and Short Term Fourier Transform. Low frequency bandwidth signal carries more energy and persists relatively for a longer duration on the system is to be taken care of. Since, the fault occurs on the ring distribution feeder near by the wind plant 2, so its effect on wind plant 2 is relatively more, clearly seen in Fig. 6. No special events or change in frequency or stiffness degradation is diagonized by the scalogram before and after the event of fault. This verifies the concrete modeling of test system.

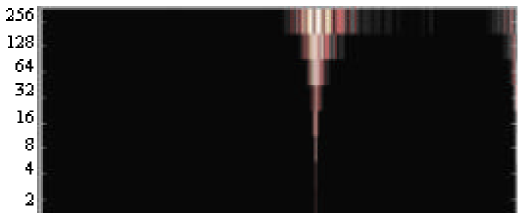

Fig. 7: Scalogram of wind plant 3 at the time of fault

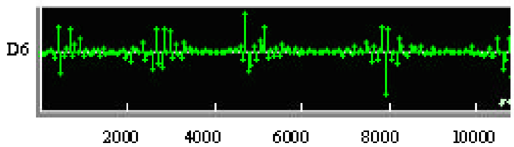

Fig. 8: Grid coefficients before fault

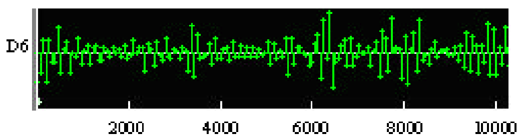

Fig. 9: Grid coefficients after fault

For discriminating the effect of fault on grid/alternator, Wavelet coefficients are plotted, shown in Fig. 8 and 9. To have the better resolution, only D6 level coefficients. The occurrence of larger magnitude coefficients in the wavelet domain is used to identify the impulsive events. This is clearly observed from Fig. 8 and 9 that the numbers of impulsive events are more after occurrence of fault.

CONCLUSION

L-G fault on interconnected distribution feeder is detected clearly. Impact of the fault on an alternator and the 3 wind plants are exhibited through wavelet coefficients and scalogram, respectively. The presence of lower frequency bandwidth signals carries more energy relatively is the root cause information for the stability and quality of the system.

The occurrence of larger magnitude wavelet coefficients is the identification of impulsive response. The absence of stiffness degradation before and after fault verifies the concrete modeling of test system.

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