Using the TESLA Power System Recorder at Wind Farm Locations

Introduction

Electrical generation of power by wind generators can be inherently unstable due to varying wind conditions and low generator inertia. Using a TESLA power system recorder to collect information at a wind farm can be very beneficial. The TESLA recorder can collect data related to harmonics, electrical faults, power swings, and many other power quality issues. In addition, the ability to collect and record time synchronized events can provide the user with information to determine exactly what happened. Obtaining this information during normal and abnormal conditions can help identify the problems and ultimately provide information needed to analyze and resolve issues. Use of the information can also be used to defend against third party claims of negligence or equipment damage. In addition, the TESLA recorder can act like the ‘black box’ used in the airplane industry to verify operation of other controllers or protective devices. Even though these devices may have their own recording capability to some extent, it is important to realize to validate these quantities using a completely independent source like the TESLA recorder.

Figure 1: TESLA 4000 Multi-timeframe Digital Fault Recorder

The TESLA power system recorder is a multi time frame recorder shown in Figure 1 is as a result of 20 years of development and in service experience by utilities all over the world.
In its present form the TESLA recorder can provide :

1. Sequence of events recording.
2. Fault recording with extensive triggering capabilities.
3. Power disturbance recording to capture dynamic swings of power systems .
4. Trend recording to capture power quantities over extended periods of time.
5. Harmonic recording with capability to capture up to the 100^{th} Harmonic.
6. Phasor Measurement capability to provide operational information on system power flows.
7. Extensive software tools to analyze data recorded.
8. Central station auto retrieval capability to bring records in after disturbances.
9. Unique distributed input quantity collection to make installations simpler and more efficient.

For a full description see the ERLPhase web site on the TESLA power system recorder.

Because of the versatility of the TESLA recorder, it can be seen that issues that can be present in the operation of a wind farm can easily be identified
Some specific issues related to the operation of a wind farm will now be identified.

Interconnection Requirements for a Wind Generation Plant

Regional Reliability Organizations (RROs) such as ERCOT and WECC have adopted NERC and FERC requirements for wind generating plants. Wind farms must comply with technical requirements such as Low Voltage Ride Through (LVRT), Reactive Power Supply, and Frequency and Voltage Limits.

Low Voltage Ride Through (LVRT): How well does a wind farm to remain connected to the power grid when experiencing very low voltages produced by faults on the transmission system? ERCOT states that voltage relays must remain in service for three phase faults for voltage levels as low as 0 for no more than 9 cycles at the point of interconnection. Figure 2 shows a LVRT tripping and recovery time, taken from Reference (11).

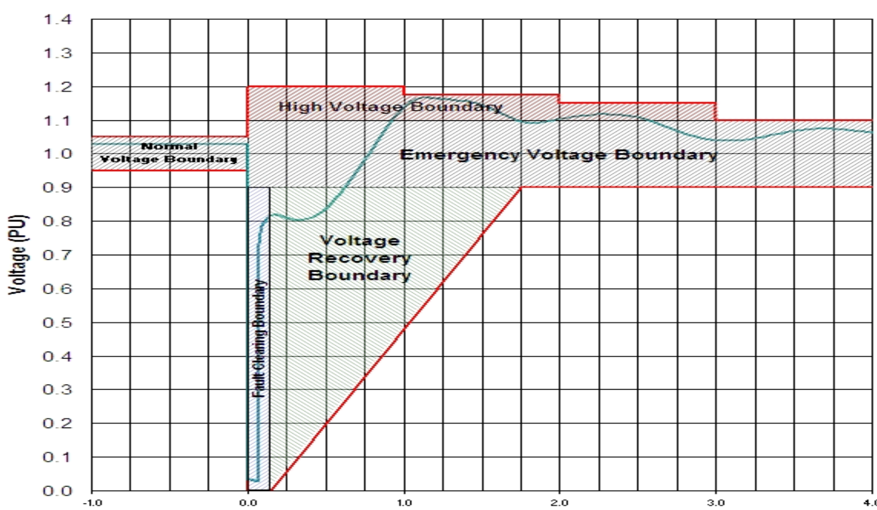


Figure 2. LVRT tripping and recovery time.

Collecting ocsillographic data for 9 cycles can be done by some microprocessor relays. However, as shown in figure 2, recovery time can take up to 2 seconds, which is beyond the recording capabilities of most microprocessor relays. Also, if voltage relays are not programmed correctly, recovery time might be longer due to failure in the system, resulting in violation of standard requirements. TESLA has the ability to record for one second before the LVRT event and from 1-30 seconds after the LVRT event, with fast sampling rates. It can also use slow sampling rates to continuously record RMS signals of the event, extending the recording capacity even further. As a result, TESLA enables the user to see the entire voltage spectrum for better system analysis. It also provides valuable evidence to verify correct operation.

Reactive Power Supply: According to FERC rule 661A, wind generators must maintain a power factor of 0.95 leading to 0.95 lagging, measured at the point of interconnection (6). Wind farms equipped with induction generators face a challenge since these types of generators are consumers of reactive power that cause not only poor power factor (PF) but power system instability and real power losses (8). In order to comply with the standard and mitigate these problems, sources of reactive power such as capacitor banks, static Var compensators (SVCs) and flexible AC transmission systems (FACTS) are installed at the point of interconnection (8). Installation of a TESLA can benefit operation of the wind farm by providing the following functions:

- monitor and record PF limits, MWs and MVar trends at the point of interconnection as seen in figure 3
- monitor and record PF limits, MWs and MVar trends for each feeder at the collector bus
- monitor and record abnormal and defective conditions of reactive power sources such as SVCs and capacitor banks
- alert system operators of possible reactive power source failures or standard violations by providing system information via Ethernet communications

Figure 3. MWs and MVar trends at the point of interconnection.

Frequency and Voltage Limits: According to ERCOT, under-frequency relaying shall remove generating units based on frequency limits, which can range from 59.4 to 57.5 Hz (5). Delay times can range from “no time delay” to 9 minutes. TESLA can record frequency information from seconds to days using trend recording (see figure 4). It can also verify that protective relay operations are correct by recording sequences of events for relay operation. In the same manner, voltage limits can also be recorded and monitored.

TESLA Frequency Recording Capability

Figure 4. Frequency behaviour before, during, and after a fault.

Power System Monitoring

Reliability of the power system is paramount when it comes to continuous operation of the power grid. However, no matter how well a protection system is designed, system abnormalities and failures will occur. Abnormal system conditions such as system faults, voltage sag/swell, and harmonics can result in huge financial losses to power producers as well as consumers (1). Therefore, monitoring and recording of these system conditions is imperative to better analyze system failure, minimize equipment failure, and avoid substantial monetary losses. Below is discussion of how disturbance fault recording can mitigate the most common abnormal conditions that are detrimental to wind farms.

Transients: Equipped with sampling rates up to 384 samples per cycle, the TESLA can record very fast variations of voltage or current magnitudes (called transients) lasting from microseconds to milliseconds (see figure 5). Transients are produced by lighting, power system short circuits, line and capacitor switching, etc. Recording analysis of transients is important to wind farms since they can affect the slip, torque and power output of wind induction generators (7). Recording the transient quantities can verify proper protection and control device operation and can also provide a very useful way to verify mathematical models of the wind generators and the connected systems.

TESLA Fault Recording Capability

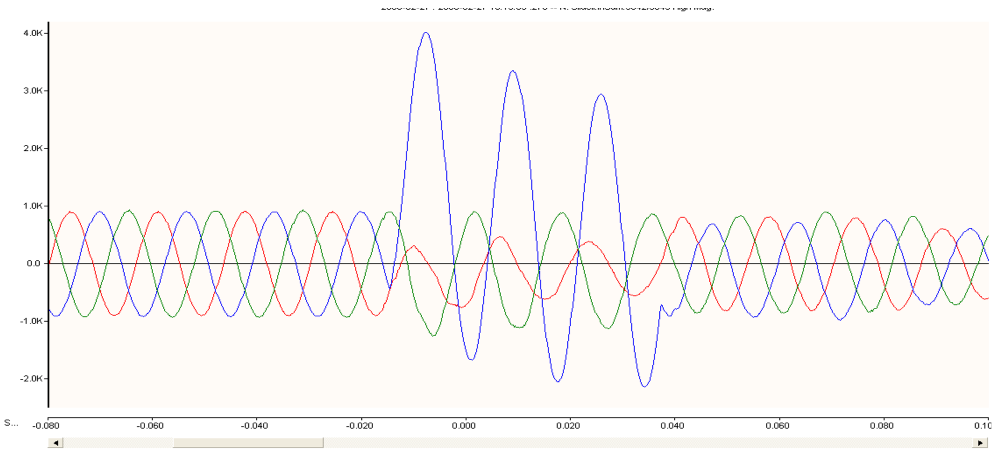


Figure 5. Recording of transients.

Voltage Sag-Swell: Voltage sag refers to a decrease of the normal voltage level between 10-90% of the nominal rms voltage at the power frequency (1). Voltage swell refers to the momentary increase of the voltage at the power frequency outside normal tolerances (1). Voltage sags are created by faults on the transmission system producing low voltages that can cause wind generators to trip offline (13). Voltage swells are sometimes created by poorly regulated transformers (1). Voltage sags can last from .5 cycles to minutes and swells can last from 1 cycle to several seconds (1). Monitoring sag-swell is critical to wind farms as explained in the LVRT section. The user can choose to trigger for sag or swell conditions on a percentage of the voltage nominal level. Figure 6 shows a voltage sag characteristic event.

Example of Voltage Sags and Swells

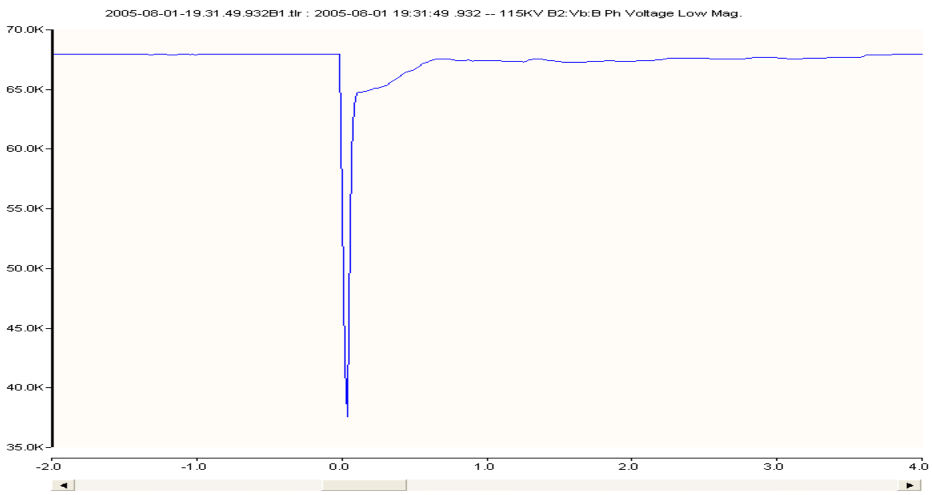
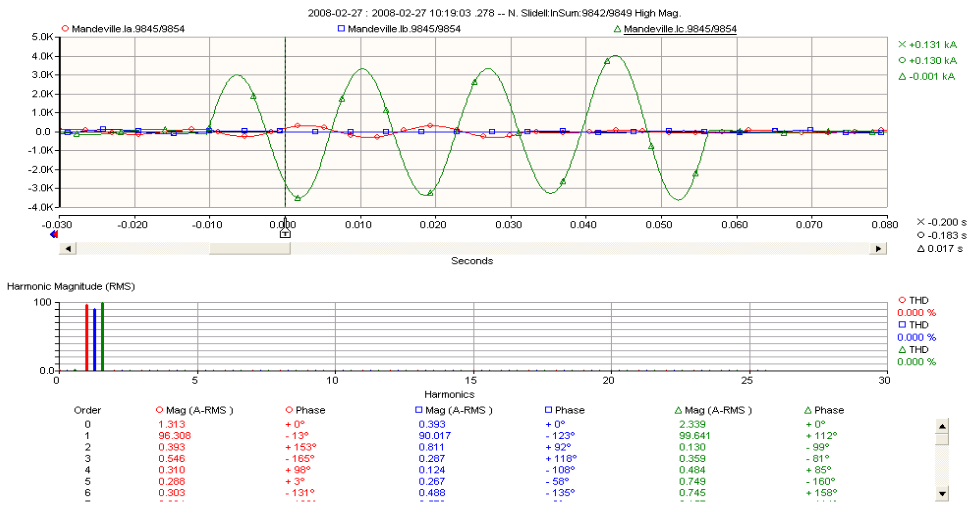


Figure 6. Recording captures a momentary sag in voltage.

Harmonics: Refers to the distortion of voltage or current signals by non-linear loads such as static var compensators, variable-speed-constant-frequency wind generators, soft starts, and industrial loads. Harmonics can be a detriment to wind farms especially when Total Harmonic Distortion (THD) does not meet the standard requirements. Wind farms must comply with the IEEE Standard 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems at the point of interconnection (4). TESLA can monitor and record the THD and individual harmonics up to the 25th harmonic at 128 samples per cycle (see figure 7). Recording of harmonics can be critical for the efficiency of wind farm operations. Left unchecked, harmonics can:

1. increase real power losses in transformers and transmission lines (12)
2. deteriorate the generator insulation and decrease efficiency of the transformers (12)
3. cause undesired operation of protective relays (2)
4. require wind farm owners to pay electric utilities for the investigation and repair of excessive harmonic conditions produced by a wind farm (10)

Typical Quantities as a Result of a System Fault and TESLA Software Analysis Tool for Analysis



Order	○ Mag (A-RMS)	○ Phase	□ Mag (A-RMS)	□ Phase	△ Mag (A-RMS)	△ Phase
0	1.313	+ 0°	0.393	+ 0°	2.339	+ 0°
1	96.308	- 13°	90.017	- 123°	99.641	+ 112°
2	0.393	+ 153°	0.811	+ 92°	0.130	- 99°
3	0.546	- 165°	0.287	+ 118°	0.359	- 81°
4	0.310	+ 98°	0.124	- 108°	0.484	+ 85°
5	0.288	+ 3°	0.267	- 58°	0.749	- 160°
6	0.303	- 131°	0.488	- 135°	0.745	+ 158°

Figure 7. TESLA can monitor and record the THD and individual harmonics up to the 100th harmonic at 384 samples per cycle.

Monitoring and Recording Special Cases in Wind Farms

Unique cases include:

- over-voltages on ungrounded systems
- self-excitation
- ferroresonance

Over-Voltages on Ungrounded Systems: Figure 8 shows a typical wind farm's one-line diagram. Collector feeders from wind farms will become isolated ungrounded systems during faults due to the separation from the ground reference provided by the utility transformer. As a consequence, the un-faulted phases will experience a voltage rise that can be as much as a line-line voltage level, which can degrade equipment insulation and eventually result in equipment failure (9). Four TESLAS, working in cooperative mode, have 144 analog inputs which can be used to record the over-voltages for up to 48 collector feeders. Analysis of the over-voltages is simplified with the ability to capture all over-voltage conditions in one record and overlay multiple graphs in a single screen.

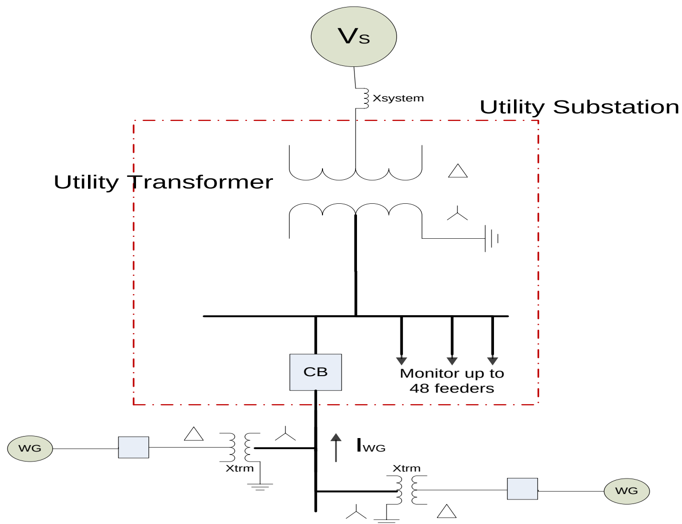
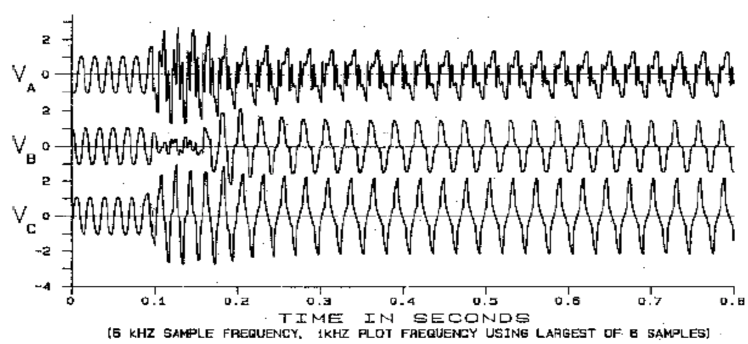


Figure 8. One-line diagram of a typical wind farm.

Self Excitation: The TESLA can also help identify problems with self-excitation experienced by wind farms. Self-excitation can occur if the wind farm (or a portion of it) loses its connection with the utility. This occurs when there is capacitive compensation in excess of the magnetization VARs required by the wind induction generator. As a result, unstable voltage and current conditions can be developed, resulting in equipment damage (7). The fast and slow recording capabilities of the TESLA can be used to capture voltage, current, and frequency deviations. These records can then be analyzed in order to determine an indication of self-excitation.

Ferroresonance: TESLA can also detect ferroresonance, which is created when a nonlinear inductive reactance such as a single or three phase transformer is connected in series to a capacitive reactance (for example a shunt capacitor (7)). Over-voltages of over 3.0 p.u. can occur affecting generators and transformers, and damaging lighting arresters (3). A ferroresonance event can be seen in figure 9 (taken from Reference (3)).



50 KW synchronous DSG, 9 kw load, 100 kvar capacitance, and wye-delta step-up transformer.
Maximum voltage: A=2.74 p.u., B=2.34 p.u., C=2.92 p.u.

Figure 9. Example of a ferroresonance event.

Conclusions

The TESLA power system recorder is a powerful tool that can be applied to windfarm applications to capture information about the operation during normal or abnormal conditions. Obtaining this information enables the owners of the windfarm to analyze problems, verify operations of controllers and protections and also verify mathematical fault or stability models that may have been set up for these installations.

Collecting good information from the windfarm using a TESLA can lead to better efficiency, less maintenance and higher returns to the owners.

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