Disturbance Recording Requirements in Smart Grids

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Smart grids are defined by several main characteristics – the requirements for improved reliability and efficiency of the electric power system, combined with the wide-spread penetration of distributed energy resources (DERs).

The DERs integration presents significant challenges to the electric power systems protection and control specialists due to the fact that they belong to many different types which have different behavior under abnormal system conditions.

The goal of the paper is to analyze the different types of DERs and specify the requirements for the recording systems in order to help the specialist from the industry to better understand the following:

- What are their contributions during short circuit faults?
- What is their ride-through capability and if it meets the standards' requirements?
- What is their behavior during changing weather conditions?
- What is their behavior during local and wide area disturbances?
- How accurate are the models used in transient and dynamic stability studies?

Each of the above listed tasks imposes different requirements for the disturbance recording system. This is the focus of the second part of the paper. It analyzes the different recording methods and which ones are the more suitable to meet specific recording requirements.

The following methods are discussed:

- Waveform recording with different sampling rates
- Dynamic disturbance recording (including synchrophasors)
- Trend recording

The components and architecture of the recording system are discussed at the end of the paper.

1 Challenges Imposed by Distributed Energy Resources Integration in Smart Grids

One of the main challenges in the integration of the different types of distributed energy resources in smart grids is the impact of several different factors on the operation of the electric power system under different system conditions, as well as their effect on the performance of different protection functions:

- Type of DER
- Connection of the DER to the distribution feeder or transmission line
- The impact of meteorological conditions or time of day on the status of the DER

That is why it is very important that the tools used for system analysis and protection coordination and fault simulation during engineering and testing are capable of properly simulating the behavior of DERs under fault and other abnormal conditions.

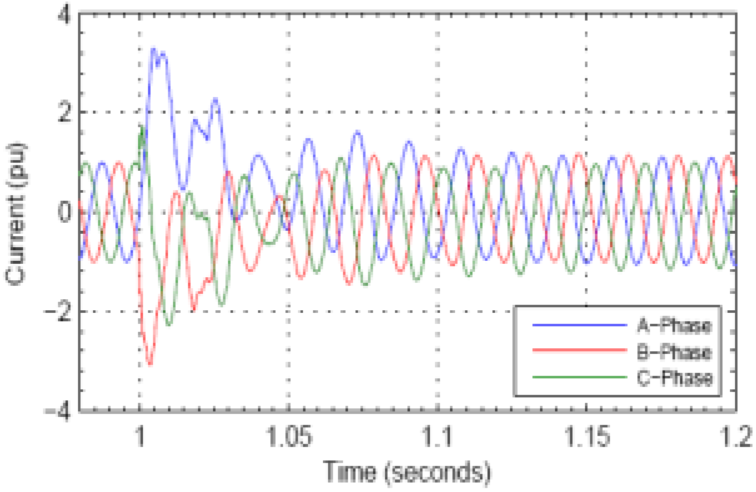

Fig. 1 Fault contribution of variable speed double fed generator

Two examples in this paper give some idea of how different the fault contribution of the DER can be. We are used to dealing with synchronous machines, but in the DERs which are rotating machines we may have asynchronous or inductions machines, as well as some machines with much more complicated operating principle such as a variable speed double fed generator. The fault contribution of such wind generator is shown in Figure 1.

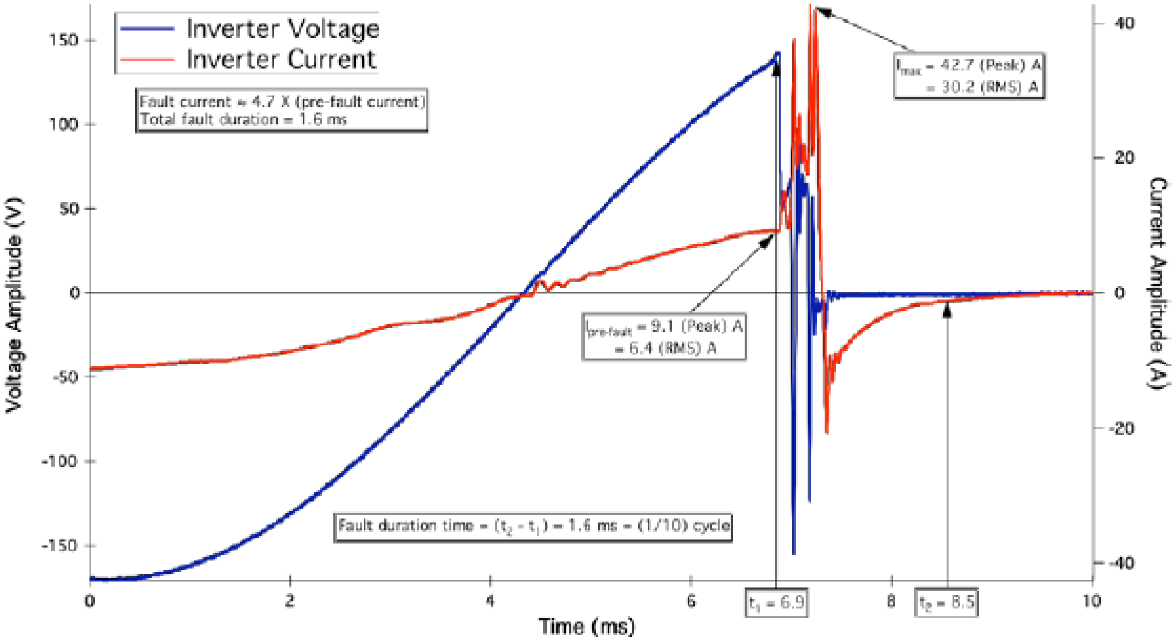

Fig. 2 Recording of the output of an inverter during a short circuit fault

A different challenge is the simulation of the behavior of many DERs that are connected to the power system using inverters. There is a wide spread understanding that the inverters can be ignored as a source of fault current and can be ignored when considering their impact on the protection schemes for systems with DERs. However a more careful examination of this issue shows that that is not exactly the case. Test results for different sizes of inverters show that in reality immediately after the fault inception there is a fault contribution for a period of a couple milliseconds (Figure 2).

While the impact of this fault contribution on typical protection functions based on phasor or rms measurements may be minimal, it may affect the operation of some high-speed fault or directional detection methods.

Another important issue that requires consideration is the capability of distributed energy resources to ride through a fault condition as required by the ride-through characteristic of many different countries with high penetration of DERs. Since it depends on the duration of the fault and the voltage level during the sag it is very important to ensure that the DER

Figure 3 shows an example of a ride-through characteristic.

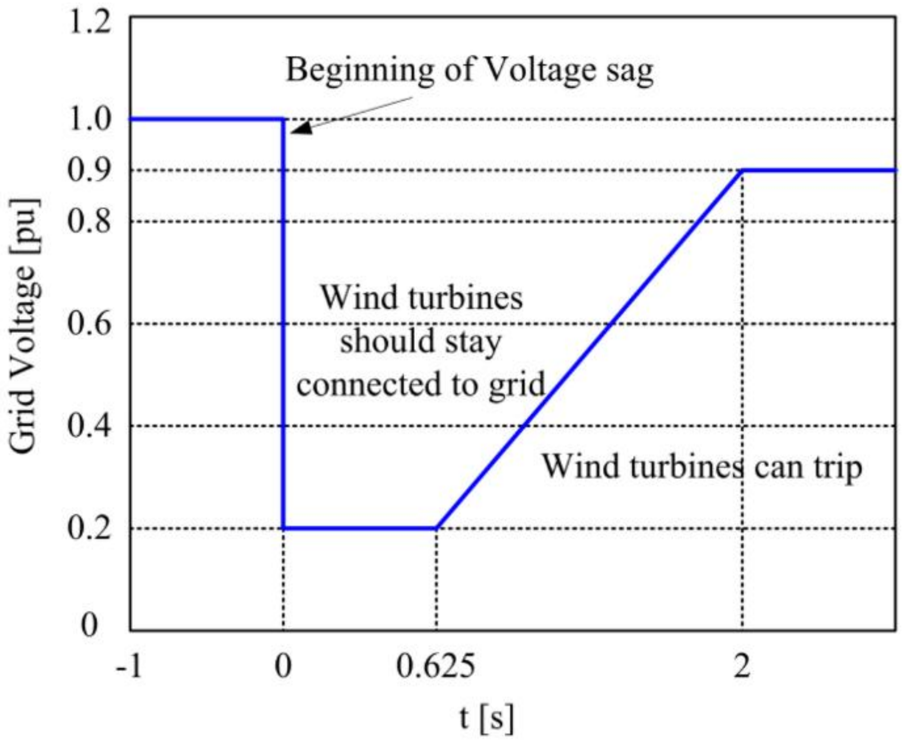

Fig. 3 Ride-through characteristic

This is something that we can’t control, but we have to study in order to be able to predict or estimate the effects of different faults on the DERs.

Last but not least we need to take into consideration the variability of the output of DERs.

Even that fast variations (seconds to minute) of individual machines may be a reality, this is not the case with the aggregated wind power output. However these variations still need to be understood in order to better understand and simulate their behavior and impact on a local distribution area of the system.

The variations within an hour are much more significant for the system as a whole. However, they should always be considered in relation to demand fluctuations. Local variations depend on geographical diversity, and will generally remain inside ± 5 % of installed wind power capacity at the regional level.

The most significant variations arise from the passage of storm fronts, when wind turbines reach their storm limit (cut-out wind speed) and shut down rapidly from full to zero power. However, due to the averaging effect across a wind farm, the overall power output takes several minutes to reduce to zero.

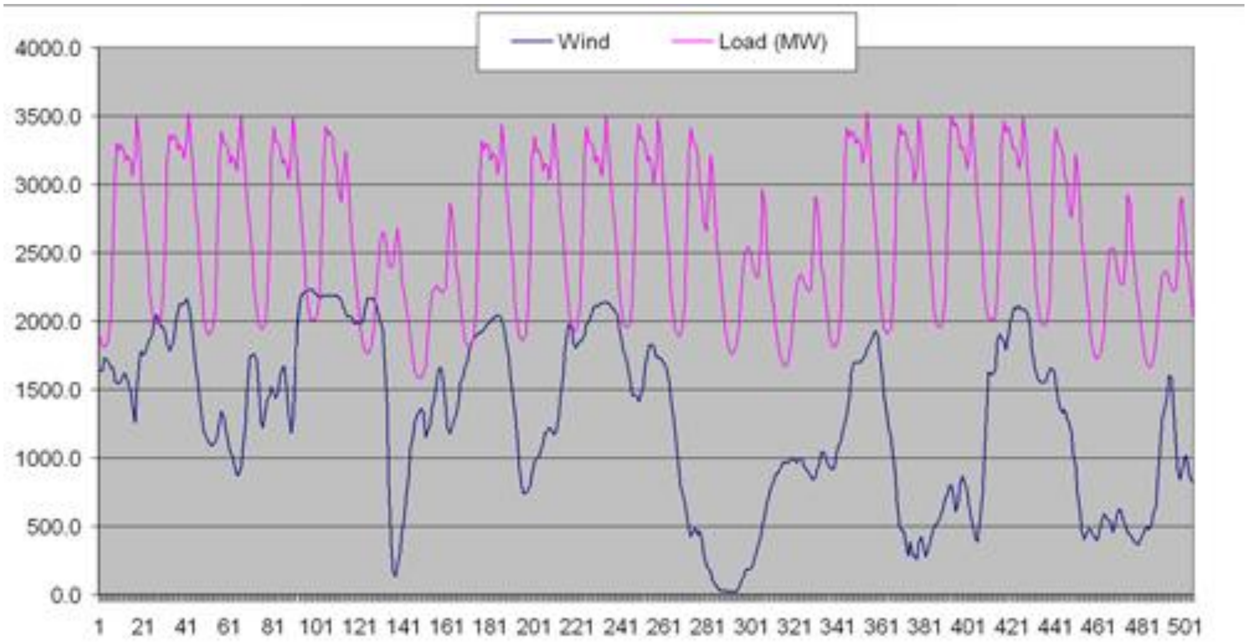

Fig. 4 Hourly load versus wind generation profile

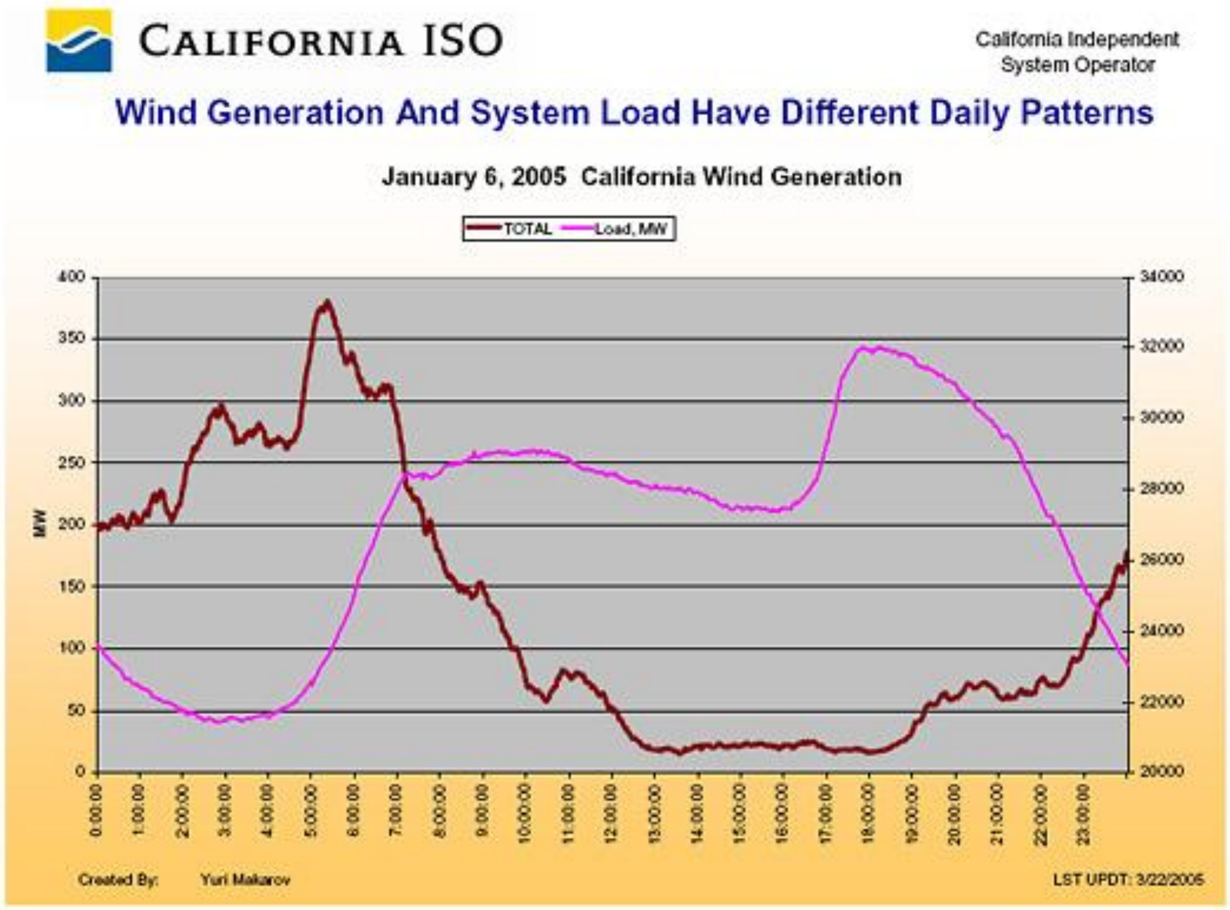

Fig. 5 One day load versus wind generation profile

From all of the above it is clear that the integration of significant numbers of DERs in smart grids imposes some specific requirements for recording of different events and their impact on the electric power system.

2 Distributed Recording

Since distributed energy resources based generation is distributed by nature it is obvious that the recording system also needs to be distributed.

At the same time the changes in the recorded system parameters can range from fractions of a cycle to minutes, hours, days and months. It is impossible to record the variety of events using the most commonly available waveform capture. Many of the power system events are also based on the changes in the value of the magnitude and angle of voltages and currents, so the waveform capture is not appropriate for the recording of such events.

Many power system applications require the recording of different system parameters with different sampling rates. That is why multifunctional protection and monitoring IEDs provide recording features that can be used to meet the primary and backup recording requirements of various utility departments.

The need for monitoring and recording at the transmission level has been recognized for a long time. The experience with local or centralized disturbance recording systems has shown how valuable this information is in order to allow for a better understanding of the steady-state and dynamic behavior of the system. More and more utilities and industries now are realizing that the same is true at the distribution level, especially in the areas with penetration of DERs. The availability of multifunctional IEDs with advanced communications capabilities and the standard IEC 61850 communication protocol leads to a new concept for distributed monitoring and recording not only in the substation, but throughout a complete electric power system.

The recording modes of multifunctional IEDs are determined by the requirements for recording of different system events. Such events are wide area system disturbances that result in power swings or frequency variations, transients during a short circuit on a high voltage transmission line or the voltage sag at the distribution level, generation and load changes caused by time of day or meteorological condition variations. As can be seen from these examples, the recording requirements can vary significantly and cover a wide range from more than a hundred samples per cycle, to more than a minute between samples.

2.1 Waveform Recording

Waveform recording in many cases is known as disturbance recording. It captures the individual samples of the currents and voltages measured by the IED with a sampling rate that may be as low as 4 samples/cycle for some low-end protection IEDs to hundreds of samples per cycle for high-end monitoring and recording IEDs.

The user typically has options to define the triggering criteria, the pre-trigger or post-trigger intervals and if extended recording should be available in cases of evolving faults or other changing system conditions.

The waveform recording trigger can be defined as a threshold on any measurement, operation of a protection or monitoring function as well as the output of a user defined programmable scheme logic. External triggering should also be possible through the opto inputs of the IED or based on a communication message from another IED.

Depending on the capabilities of specific multifunctional IEDs the sampling rates for waveform recording may vary significantly as a function of their design. An improvement in that area is due to the increasing acceptance of IEC 61850 sampled values based solutions which in the current implementations according to IEC 61850 9-2 LE is typically 80 samples/cycle at the nominal system frequency for protection and measurement IEDs or 256 samples/cycle for specialized power quality monitoring or recording devices.

COMTRADE is the file format that has been used for a long time for recording of waveforms and will continue to be used in the future as well.

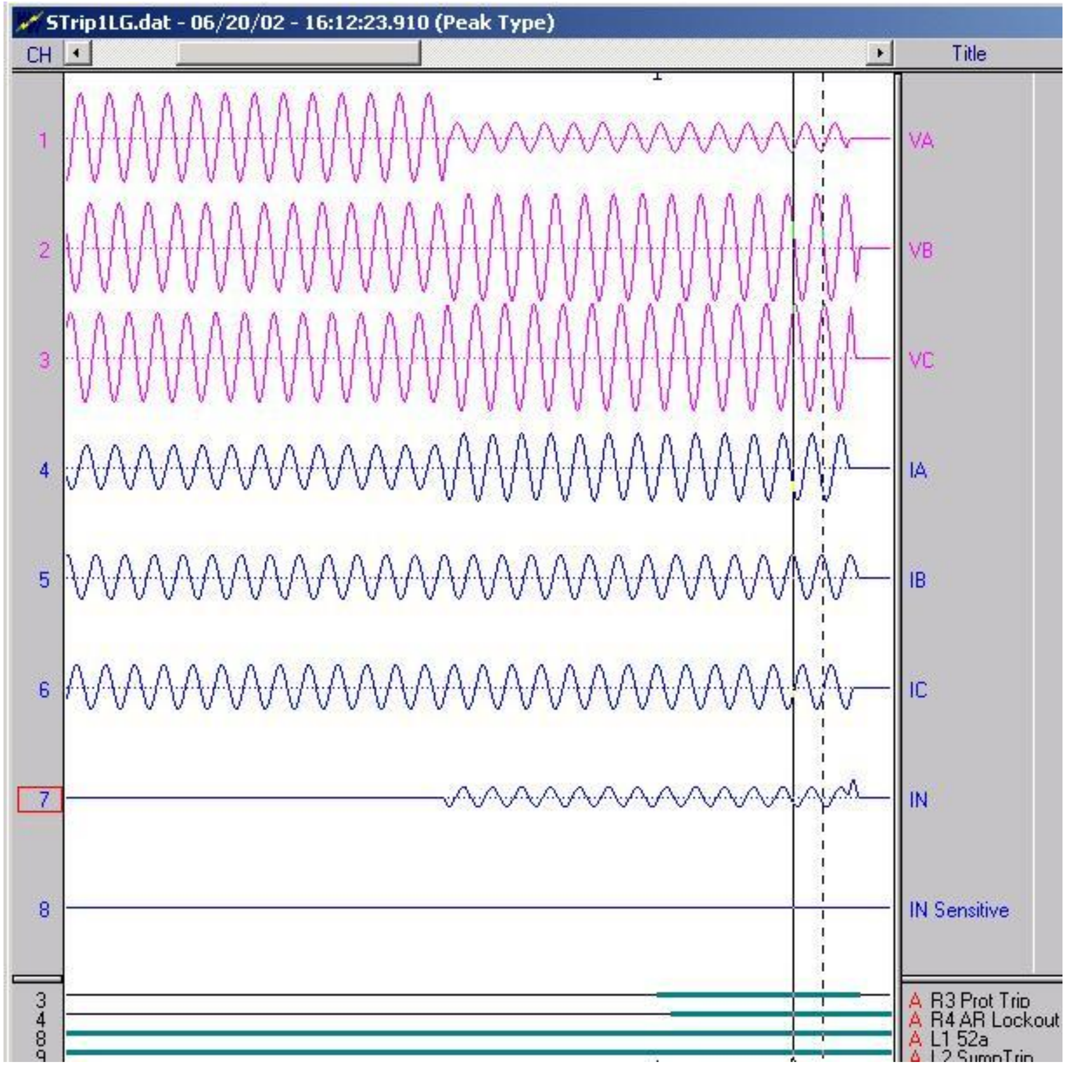

Fig. 6 Waveform record including state change information

2.2 High- and Low-Speed Disturbance Recording

High-speed or low-speed disturbance recording is intended for capturing high-speed power quality events such as voltage sags or voltage swells during short circuit faults on the transmission or distribution system.

The availability of synchrophasor calculations in many multifunctional IEDs makes them usable for the recording of disturbances and the dynamic behavior of DERs. This is especially true when P-class synchrophasors are used for recording.

The disturbance recording IED stores the values of a user-defined set of parameters for every log interval.

The setting range should allow the user to define the sampling rate, for example from 1 to 3600 cycles and can be changed with a step of 1 cycle.

When P-class synchrophasors are used this recording rate can be increased to up to 4 measurements/cycle.

A schema has been defined by an IEEE PES PSRC working group H8 which allows the recording of synchrophasor measurements in COMTRADE format.

2.3 Periodic Measurement Logging

Planning studies and short and long-term load forecasting require the recording of system parameters over long periods of time. The recording device should be able to store the values of a user-defined set of parameters for every log interval. This interval defines the sampling rate of a trend recording and the user should be able to change it as required by the application.

The measurement log file can contain user settable number of samples. For example, a record with 3072 samples is equivalent to 32 days of logging when using a sampling interval of 15 minutes. Once the log file has reached its maximum length it will wrap around to the beginning and overwrite the oldest entries in the file. For each parameter the minimum, maximum, and average values that occurred during the previous interval might be required to be recorded.

All records – waveforms, disturbances or trends - should be in a standard file format, such as COMTRADE. This allows the use of off-the-shelf programs for viewing and analysis of the records. Since this is a comma separated text format, the files can easily be imported in other applications for further processing.

3 Time-Synchronization

One of the main requirements for a distributed recording system is the ability to properly synchronize the different devices. This will ensure that all events or disturbance records are time-stamped with sufficient accuracy, so that the analysis tools can generate the sequence-of-events record for the whole substation or electric power system and align the disturbance records from different devices for further analysis.

Time synchronization of the different IEDs can be achieved using several common methods. One is to manually synchronize the IED clock to the clock of a laptop connected to a serial port of the IED. It is obvious that this method of synchronization will not meet the accuracy requirement for any of the typical disturbance analysis applications. That is why a distributed monitoring and recording system needs to include a master time device that generates a standard time code.

Several vendors manufacture such master time devices and support different standardized time synchronization protocols. IRIG-B is one of the more commonly supported standard time code formats that has been widely accepted by the electric utilities and is supported by most IEDs installed in substation automation systems. IRIG (InteRange Instrumentation Group) standards consist of a family of serial pulse time clock standards. There are several

Time Code Formats within the family such as A, B, E, G, and H. Each Time Code Format has its own unique bit rate.

There are two common ways of synchronizing various devices to the same clock source:

- Synchronization over direct connection
- Network synchronization

Synchronization of IEDs over direct connection requires each device to have an IRIG-B communications port in order to connect it to the master time device. This synchronization scheme can be expanded such that two devices half a world apart could be synchronized to within fractions of a second if each is connected to an accurate local time master.

Having a permanently connected IRIG-B source provides an accurate IED clock with a typical clock error of less than 10 microseconds. However, the failure of the master time device is a possibility that should be considered in the design of the time-synchronization feature of the IED in order to ensure accurate time-stamping even in the cases where the master is lost.

A disadvantage of the direct time-synchronization is the requirement for an IRIG-B input for each IED and the hard wiring between the individual devices and the master. The network synchronization method eliminates this problem by allowing the IEDs real time clock to be synchronized over the substation LAN with the network time-synch master using the methods specified by the protocol. The time synchronization model is based on UTC synchronized time provided to the applications located in server and client substation IEDs. The resulting time accuracy in the whole system should be +/- 1 ms for time tagging of events and +/- 0.1 ms for time tagging of zero crossings and data for distributed synchrocheck.

For synchrophasor measurements and IEC 61850 sampled values the required accuracy of time synchronization is 1 s, and in today’s environment it is based on IEEE 1588 Precision Time Protocol (PTP) related profiles such as IEEE C37.238 or IEC 61850 9-3.

4 Conclusions

The widespread penetration of distributed energy resources is one of the main characteristics of the smart grid.

The fact that different types of DERs, especially wind generators and photovoltaics, have a behavior very different from synchronous machines and also have power output dependent on the weather conditions imposes specific requirements for their recording. Waveform, disturbance and long term recordings are all required as part of the recording system.

Considering the distributed nature of systems with DERs it is clear that the architecture of the recording system will be distributed as well and will require accurate time synchronization based on IEEE 1588 PTP power profiles.