RECORDING OF POWER QUALITY EVENTS IN DISTRIBUTION SUBSTATIONS

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ABSTRACT

The paper analyzes the requirements and available tools for the recording of power quality events. Different types of events are considered from the point of view of recording. Recording capabilities of IEDs are analyzed and possible use in substation applications is described. The impact of IEC 61850 on power quality recording is discussed later in the paper.

INTRODUCTION

Recording of different abnormal system conditions that can be identified as power quality events is very important for their analysis and the identification of methods for improvement. The increasing number of multifunctional protection relays installed in distribution substations significantly improves the recording of different system events. Unfortunately the recording capabilities of most relays are not suitable for use in many power quality event related applications.

The design of a good power quality recording system needs to follow several main steps:

- Take into consideration all the requirements based on the types of events to be recorded by the system
- Determine the recording capabilities of the IEDs existing in the substation
- Analyze the recording capabilities of the IEDs available on the market and select the ones to be used
- Consider the trends in the development of new technology that can be used for power quality events recording
- Define the optimal power quality recording system architecture

These four issues are discussed in more detail in the following sections of the paper.

RECORDING REQUIREMENTS

The use of different types of records for analysis of power quality events defines the requirements for recording of such events in distribution substations.

Recording of voltage dips and swells imposes quite different requirements from the recording of transients. Even when we think about the recording of voltage variation events, the requirements for an instantaneous are different than for the temporary. Some examples are the non-sinusoidal waveforms resulting from switching transients or the voltage and frequency magnitude profiles during a wide area disturbance. 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 of the phase voltages to one sample of minimum, maximum and average values per multiple cycles.

Waveform Recording

Waveform recording is available in many power quality monitoring devices. It captures the individual samples of the currents and voltages measured by the IED with a sampling rate that may be in the 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 capture of several cycles of pre-fault data, as well as the ability to record the waveform over a period of several seconds will result in better use of the record.

The trigger for waveform recording 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 of the recording should also be possible through the opto-inputs of the device or based on communication messages from other IEDs or the substation computer.

High- and Low-Speed Disturbance Recording

High-speed or low-speed disturbance recording is intended for capturing events such as voltage sags or voltage swells during short circuit faults on the transmission or distribution system or frequency and voltage variations during wide area system disturbances. The disturbance recording IED stores the values of a user-defined set of parameters for every log interval. The setting range is dependent on the available memory in the IED. If the sampling rate is more than one cycle per sample, the user should be able to select the recording of minimum, maximum and average values through the specified sampling interval.

An option to trigger High-speed disturbance recording when a Waveform capture is triggered is achieved by using the same trigger with different recording modes. The combination of waveform capture and high- or low-speed disturbance recording triggered by the same power system event allows the recording of long events, while at the same time providing the details of the transitions from one state to another via the waveform capture. This allows the use of the same event record for the analysis of relay operation or verification of the system models used by different analysis tools.

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.

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.

IED RECORDING CAPABILITIES

After we define the requirements for recording of power quality events in the substation, we have to consider if the recording capabilities of the IEDs that are already installed in the substation can meet them.

Recording Capabilities of Protection IEDs

The typical protection IED is designed to record the current and voltage waveforms when a fault occurs in the zone of protection. This information can later be used to determine the cause of the fault and if the relay operated as expected. Since it is possible to design a power quality monitoring system that records events when they happen, and then determines the type of event based on off-line analysis of the records, the system designer may conclude that since the protection IEDs in the substation have waveform recording capabilities, they may be used as the recording device in such a system. Unfortunately, this is not the right solution for most power quality event analysis applications due to the following reasons:

- Protection IEDs may have a low sampling rate – starting from 4 samples/cycle. This is definitely not sufficient for capturing transients or determining the harmonic content of the recorded waveform
- Protection IEDs have analog filters that typically filter all harmonics higher than the 5th. This means that even if a relay can record 64 samples/cycle, the user will not be able to see the 31st harmonic in the recorded waveform
- Protection IEDs typically have a relatively short recording time – in most cases they can record an event of a couple of seconds. There are some exceptions when the recording time can be in the range of 10 sec., but this is not sufficient for recording of some power quality events that can have much longer duration
- The most common voltage variation power quality events by definition are based on r.m.s. values, while the protection IEDs are recording waveforms, i.e. there is a need for additional processing

It is clear from the above listed recording capabilities of protection IEDs that they can be used for recording of some power quality events, but it is necessary to carefully analyze the limitations of the specific devices currently installed in the substation and what specific recording requirements they can meet.

Recording Capabilities of Power Quality Monitoring or Disturbance Recording IEDs

Power quality monitoring and disturbance recording IEDs have some significant advantages compared to the protection IEDs regarding their recording capabilities as should be expected, since they have been designed with such functionality in mind.

The following is a list of some of these advanced capabilities:

- Monitoring and recording IEDs have high sampling rates – typically 128 or 256 samples/cycle. This allows capturing of transients and determining a very high harmonic content of the recorded waveform
- They don't have analog filters that filter high harmonics
- They record not only waveforms, but also disturbance profiles – calculated values such as r.m.s. or phasors. The calculated values can be recorded with a sampling rate of 1 sample/cycle up to a user selected number of cycles between samples.
- Power quality monitoring and recording IEDs can record events of any duration due to the fact that they do not record waveforms for events with duration of more than several seconds. They also have larger memory, which, especially with the addition of industrial flash memory cards can be in the GB range.

The advantages of power quality and disturbance recording IEDs compared with protection IEDs in covering the requirements for recording power quality events provide a strong case for the installation of a separate device in certain applications.

DISTRIBUTED POWER QUALITY RECORDING SYSTEM ARCHITECTURE

The architecture of a power quality monitoring system in a distribution substation can vary significantly depending on the recording requirements, existing devices and the selected recording IEDs.

For example, let's consider a small distribution substation with a single transformer and electromechanical or solid state protection relays. Recording of most power quality events in the substation can be achieved by the addition of a single multifunctional recording IED with one set of three phase current inputs and two sets of three phase voltage inputs as shown in Figure 1. The same approach can be used if the distribution feeder relays are current only based.

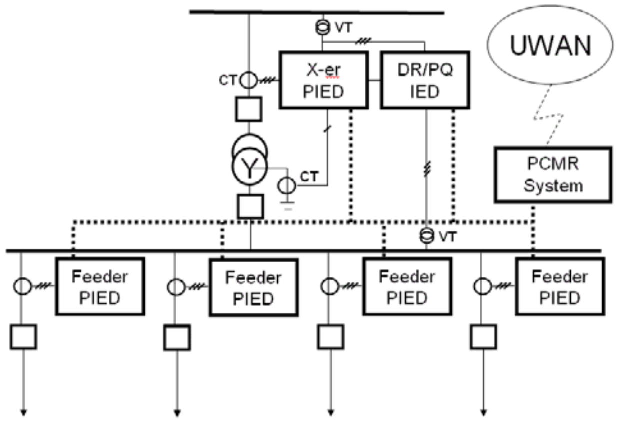

Fig. 1 Power quality event recording in small distribution substation

In this case the IED is monitoring the voltages on the high (transmission) side of the substation transformer and on the distribution bus. This is sufficient, since typically distribution substations have voltage transformers only on the distribution bus and not on the individual distribution feeders. Triggering of the recording can be based on set thresholds or from the feeder or transformer protection relays.
If the requirements for recording of power quality events include current measurements as well, the IEDs are installed on each individual distribution feeder, measuring currents from the feeder CT and voltage from the bus voltage transformer. It is very important that the IEDs are accurately time synchronized, which will allow the creation of a common power quality event record file as defined by the user requirements.

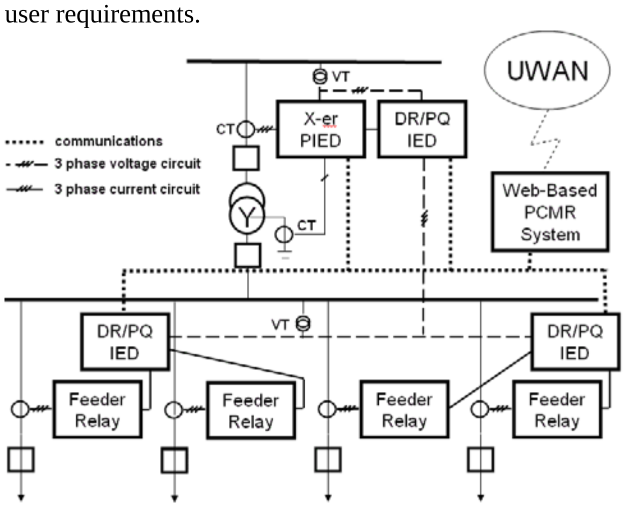

Fig. 2 Power quality event recording using IEDs with dual CTs

A more efficient architecture is achieved by using IEDs that have two sets of current inputs and one set of voltage inputs. This allows the use of one device per two feeders, thus significantly reducing the cost of the system.

The substation power quality monitoring and recording system automatically extracts all waveform or disturbance records files and stores them in a hierarchical file system for further processing as needed.
Such an architecture can be used in a distribution substation of any size. It offers significant flexibility, since if the number of transformers or distribution feeders is increased, new power quality monitoring or recording IEDs can be added.

IEC 61850 AND POWER QUALITY EVENT RECORDING

The new IEC 61850 international standard for substation communications will have a significant impact on the future of recording of short circuit faults, wide area disturbances or other abnormal system conditions that can be seen at the distribution level as power quality events.
IEC 61850 defines a distributed function model that includes sampled measured values. The building blocks of the model are the logical nodes that represent different functional elements available in the IEDs. The standard does not define where the logical nodes are located – in some cases they can be in a single device, while in others they can be in multiple physical devices.

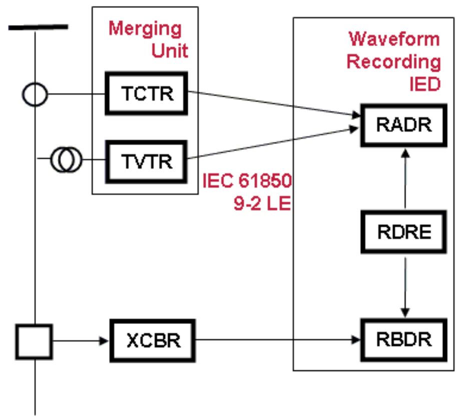

Fig. 3 Distributed waveform recorder object model

The processing of the secondary currents and voltages represented by the logical nodes TCTR and TVTR is performed in a new type of device – the Merging Unit. It is defined as an interface unit that accepts multiple analogue CT/VT and binary inputs and produces multiple time synchronized serial unidirectional multi-drop digital outputs to provide data communication via the Ethernet link.
Digital interface in a point-to-point communications scheme was defined by IEC in the IEC 60044-8 standard. The development of Merging Units that are used to convert the optical signal into a digital message containing sampled values and protection devices with a digital interface that perform multiple protection functions resulted in demonstration projects that show the advantages of this technology.

IEC 61850 further developed the sampled analog values interface at the process level of the substation automation system. This is the logical interface 4 shown in Figure 1 between the process and the bay levels.

The frame format from IEC 60044-8 is reused, but the new standard defines the transmission of sampled analog values over the Ethernet in both a point-to-point (unicast) and multicast mode.

Interoperability between merging units and protection, control, monitoring or recording devices is ensured through documents providing implementation guidelines. Two modes of sending sampled values between a merging unit and a device that uses the data are defined. For protection applications, the merging units send 80 samples/cycle in 80 messages/cycle, i.e each Ethernet frame has the MAC Client Data containing a single set of V and I samples. For power quality monitoring and waveform recording applications, such sampling rate may not be sufficient. That is why 256 samples/cycle can be sent in groups of 8 sets of samples per Ethernet frame sent 32 times/cycle.

The information exchange for sampled values is based on a publisher/subscriber mechanism. The publisher writes the values in a local buffer at the sending side, while the subscriber reads the values from a local buffer at the receiving side. A time stamp is added to the values, so that the subscriber can check the timeliness of the values and use them to align the samples for further processing. The communication system shall be responsible to update the local buffers of the subscribers. A sampled value control (**SVC**) in the publisher is used to control the communication procedure.

The sampled values from TCTR and TVTR are directly used as analog signals by the power quality event waveform recording function.

There is a difference between conventional multifunctional IEDs and the same distributed function implementation based on merging units and sampled measured values based IEDs. In the first case, all sampled measured values exchanged between the Txxx logical nodes and recording logical nodes are sampled at the same moment in time using a sample-hold type method and transmitted over the internal IED data bus for use by the different function modules. In the distributed applications the sampling may occur at different times.

DISTRIBUTED WAVEFORM RECORDING SYSTEM ARCHITECTURE

The distributed power quality event recording system architecture includes three types of devices: recording, interface and synchronization (Figure 4).

The synchronization device (or synchronizer) is used to ensure that the waveform recording system meets the requirements for time-synchronization according to the implementation guidelines in ??????. It sends a 1 pulse per second (1PPS) signal through the RS485 network to all interface devices included in the system in order to achieve accuracy better than 1 microsecond.

Each interface unit is connected to an Ethernet switch that in this case is dedicated to the Process Bus.

The recording device receives from the switch all Ethernet messages from the interface units included in the system. Considering the size of the Ethernet frames a single 100 Mb/sec port of the recording device can handle the traffic from up to seven interface units. If the central power quality event recording unit needs to record currents and voltages from more than 7 interface units, a 1Gb/sec port may be used to expand the recording system to up to 70 units.

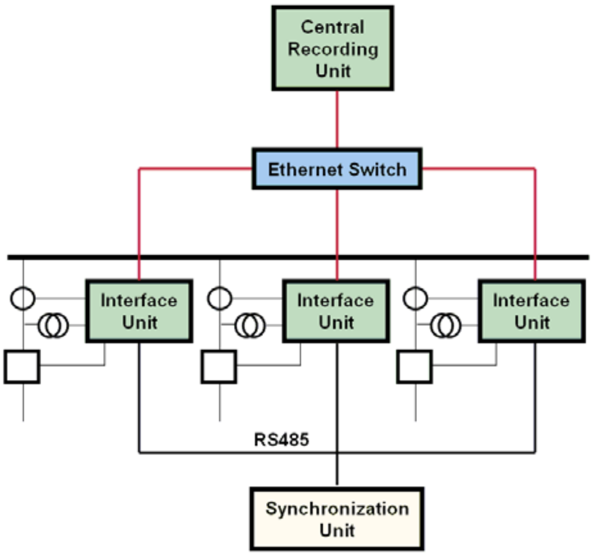

Fig. 4 Waveform recording system architecture

The recording device runs the triggering algorithm, records the samples and generates the COMTRADE files that are stored in its memory for further processing and analysis as necessary.

CONCLUSIONS

Recording of power quality events in distribution substations is based first on taking into consideration all the requirements based on the types of events to be recorded by the system, determining the recording capabilities of the IEDs existing in the substation and analyzing the recording capabilities of the IEDs available on the market.

Distributed recording systems can use conventional IEDs or be based on IEC 61850 sampled analog values from merging units.

Automatic record extraction by the central substation power quality event recording device should be supported.