

Records from DFRs vs. Records from Microprocessor-Based Relays

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Abstract--Today the use of digital IEDs for protection, monitoring and recording systems brings questions about the management and analysis of fault and swing records. Basic questions include: “what is the difference in between records captured from DFRs versus relays?”, “do I need a DFR in my system, and why?”, and “is my fault information good enough for complete fault and disturbance evaluation?”. Quality recording data is available, and needs the proper tools to ensure that timely power system disturbance analysis can save money, avoid blackouts and result in a more reliable system.

This paper overviews the importance of record data, and explores how it can benefit power system performance. We focus on the importance of record length, record resolution, the presence of harmonics, sample rates, and the ability to record in multiple points of the plant (enabling comparison of data by one centralized device, rather than independent analysis). We will show the difference in triggering methods, length of the pre- and post-trigger data, sampling rates, wide area event monitoring and cross triggering.

Index Terms--Generation, transmission, distribution, record quality, record length, record tools for analysis, data, exchange, waveform fundamentals.

I. INTRODUCTION

FAULT recording devices have been in use for several years; in the past we used ink chart recorders (often referred to as DFRs) which were responsible for recording faults in the power system. Back in those days electromechanical or discrete relays were responsible for protection of the power system.

The paper aims to help engineers/technicians performing protection and disturbance analysis clearly understand the value of DFRs in power systems, specifically the differences in recording information available, when compared with microprocessor-based relays. For a long time many protection engineers considered fault and disturbance recordings captured from relays to be “good enough”. This paper highlights the main differences between these two important devices in the power system, including how they address their work and for what purpose they were designed.

At the end of this paper, readers should have a clear answer to the question “**Do I still need a DFR in my system or is my system OK with the limited records I can capture from relays**”.

It is significant to remember the origins of DFR and microprocessor relays:

Relay’s main role: Provides protection to the equipment (and power system) by using sophisticated techniques. To perform such work, the relay may have other optional features including control, monitoring and recording; remember though, that the relay is intended mainly to protect devices in the electrical system.

DFR’s main role: Provides recording of transient faults and swing disturbances by using sophisticated techniques for record capture, record compression, record extension, and continuous recording. Although a DFR may have extra features to alarm or trip the system under fault conditions, its main role is the capture of sophisticated records for complete analysis, including supervision of the relay’s performance during abnormal power system conditions.

A. Definitions and Acronyms

The following terms are often used in discussion of disturbance recording.

Digital Fault Recorder (DFR) – records instantaneous values (waveforms) of current and voltage, ample times per cycle, for time periods on the order of a second. May also record computed quantities. Developed for the purpose of analyzing system protection operations and circuit breaker performance.

Disturbance – Any perturbation to the electric system. Other definitions exist, but are not related to electric system disturbance recording (IEEE 100, The Authoritative Dictionary of IEEE Standards Terms, Seventh Edition, 2000).

Oscillograph – An early fault recorder which generally used light beams writing on photo-sensitive paper or film. Since this term is firmly established, engineers frequently use "oscillograph" or "oscillography" when they are in fact referring to a DFR or to digital fault recording. Very few operative oscillographs remain, primarily because the special photo-sensitive paper has gone out of production.

Phasor Measurement Unit (PMU) – Device that records phasor quantities and accurately references them to a standard time signal (see IEEE Standard 1344-2006 for more details).

Digital Swing Recorder (DSR) – Device that capture swing records in power systems.

Sequence-of-Events Recorder (SER) – Records the sequence and time-of-day of digital events, such as contact operations. Developed to analyze the operation of protection and control systems.

B. Types of Disturbances of Interest to Protection Engineers

There are typically four types of disturbance or event records of interest to a protection engineer.

These are categorized by the event's duration, as follows:

Transient – These events are very short in duration and typically include faults that are cleared immediately by circuit breaker operation. These events are generally no longer than 8 cycles for high speed clearing, and 16 cycles for sequential line clearing. These events are usually analyzed to determine correct protection operation, fault location, or verification of system model parameters.

Short Term – These generally include all other time-delayed fault clearing and reclosing events where the system operation (stability) is not affected. These events are typically 20 to 60 cycles in length but may be longer if multiple protection operations are required to clear the fault. These events are usually analyzed to determine correct protection operation, fault location or verification of system model parameters.

Long Term – These include events that affect system stability such as power swings, frequency variations and abnormal voltage problems. Such events are usually analyzed to determine causes of incorrect system operations. Data management techniques are employed to process a number of samples and record the value for the parameter of interest. Record length parameters may be defined.

Steady State – There are steady-state disturbances where system operation is not threatened, but power quality is affected. This may include harmonics or sub-harmonics produced by the load and/or the interaction between power

system's components. Depending upon the type of phenomena being analyzed, higher sample rates may be required to capture the events and data of interest. Record length parameters may be defined.

II. SAMPLING RATE

A recording device's sampling rate impacts the accuracy of data captured for later analysis. The sampling rate also affects performance of the analog and digital filters, and the input magnetics of the recording device.

DFRs typically use a sampling rate of 32-384 samples/cycle. Relays sample as low as 4 to 20 samples per cycle, which simplifies analog to digital conversion and filtering. Some modern relays sample in the range of 32 to 128 samples per cycle (or more for recording purposes), providing good spectral coverage.

Unlike a typical DFR, a typical relay may apply a variable sampling rate based on the system frequency.

The sampling rate, and sampling frequency, of a recording device is not necessarily fixed. DFRs generally use the same time interval between samples, without respect to the actual system frequency. In modern DFRs, different sampling rates may be used for different trigger conditions.

As shown in the following pictures, you can appreciate that record quality depends on the sample per cycle (Fig. 1 is an example). The higher the resolution, the better the data quality for record analysis (see Fig. 2).

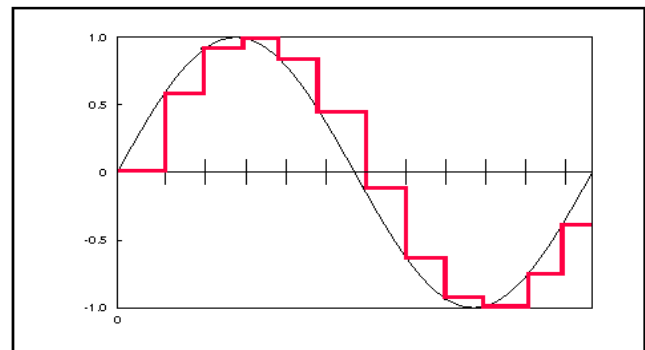


Fig. 1. Record quality

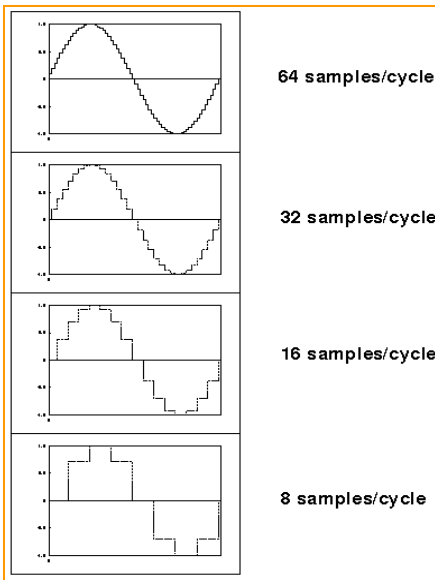


Fig. 2. Record quality at different sample rates

III. TYPE OF TRIGGER

Recording devices may use edge triggers or duration triggers to initiate recordings. Fixed length recording, as illustrated in Fig. 3, simply initiate a recording of pre-determined length, while duration triggers attempt to capture the length of an entire fault within one record. Edge triggering is the most common triggering mode in use.

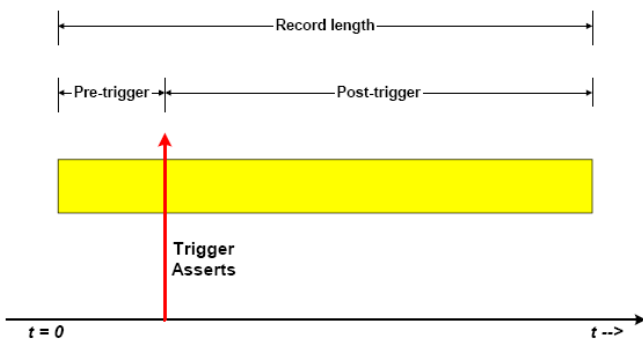


Fig. 3. Edge triggering

A device using edge triggering initiates a recording on the rising edge of a trigger, and continues recording for a pre-determined length of time. The total record length is determined by the amount of pre-fault data, the length of the fault, and the amount of post-fault data. The amount of pre-fault data is generally configurable in digital fault recorders, and may be a fixed or configurable value in protective relays. The amount of post-fault data is either determined by an explicit setting for post-fault data, or by a setting for the normal record length. The amount of post-fault data is generally configurable in digital fault recorders, and may be fixed or configurable in protective relays.

A device using duration triggering, as shown in Fig. 4, initiates a recording on the rising edge of a trigger, and

attempts to keep recording as long as the trigger remains active. Once the trigger de-asserts, a device using duration triggering generally captures some amount of post-fault data. The total record length is determined by the amount of pre-fault data, the duration of the event, the amount of post-fault data, and the maximum record length. The amount of pre-fault data and the amount of post-fault data for duration recording is generally configurable. The maximum record length may be configurable or a pre-fixed value. When the trigger duration exceeds the maximum record length, the recorder typically stops recording further data, resulting in possible unrecorded data.

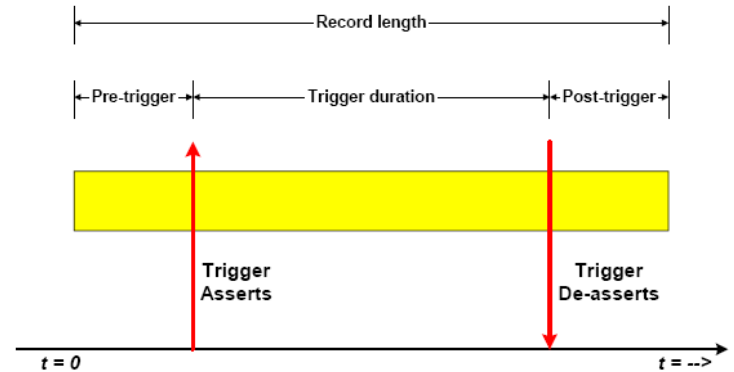


Fig. 4. Duration triggering

Duration mode recording is one method that attempts to capture an entire power system event in one fault record. A second method that is available in some recording devices is automatic extension of fault records for multiple trigger conditions (as shown in Fig. 5). When a second trigger occurs while a prior recording is still active, the device extends the first recording to capture the appropriate amount of post-fault data for the second trigger. Similar to duration triggers, automatic extension is limited by a maximum record length setting, which is typically set far greater than the normal record length.

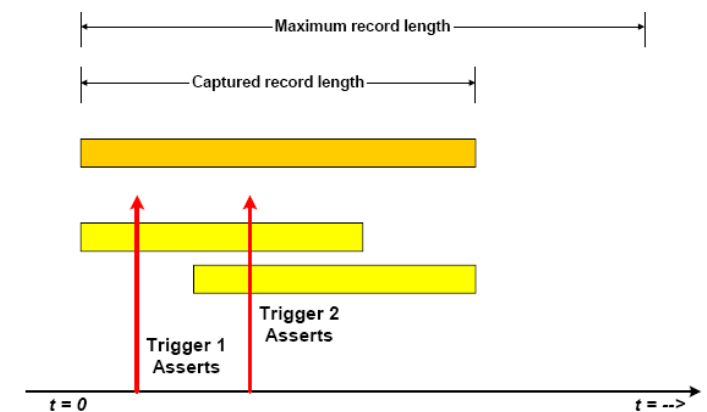


Fig. 5. Automatic extension of records

IV. RECORDERS VERSUS MICROPROCESSOR RELAYS: COMPARING RECORDING CAPABILITIES

The following table shows typical specs of DFRs and relays in the power industry today:

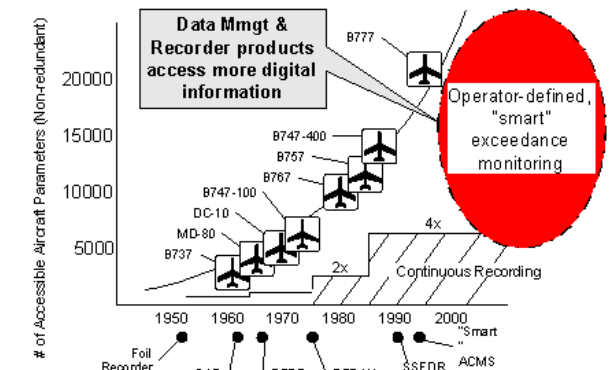
Description	Typical Recorder	Typical Relay
Sample rate	32-384 samples/cycle	4-32 samples/cycle
Analog signal filtering	No	Yes (typical)
CDR (continuous digital recording)	Yes	No
Record quantity	Over 1000	Very limited (40)
Harmonics	Up to 100 th	Up to 16 th
Wide Area Recording Application	Yes	No
Recording memory size	Over 3Gb	Very limited
Frequency response	23.04 kHz	3.6 kHz
Trigger options	V, I, P,Q, f, Z, Io, I1,I2,Vo, V1,V2, summations, dv/dt, dp/dt, dq/dt, df/dt,THD, harmonics (all spectrum), external inputs, relay activations, etc.	V, I, f, Z, Io, I1,I2,Vo, V1,V2, df/dt, THD, harmonics, external inputs,
Analog channels	0-144	0-12
Digital channels (IN-OUT)	0-288	0-30
PQ monitoring	Yes	No
Record length (fault)	60 cycles 1800 cycles	10 cycles 120 cycles
Record length (swing)	60 sec 1800 sec	30 sec 120 sec
Trend length		
Recording:		
• Edge type	Yes	Yes (typical)
• Duration type	Yes	Very few
• Record extension	Yes	No
• Transient	Yes	Yes
• Swing	Yes	No (very limited)
PMU channels	Minimum 10	2

A. Comparing Airplane Recorders To Power System Recorders

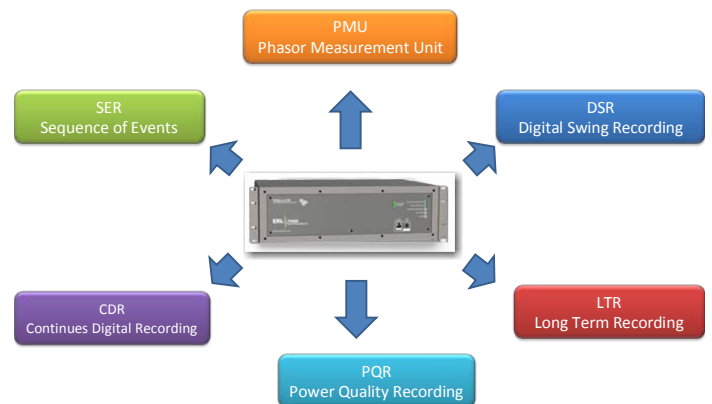
We can compare the importance of use today’s DFR with the black box in an airplane (see Fig. 6). The airplane has many controls, relays, and monitoring devices for the crew, but it is extremely important to have a separate “black box” to capture extended recordings and events. The black box is intended to provide extremely important recording data for the investigation of critical scenarios. In the same way, the power system can have several IDs (relays, controls, etc) but during a fault and disturbance scenario or blackout, we need a black box (DFR) to provide us with valuable information for a complete analysis of the disturbance or fault, this valuable information will include:

- Extended wave forms
- Continuous recording data
- Report of events with time synchronization
- Extended PMU information
- Overall power system information
- Data to evaluate a relay’s performance during faults and disturbances
- Wide area recording
- Tools for fault analysis (graphics, waveforms, phasors, fault trajectory, etc)

These devices have improved their capacities and features in recent years.



a) Airplane black box trend



b) DFR trend today

Fig. 6. Airplane black box and power system DFR

V. SIX REASONS WHY STAND-ALONE RECORDERS ARE NEEDED ON THE POWER SYSTEM

1. Recording power system quantities independently of other devices is essential in order to obtain information about the power system during disturbances (or to ensure information is captured during faults that are independent of relays or other devices that operated during the disturbance). In these cases information misprocessing or information corruption must be avoided. A stand-alone recorder like the TESLA recorder can provide information about what happened on the system at several locations over a period of time, in more detail than is generally obtainable from a recording relay. Analyzing the data after the fact is analogous to examining black box data from an aircraft after a catastrophic plane crash.
2. Data from recording relays can be useful for disturbance analysis. A stand-alone recorder can however be used to determine whether the relay is recording correctly during fault and during nominal system conditions. In this way, the analog front-end of a relay can be verified using a stand-alone recorder, extending relay maintenance periods.
3. Multi-timeframe recorders can provide valuable information about the power system by triggering on system anomalies and by collecting data over a wide frequency spectra. In this way, information from ranging from sub-nominal to harmonic frequency data can be collected and analyzed to determine cause and effect.
4. Relays (whether recording or not) need to be connected to CTs and PTs that are suitable for collecting fault data, since their primary goal is to provide protective functions. Recorders, on the other hand, in addition to collecting fault data, can have separate input channels connected to metering CTs and PTs to collect metering data with a high degree of accuracy. This activity can replace or enhance metering quantity collection into SCADA or EMS systems.
5. The role of recorders is to record power quantities. Having devices with this dedicated function makes them more effective in providing the information needed to analyze system disturbances.
6. The distributed nature of the TESLA recorder input configuration can make recording installations more compact in size than those of relay IEDs for a given number of analog and digital inputs being recorded. This makes for smaller panel requirements and ultimately smaller substation building requirements that can allow a station to be expanded with less cost.

VI. PROTECTIVE RELAYS WITH OSCILLOGRAPHY RECORDING

Microprocessor relays can also capture records and events based on their individual element and digital I/Os. But relays as recording devices distribute data over many devices, rather than combining that data in one device. Time synchronization of all the relays, and other recording devices, is a significant issue. Gathering and combining all data from these individual sources (relays) is a manual activity. There may also be differences in triggering method, sampling rate, and record length to consider. Triggering of the recording function within a relay is programmable, and based on the internal measuring elements within the device. Typically these records are limited to the “zone of protection” associated with the device, as see in the application figures.

VII. RECORDING AND MONITORING FROM RELAYS AND DFRS

Let’s discuss monitoring and capture zones of faults and disturbances from relays and DFRs in three typical power system applications.

A. Generation Power Plant Application

Below we see a single line diagram of a typical power plant, showing the zones coverage for fault and disturbance capture. We clearly see the relay limited coverage of fault information and the quality of information needed for analysis. At the same time the DFR coverage includes the overall power plant comprised of the generator, bus, lines, step-up transformer, and others points. The DFR will be able to monitor voltages, currents, frequency, active/reactive power, symmetrical components, excitation currents and voltages, battery dc system, blade positions (nozzle positions), pressure, temperatures, and breaker status (see Fig. 7.1).

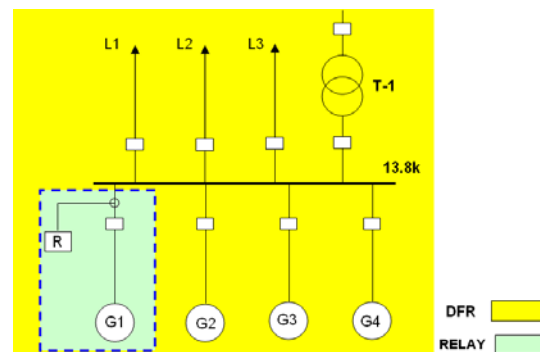


Fig. 7.1. Zones of DFR and relay coverage in a generation power plant

B. Substation Application

This scheme show the zones coverage in the substation. Again the relay monitors a single line with limited information, while the DFR cover the entire substation (lines, buses, transformers, capacitors and reactors), as shown in Fig. 7.2.

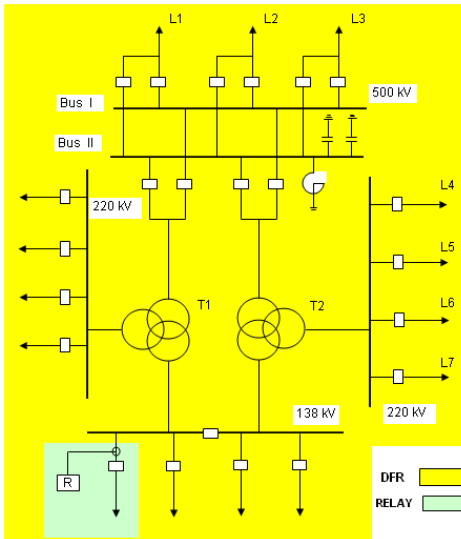


Fig. 7.2. Zones of DFR and relay coverage in a substation

C. Distribution Application

In this case the relay data is limited to the feeder inside the distribution system, while the DFR has very extended and complete coverage of the complete substation (Fig. 7.3).

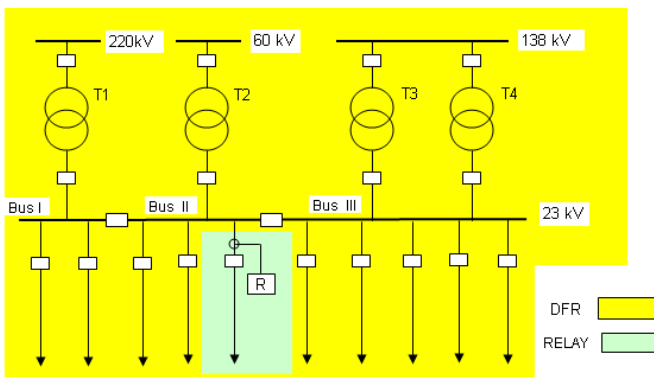


Fig. 7.3. Zones of DFR and relay coverage in a distribution system

VIII. RECORDING CAPABILITIES AND TOOLS APPLIED IN POWER SYSTEMS

Using DFRs in our power systems enables better performance and a complete understanding not possibly by simply using relays for record fault capture. Below, several screenshots from multi-timeframe recorders illustrate the quality of event capture.

A. Analog Channels

High sampling rates enable several analog channels to be captured at a time.

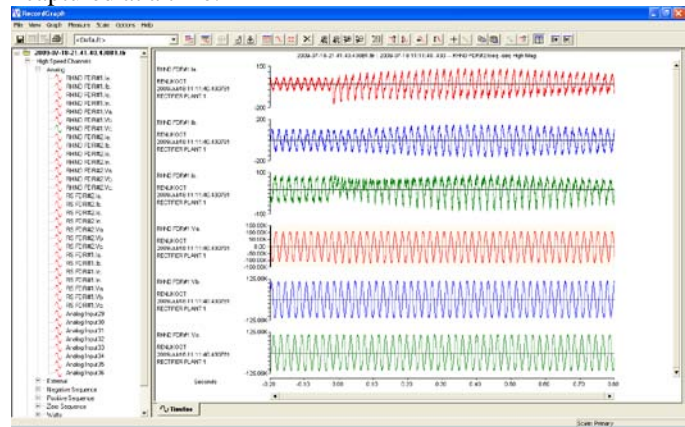


Fig. 8.1. Analog channel recording

B. Digital Channels

Up to 256 digital channels can be captured in a DFR set.

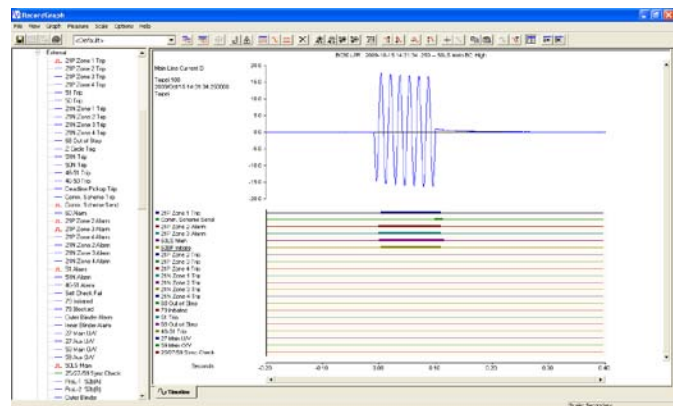


Fig. 8.2. Digital channel recording

C. Low-Speed Analog Channels

The following snapshot shows swing data captured by a DFR:

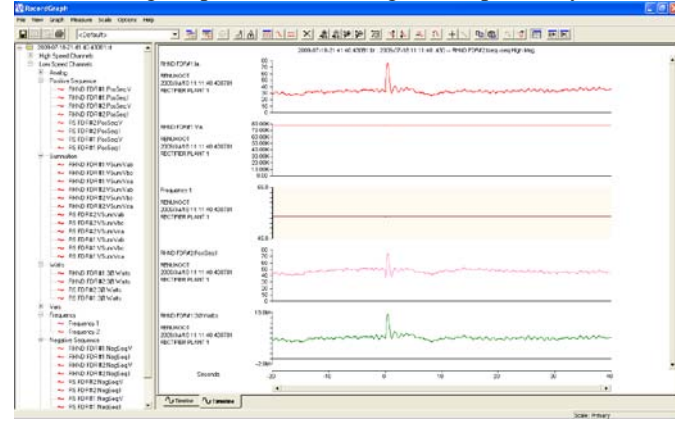


Fig. 8.3. Low-speed analog channel recording

D. Impedance Plot

For distance protection analysis, very sophisticated tools enable easy plotting of the fault and of the distance relay's impedance zones.

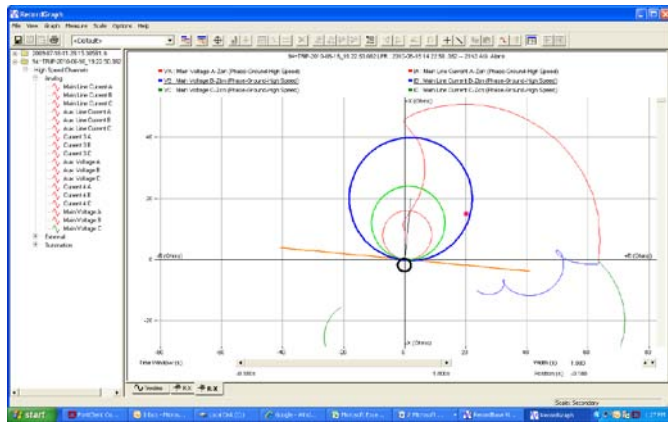


Fig. 8.4. Impedance plot

E. Differential Plane

For differential relay protection analysis, very sophisticated tools enable easy plotting of the fault and of relay characteristics (minimum pick-up and slopes).

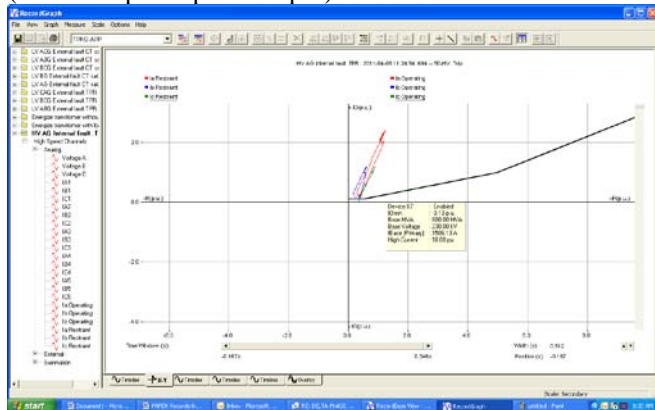


Fig. 8.5. Differential plane

F. Trend Capture

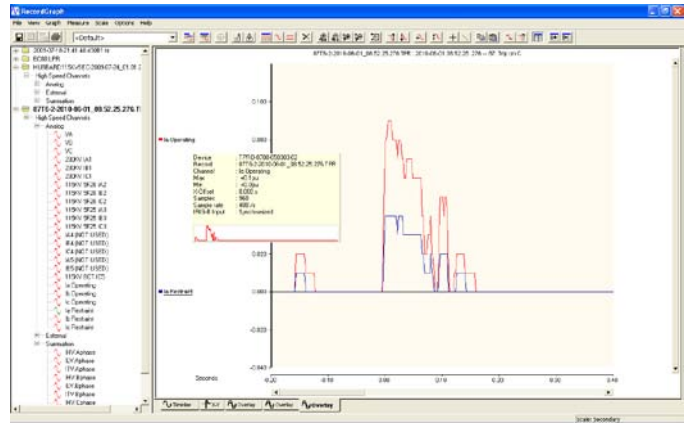


Fig. 8.6. Trend capture

G. Symmetrical Component and Phasors

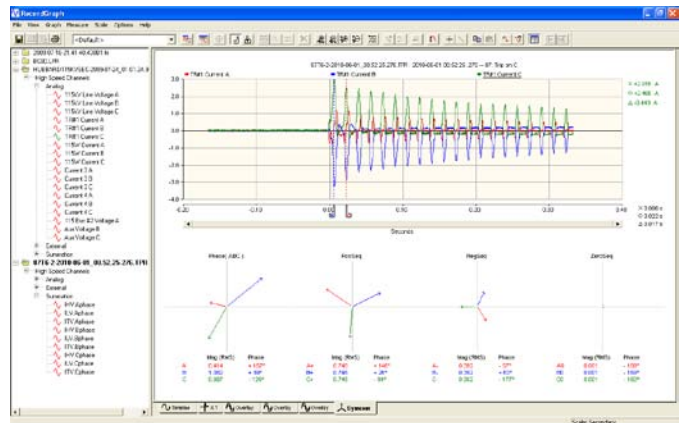


Fig. 8.7. Symmetrical component and phasors

H. Harmonics

The following snapshot provides a scan of the harmonics spectrum and THD along the analog channels for power quality analysis.

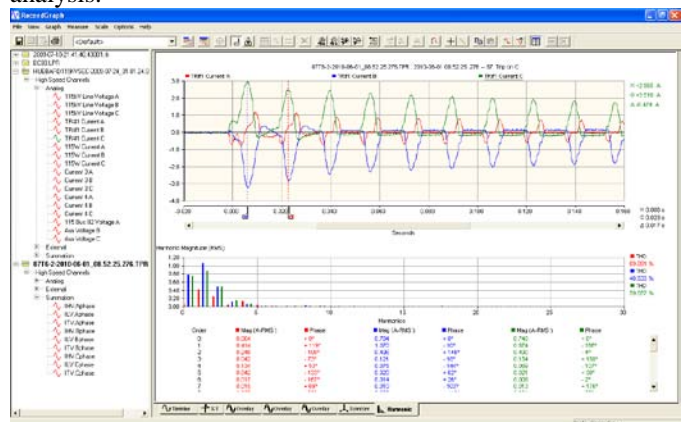


Fig. 8.8. Harmonics

IX. CONCLUSIONS

- DFRs provide better record resolution and quality
- DFRs present multi-timeframe records and provide valuable information about the power system by triggering on system anomalies and by collecting data over a wide frequency spectra
- DFRs can coverage the complete system application on faults and events detection in the all zones
- DFRs allow the system to have extended PMU data for planning analysis
- DFRs can evaluate Relay performance in terms of protection and recording capture
- **We strongly recommend the use of DFRs in Power Systems.**

X. REFERENCES

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Papers from Conference Proceedings (Published):

- [2] Fedirchuk, D. J. 2000. Integration of recording relays into disturbance analysis. Fault and Disturbance Analysis Conference. Atlanta, Georgia, USA.

Other:

- [3] IEEE. The Use of DFRs in Power Systems, USA.

XI. BIOGRAPHIES



Hugo Davila has a degree in Electromechanical Engineering from the Engineering University of Lima, Peru. Mr. Davila is an IEEE active member. Hugo is a Regional Manager at ERLPhase Power Technologies Ltd, formerly a part of NxtPhase T&D Corporation. Before joining NxtPhase, Hugo worked for Beckwith Electric as a Technical Support Engineer in protection and control systems. Hugo also has protection experience working as a field engineer at the main power electric utility in Lima, and is an author/co-author of several papers about power system protection applications (e-mail: hdavila@erlphase.com).