Software Tools for Record Fault Analysis in Power Systems

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Abstract

We have available, in today's application of microprocessor based relays and digital fault recorders, record analysis software. This software shows graphical and numerical information along with powerful tools that are easy to use. These are applied by relay protection engineers, to analyze the records and provide a more efficient analysis for simple and complex cases. These tools also provide a mechanism for prompt response to high demand industrial or domestic consumers. This paper focuses on the software tools used to analyze real fault analysis showing waveforms, phasors, symmetrical components, I/O events, harmonic spectrum and R-X impedance plots. This also shows trends of multiple disturbances dependent on the fault or disturbance that is under study.

Presented in this paper are several transient and dynamic record faults acquired from real triggered faults, and normally saved in the IEEE C37.111 COMTRADE format from different protective devices and customers at different locations. Playback of some of these fault records using a test set into multifunction relays is analyzed for better real analysis, discovering the cause of the fault effect and to provide suggestions on each independent case.

INTRODUCTION

In the field of protection dealing with record faults, the protection technical personnel will encounter cases where it is difficult to determine the nature of fault. For this reason, there has been several analysis software packages developed with tools that help the engineer to easily recognize the fault type and nature, in order to provide a complete report on the failures associated in the power systems.

Fault Classification

In conventional power systems we should find faults, disturbances and events.

This paper presents various real case scenarios for analysis, using the records captured from relays and recorders. These files were converted into COMTRADE format (Standard IEEE C37.111) and some of the records were replayed using a relay test set for more in-depth analysis of the case.

1.0 Single Phase to Ground Fault
2.0 Phase to Phase Fault
3.0 Three-Phase Fault
4.0 Transformer Overexcitation
5.0 Stator Ground Fault
6.0 Transformer Inrush Current
7.0 Power Swing
8.0 Industrial Application

1.0 Single Phase to Ground (ϕ-g)

The following fault demonstrates a ground fault in a transmission line. Using the analysis software we can visualize the behavior of the phase C current, shown on Fig-1a. This current is reflected on the residual current 3Io that is shown in the same figure. We also see how the current is increased to 7 times the load current, and the voltage is decreased to 0.3 times the normal voltage. We are also able to view the relay performance tripping the circuit in its first zone, represented in Fig-1a, in their digital outputs status. The different zones of the ground distance function of the relay show a pickup on this fault, and the 51N function as well. Nevertheless, the fault was cleared in approximately 1.0 cycle.
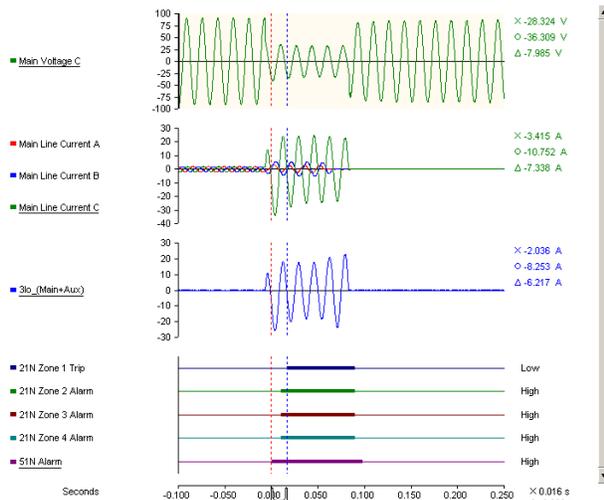
Fig-1a: Record of a typical phase to ground fault at phase C

Also making use of the phasor tool from the symmetrical components (Fig-1b) we can observe the high zero sequence current content, typical in single-phase failures.
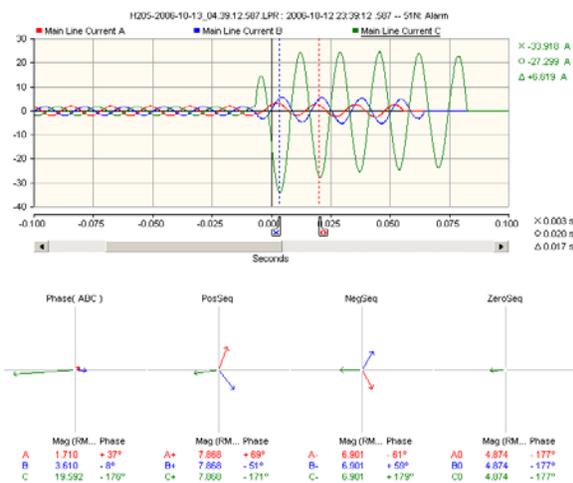

Fig-1b: Symmetrical components of the phase to ground fault at phase C

The program is also capable of showing an R-X impedance plane. Fig-1c shows the development of a failure inside the zone of operation of the distance relay associated to the point of failure, where it displays the polygonal characteristics of the different zones of the distance relay for phase to ground faults.
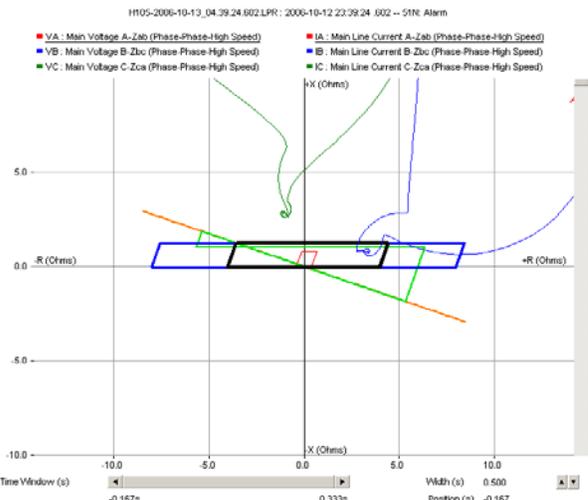

Fig-1c: R-X impedance plane, an evolution of the failure inside the trip zone of the relay

2.0 Phase to Phase Fault

The records in Fig-2a show us a typical phase to phase or two-phase failure among the A-C phases. The currents increase with relation to the phase B current, which is a typical behavior in phase to phase failures. The phasors of the symmetrical components confirm the characteristic of the failure with a high current value in the negative sequence component, showing the total A and C phase currents with high magnitude which is typical in these cases.
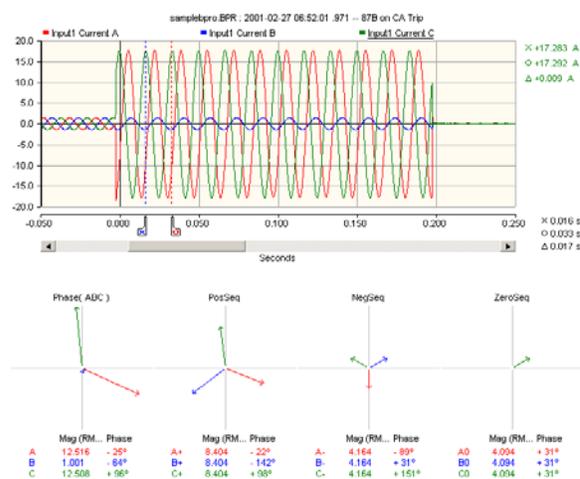

Fig-2a: Symmetrical components for phase to phase faults

In Fig-2b, we can visualize the good performance of the protection system, indicating its pickup alarm and trip of the phase overcurrent function (51).
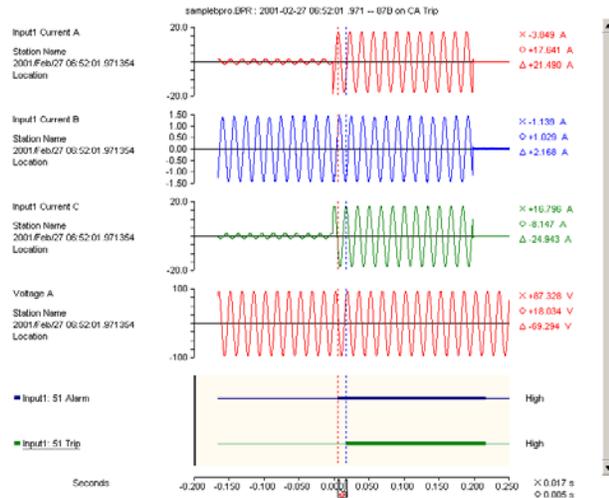

Fig-2b: Record of phase to phase A-C fault, alarm, and pickup of the overcurrent relay

3.0 Three-Phase Fault

Fig-3a shows a record of a three-phase failure occurring in a power transformer. Here we observe how the currents reach 4 times the nominal current. From the waveforms behavior in all three phases it is very clear the operation of the transformer protection is activating the differential function.
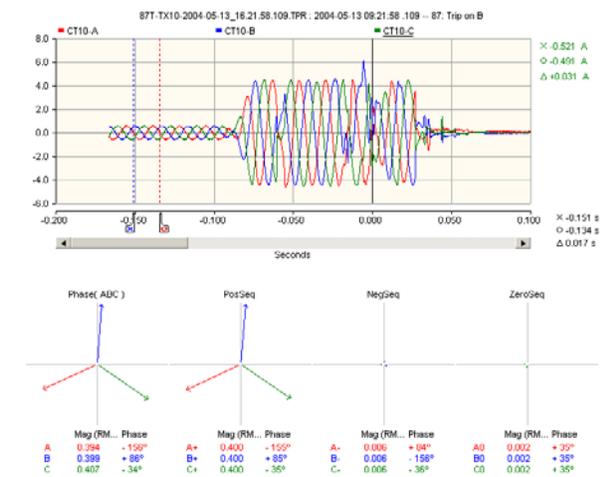

Fig-3a: Records of a three-phase fault in a power transformer HV side
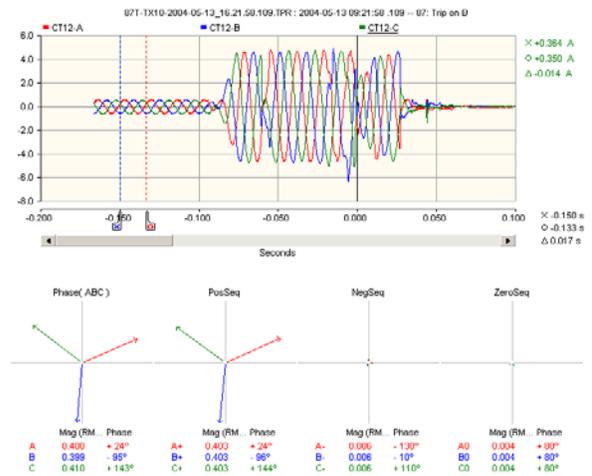

Fig-3b: Records of three-phase fault in a power transformer LV side

The phasors of positive sequence also confirm the presence of a three-phase failure. Besides the analysis and for the case to verify the phase shift of the currents, we can identify the group of connection of the power transformer by having the phasors of two groups of currents in high voltage and low voltage. See Fig-3a and Fig-3b, the records are showing currents of Ia = 0.394 < -156º in high voltage, and Ia = 0.408 < +24º in low voltage. The 180º of phase shift approximately one of another, indicating that in the conventional European diagram, the primary current is in position "0", and secondary in position "6", which means the group of transformer connections under IEC standard is Yy6.
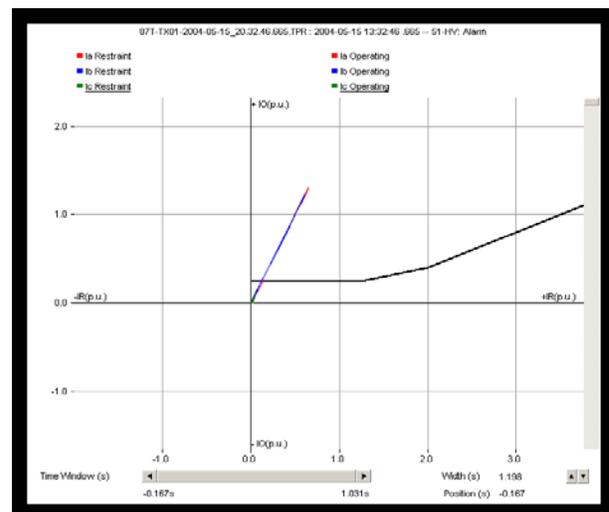

Fig-3c: Differential relay characteristic plane

Fig-3c shows the point of failure in a curve of operation of the differential function of the relay. We can observe how the current enters directly to the zone of operation of the relay, hence, becoming a very useful tool to confirm the operation inside the zone of tripping of the relay.

4.0 Overexcitation Phenomena (V/Hz)

This phenomenon appears when an excessive voltage exists in the system or frequency under the normal conditions, or a combination of both. The sudden loss of load can show up a substantial over voltage to a step-up transformer inside the plant. An overexcitation condition presents an overfluxing with excessive V/Hz if the transformer is saturated. Then the excitation current is increased, resulting in high interlamination core voltage and causing iron melting within the transformer. The overexcitation originates false differential currents and can exist for a long time, causing serious damage to transformers and generators. This phenomenon is characterized by their high content of fifth harmonic current, which often leads to disconnection of transformers through the differential protection, causing unexpected trips. Therefore, differential relays should be adjusted for restriction of fifth harmonic to block false tripping.

Using the software as a tool to describe this issue we captured a record in a power plant that has thermal turbines with step-up transformers. We can visualize the fifth harmonic content and the relay activation without tools that show us the records with harmonic content. It will be very difficult to define the real cause of the trip.
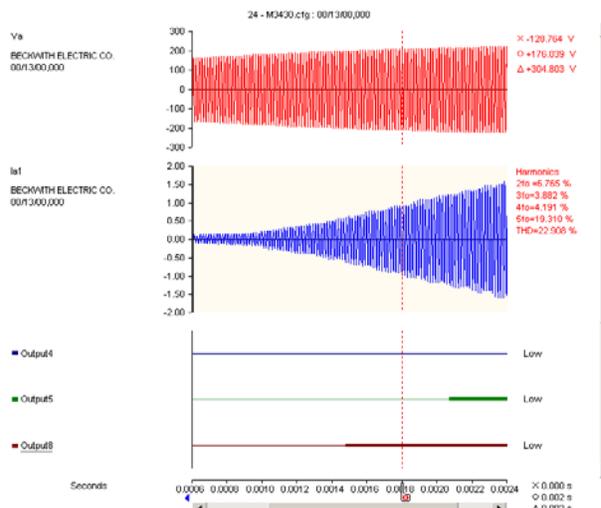

Fig-4a: Record captured at a large thermal power plant showing a typical disturbance of overexcitation

The record in Fig-4a shows the progress of the voltage and current. Using the software tools we make a zoom of the current waveform of Fig-4a and plot it in Fig-4b where we can appreciate the high fifth harmonic level up to 20% of the normal current. This value should cause a trip to the differential relay but we have the relay configured to block this current level or unblock depending on the fault condition.
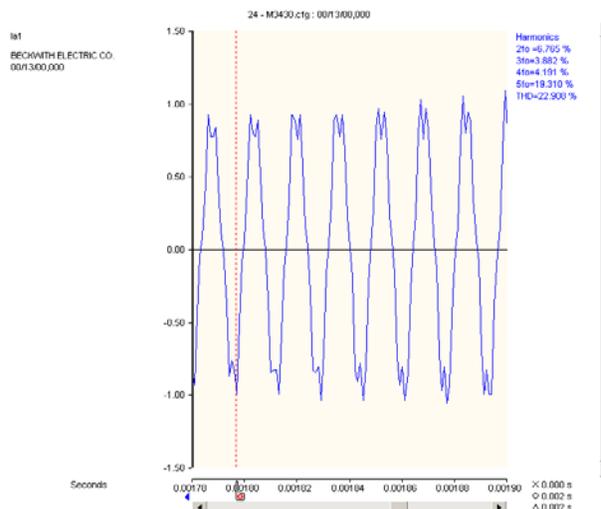

Fig-4b: Current record in zoom view from Fig-4a

Fig-4b shows a record captured from the previous records at Fig-4a using the zoom feature of the software, very clearly showing the fifth harmonic component in the current produced by the overexcitation condition.

5.0 Stator Ground Fault

In this case, we captured a record in a power plant at the neutral side of the stator as shown in Fig-5a and Fig-5b. This shows a progressive phenomenon of failure. There is an insignificant amount of voltage (A) at the beginning. Then by using the software tools and by zooming (Fig-5b) we showed that this voltage is a typical third harmonic voltage (2.0 V) where the presence of earth fault exists near the physical neutral of the machine (5% of the stator). As a result of this unclear fault, the fault progress (B) reaching a high voltage level of 37 V. This fault level remains for approximately 12 cycles, and after a time of approximately 14 cycles (C), the failure is extinguished and appears again, reaching a even higher voltage (D). The fault then again was extinguished for about 8 cycles (E), and eventually became a permanent failure (F) reaching a voltage of 57 V.
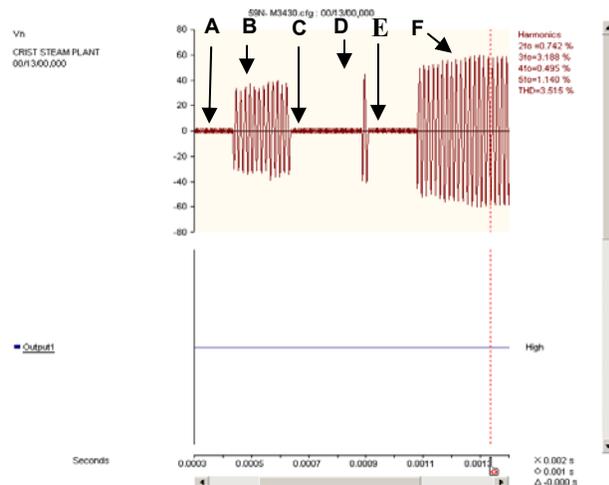

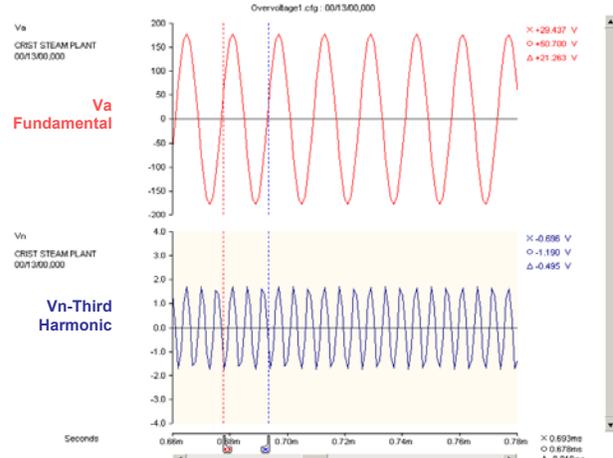**Fig-5a: Record of stator ground fault**

Fig-5b: Zoom captured from the record in Fig-5a, stage A showing a premature ground fault

6.0 Inrush Current in Transformers

The following record shown in Fig-6a is a typical phenomenon in transformers, known as inrush current. This current exists as we energize the machine and it is characterized for its high content of second harmonic. Phase C is showing the most critical level of inrush current where the current reached 8 times the nominal current, indicating up to 34% of second harmonic. This record is helpful in that it enables users to adjust the level of the second harmonic restriction inside the differential relay in order to avoid unexpected trip at the beginning of energizing.
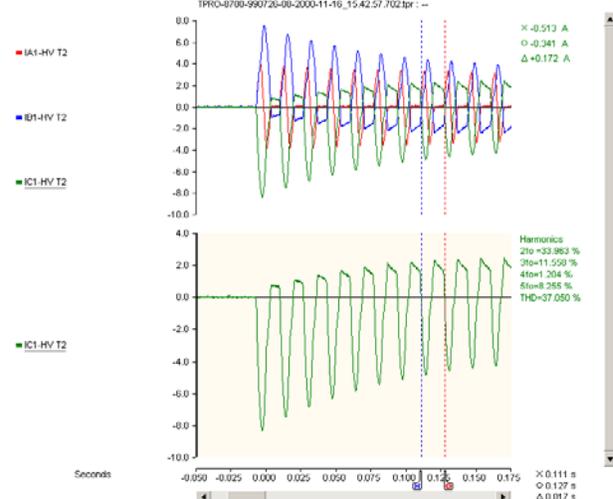

Fig-6a: Record of a typical inrush current in a power transformer

The record in Fig-6b shows how the relay has detected the operation and how it restricts a false trip. It detects the ratio of 2nd harmonic current to the fundamental. Maintaining the tripping output inactive, this type of analysis without having the software tools would be very difficult in comparison to the old electromechanical relay or solid-state relays where the relay engineer would have to guess the operation of the relay.
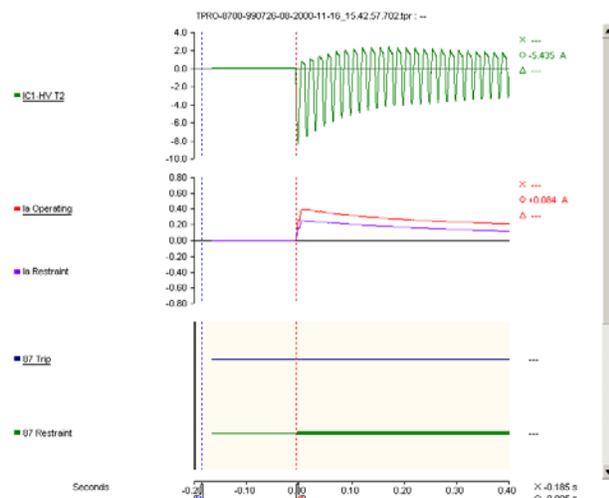
Fig-6b: record showing inrush current with appropriate activation of the differential relay via the output contacts (differential trip and restrain)

Once again, the use of software tools enables protection engineers to identify typical disturbances in the transformer. In this case, the software tool for harmonic spectrum is utilized in order to visualize the harmonic content in Fig-6c. These values are often disregarded by relay engineers, setting the relay using rules of thumb or the usual values from other places. By using these software analysis tools we can now capture records using digital fault recorders and measure the values of each individual transformer.

Fig-6c: Record and harmonic spectrum for a typical inrush current at phase C of the transformer

7.0 Out of Step Condition

The problem of out of step is a phenomenon that occurs in a system caused by short circuit, auto-reclosing, line switching, fluctuation of large loads, or a combination of these phenomena. In Fig-7a, we demonstrate a record captured in a hydro power plant. Under this condition, the shaft of the machine was subjected to high levels of mechanical stress that can easily break the shaft that joins the generator and the turbine. Due to the continuous mechanical efforts and fatigue that is transmitted, many times these types of circumstances are not clearly seen. The operators of the machine will sometimes report noises and vibration. These kinds of phenomena are typical of out of step conditions, shown in Fig-7a.
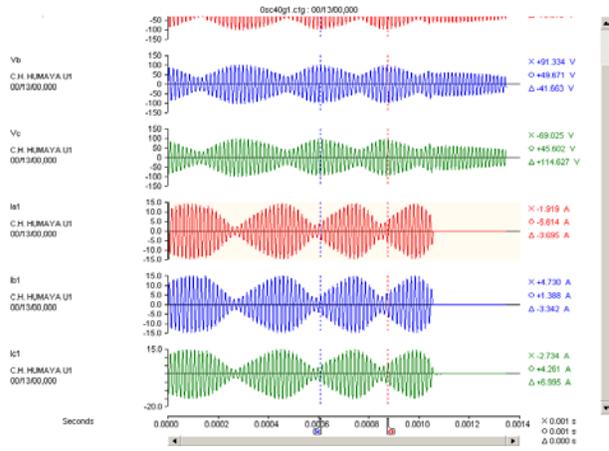
Fig-7a: Record of oscillation phenomena (power swing)

Using the analysis tools of R-X impedance plane we observed the impedance trajectory of this particular disturbance. Due to inadequate protection, we note that the relay did not clear the power swing disturbance. The loss of field relay caused a trip under this condition which worked like a backup protection.
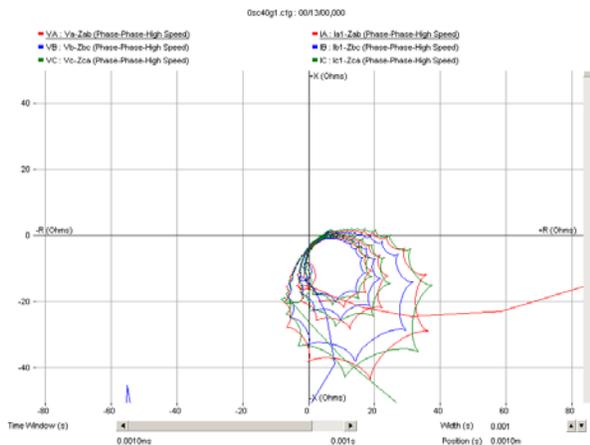

**Fig -7b: Progress of the impedance in the R-X plane**

8.0 Industrial Application

The records shown in Fig-8a shows us clearly the deformation of the waveforms in current caused by non-linear loads, through the software of analysis we can identify which harmonics are more pronounced, as well as also the THD (Fig-8b).

Using these tools we are able to indicate if the harmonic levels fall under the standards of the IEEE for industrial applications.
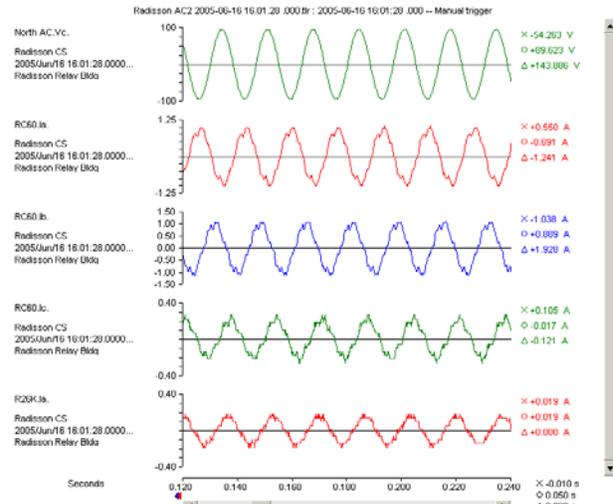
Fig 8a: Records of current and voltage distortion caused by non-linear loads
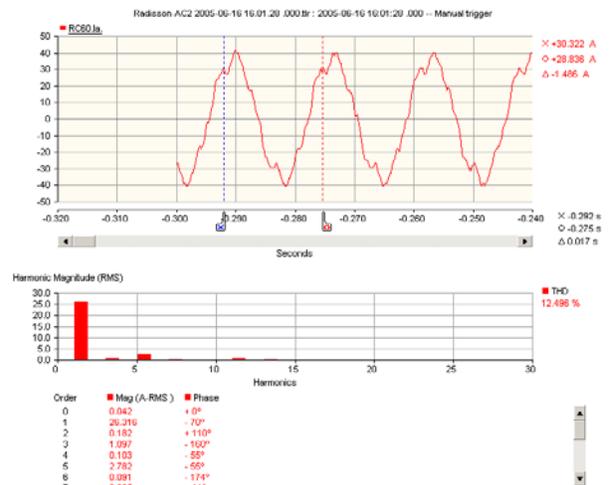
Fig 8b: Record of harmonic spectrum of current phase A

CONCLUSION

Today, software for record fault analysis becomes a critical point for protective engineers. Relay false tripping should be avoided using the software tools as part of the setting levels. Using these tools and correct interpretation of the record fault diagrams can lead to many avoided blackouts and disasters. We encourage protection engineers to use the potential of the software tools in order to maintain performance and reliability of their power systems.

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BIOGRAPHY

Hugo Davilia received a degree with honors in Electromechanical Engineering, majoring in Power Systems from the Engineering University of Lima-Peru. He has been an active member of IEEE since 1995. Hugo is an Application Engineer for the Latin American region of **NxtPhase T&D Corporation**. Previous to joining NxtPhase, Hugo worked for Beckwith Electric in Largo, Florida as Technical Support Engineer in protection and control systems; Hugo also has experience in protection working as a Field Engineer at the main power electric utilities in Lima-Peru; and co-author of various technical papers on protection.