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IMPROVING THE ANALYSIS OF PROTECTION OPERATIONS

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REQUIREMENTS FOR ANALYSIS OF PROTECTION OPERATIONS

The analysis of the operations of protection relays during short circuit faults or wide area disturbances plays a very important role in detecting problems with the settings of the relay, the electric power system model used to calculate them or with the protection devices interface to the substation equipment.

The tools required to perform this analysis depend on the purpose of the analysis, as well as the knowledge of the person performing it. Some of the tools are used to convert the recorded waveform samples into images that can be analyzed, while others perform calculations using the samples and present the results as information.

The users of analysis tools are usually protection, planning and power quality specialists that may be interested in different aspects of the event that occurred in the system.

The successful analysis of different power system events requires good understanding of the phenomena, the operating principles of primary and secondary system equipment, as well as the limitations imposed on the analysis by the available data. A proper classification of the types of events is a pre-requisite in the development of a system for automatic event analysis.

The types of events that can be typically analyzed within a substation automation system may be divided in several categories, such as:

- Shunt (short circuit) faults
- Series (open conductor) faults
- Breaker switching
- System parameter variations
- Equipment failure
- Protection operation
- Control system operation
- Operator action

The problem with the analysis of system events, such as the ones listed above, is that usually they are complex events that fall within several of the categories. For example, breaker closing is an event that may be the result of operators’ action or protection operation. A protection operation may be the result of incorrect setting under maximum load conditions. But it may also be the result of a short circuit fault.

Because of the above, we need to identify two main classifications of events:

- Primary event: This is a single event that may result in a sequence of related events of different types
- Secondary event: Any event that is the result of a primary or other secondary event (caused by the same primary event)

Several simultaneous secondary events may be associated with a single primary event. Or they may represent a sequence of secondary events. An example will help clarify these definitions.

Primary event: Single phase-to-ground fault in phase A

Secondary event 1: Voltage variation (sag) in phase A

Secondary event 2: Voltage variation (swell) in phase B

Secondary event 3: Voltage variation (swell) in phase C

Secondary event 4: Protection operation

Secondary event 5: Breaker trip

Secondary event 6: Autoreclosing relay operation

Secondary event 7: Breaker close

If we look at the above listed secondary events, we see that events 1 through 3 are simultaneous, while events 4 through 7 are sequential.

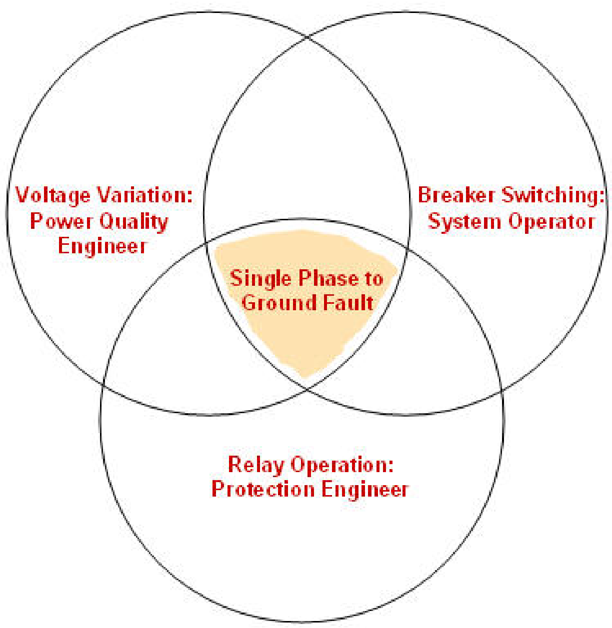

Figure 1 - Primary and secondary events and their users

The importance of event analysis is the requirement for converting data into information. And information has a different meaning to different users (see Figure 1). Something that is an important event to one user may not be significant to another. If we analyze the above example, secondary events 1 through 3 will be classified as a Momentary Voltage Variation event – important to some users with equipment sensitive to voltage sags. However, such an event is of no interest to the system operator.

The Protection operation and Autoreclosing relay operation events are of interest to the protection engineer, but of no interest to the power quality engineer.

What is of interest to the system operator is the fact that there was a temporary fault in the system, followed by successful relay operation and return to the pre-fault system configuration.

The protection engineer in this case will be interested in the fact that the primary event was a change of an overcurrent pickup setting.

To the system operator the important event is the breaker open status after the sequence.

Since there were no power system parameters variations, none of the above events is of interest to the power quality engineer.

It should be clear from the above that one of the main requirements is to be able to analyze an event, determine the primary event and provide information in a suitable format for the secondary events of interest to specific users.

ANALYSIS TOOLS

Some of the first tools used by protection specialists for the analysis of the operation of protection relays during short circuit faults were oscillographic records. The trained eyes can recognize easily the type of fault, its duration and can see many other things in the recorded waveforms.

Waveform display

The display of the recorded waveform during an event such as a short circuit fault allows the protection specialist analyzing the event to immediately see some of the key parameters of the fault, such as:

- Fault inception angle
- DC offset
- Evolving faults
- Operation of recorded protection functions
- Current reversal in case of double circuit lines

Today the recording of current and voltage waveforms is a built in function in most Intelligent Electronic Devices (IEDs). Displaying the COMTRADE files (as shown in Figure 2) is the first thing that any analysis tool should be able to do.

If the recording is with high sampling rate and without analog filtering (for example from a disturbance recording device instead of from a protection relay), then it is also possible to see transients in the waveform caused by a CCVT or any other source.

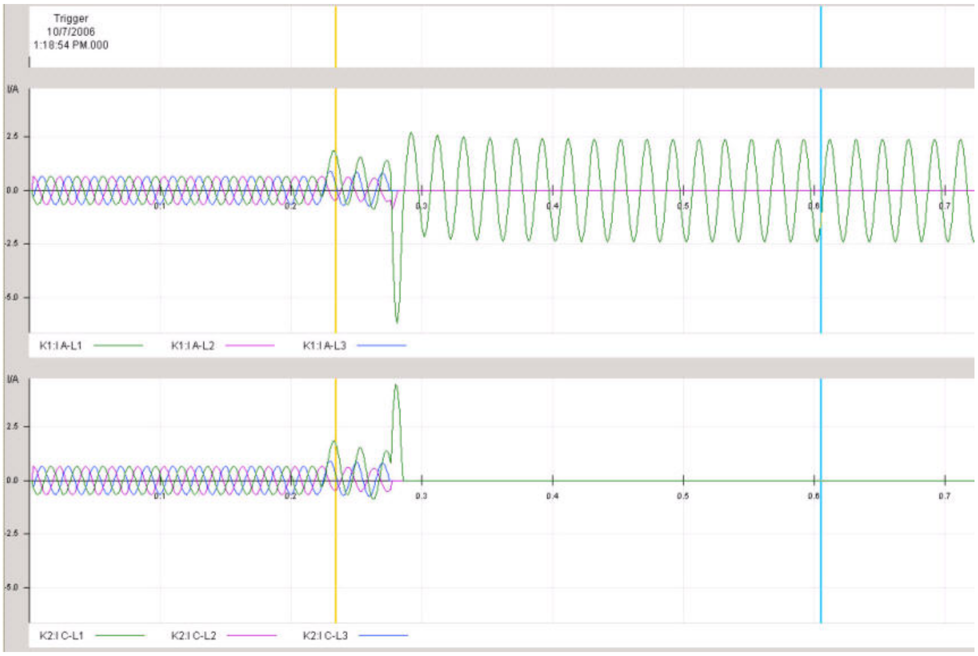

Figure 2 - Waveform record of a fault with current reversal

Calculation and display of phasors

The task of understanding some of the characteristics of the analyzed event can be further simplified by the representation of the currents or voltages (or both at the same time) as a vector diagram calculated from the samples in the COMTRADE file.

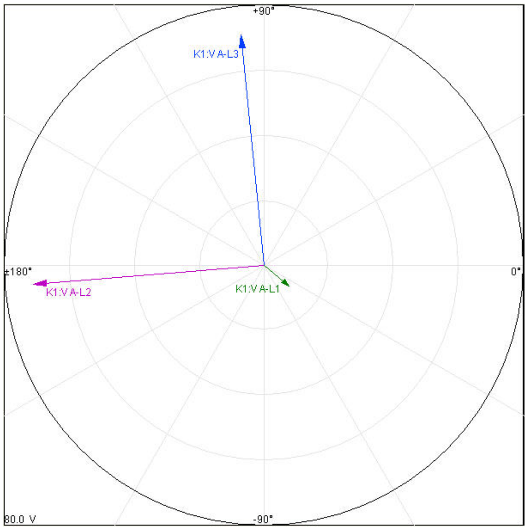

Figure 3 - Vector diagram calculated from recorded waveform

Sequence components calculation

Since most of the faults are unbalanced, calculation of the sequence components of the fault currents and voltages can be very helpful in determining the reasons for the operation of a protection relay. Even when there is no fault condition, but the system is experiencing power swings with significant levels of current flow, most lines with unsymmetrical configuration and without transposition might be tripped due to a significant value of zero sequence current. The above clearly defines a requirement for the availability of sequence components calculation in the analysis tools.

Impedance plot

Distance protection is probably the most commonly used type of protection for transmission lines. The apparent impedance seen by the relays during abnormal system conditions determines if they are going to operate or not.

Visualization of the apparent impedance calculated based on the recorded current and voltage waveforms is another valuable tool that can help the protection specialist to determine the cause of the relay operation or failure to operate.

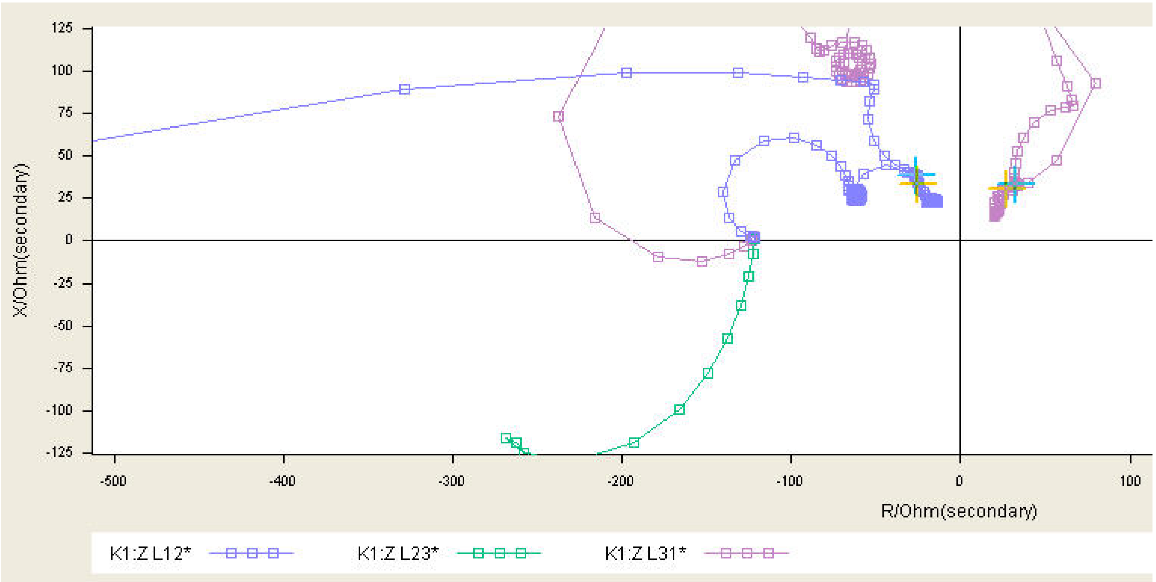

Figure 4 - Impedance plot for a single-phase-to-ground fault with current reversal

Fault location calculation

Both the protection engineers and system operators are also interested in determining as quickly as possible the location of the fault. This is a function typically available in microprocessor based protection relays. However, there are still too many electromechanical and solid state relays around the world that can not do that. That is why the analysis tools should be able to calculate the location of the fault based on the recorded waveforms.

The fault locator is a function, which allows the precise calculation of the location of faults even on mixed line sections by using the line data entered. For transmission lines with sources at both ends single ended fault location calculation methods are not very effective, especially in the case of faults with resistance.

The use of two-ended fault location enables significantly improved fault location, especially for lines with involving ground or faults with high resistance.

If data for the remote end of the line is available, it is possible to calculate three fault locations:

- One calculated by means of two-ended fault location
- Two calculated by means of single-ended fault location (one from each end)

Using the three calculations it is easy to determine the most probable location of the fault. Usually the fault location calculated by two-ended fault location method is the most accurate, although for high current faults with no resistance in the close vicinity of one end of the line the unidirectional fault location may be more reliable.

Harmonics calculation

The above described tools are mostly of interest to protection specialists that analyze short circuit faults from the relay operation point of view. To the power quality specialist these tools do not offer significant help. They are more interested in the harmonic content of the recorded waveforms (Figure 5) or in the voltage sag or swell that occurred as the result of the short circuit fault.

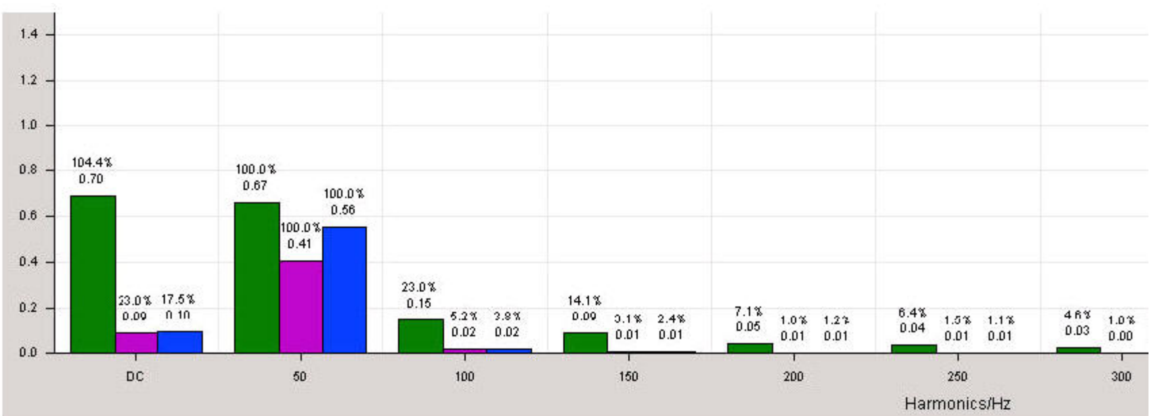

Figure 5 - Harmonics calculated from recorded waveform

The harmonics are calculated by means of a full-cycle **DFT** (**D**iscrete **F**ourier **T**ransformation) based on the selected user position on the waveform used for the analysis.

RMS values calculation

The calculation of the RMS values of the currents and voltages can be helpful in the analysis of different events – for example voltage sags and swells. It is much easier to use the voltage profile based on the RMS values, instead of looking at the instantaneous values of the samples shown in the waveform.

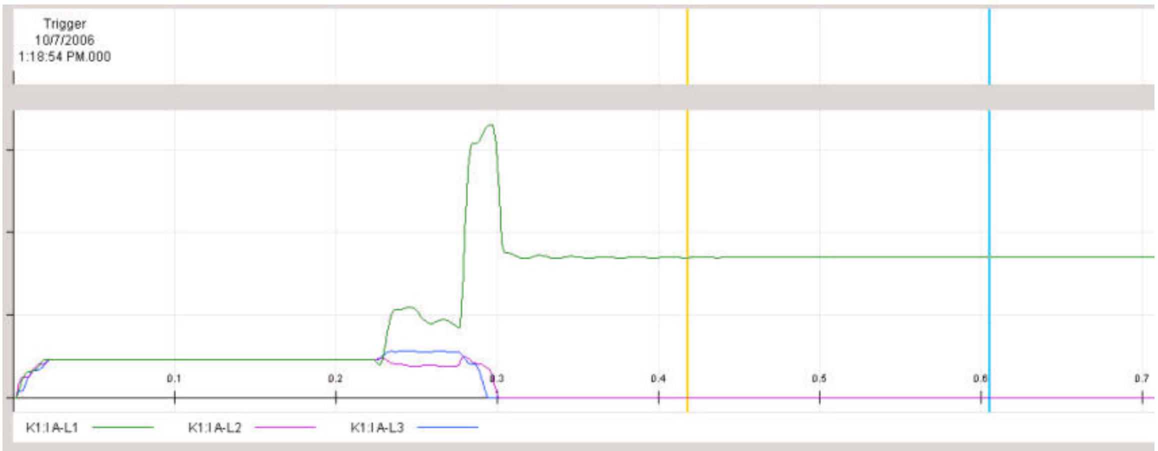

Figure 6 - RMS values calculated from recorded waveform

CONCLUSIONS

Analysis tools play an important role in determining the type of event that occurred in the electric power system and its impact on different equipment, as well as sensitive loads.

Different types of tools are required to meet the needs of protection, planning or power quality specialists.

The following tools are essential in the analysis of electric power system events:

- Visualization tools – allow the user to see the disturbance record as a waveform, vector diagram or in the impedance plain
- Fault location tool – calculates the location of the fault based on a single or two-ended method (when disturbance records are available from both ends of the protected line.
- Harmonic analysis tool – calculates the different harmonics and displays the amplitudes of measured variables as a bar chart
- RMS calculation tools – calculate and display the profile of currents and voltages

Alexander Apostolov received MS degree in Electrical Engineering, MS in Applied Mathematics and Ph.D. from the Technical University in Sofia, Bulgaria. He has worked for fourteen years in the Protection & Control Section of Energoproject Research and Design Institute, Sofia, Bulgaria.

From 1990-94 he was Lead Engineer in the Protection Engineering Group, New York State Electric & Gas where he worked on the protection of the six-phase line, application of microprocessor relays, programmable logic and artificial intelligence in protection. 1994-95 he was Manager of Relay Applications Engineering at Rochester - Integrated Systems Division. 1995-96 he was Principal Engineer at Tasnet. 1996 – 2006 he was Principal Applications Engineer at AREVA T&D Automation.

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He is IEEE Fellow and Member of the Power Systems Relaying Committee and Substations C0 Subcommittee. He is the immediate past Chairman of the Relay Communications Subcommittee, serves on many IEEE PES Working Groups and is Chairman of Working Group C9: Guide for Abnormal Frequency Load Shedding and Restoration (IEEE Standard C37.117).

He is Member of CIGRE and Convener of CIGRE WG B5.13 "Acceptable Functional Integration in Transmission Line Protection" and member of CIGRE WG B5.07, B5.09, B5.35. He is member of IEC TC57 WG 10, 17, 18 and 19. He is Chairman of the Technical Publications Subcommittee of the UCA International Users Group.

He holds three patents and has authored and presented 300 technical papers. He is also Editor-in-Chief of the industry magazine PAC World.

Benton Vandiver III received BSEE from the University of Houston in 1979. He began his career with the Substation Division of Houston Lighting & Power in 1978. In 1991 he joined Multilin Corp. as a Project Manager. In 1995 he joined OMICRON electronics as a Sales & Application Engineer and is currently Technical Director for OMICRON Electronics Corp. USA in Houston, TX. He is a long time member of IEEE / PSRC and is past Chairman of Working Group H5-C Common Data Format for IED Sampled Data. He holds a US Patent and has authored or co-authored over 70 technical papers in North America.