Automatic Identification of Non Compliant Fault Records

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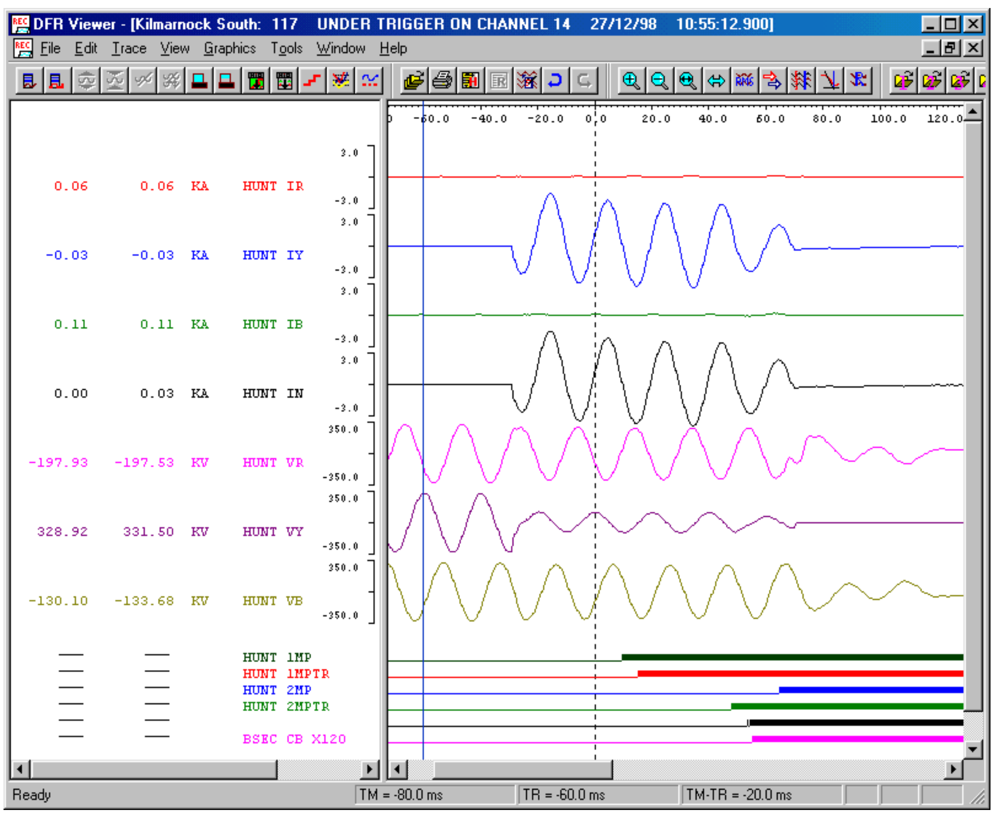
The traditional use of fault records is for post mortem analysis of system faults to check the performance of relays, end to end signalling associated with the protection scheme and correct operation of the circuit breaker to clear the fault. Very often Utility practice is to only download records after a major incident has occurred; other records recorded for other reasons are largely ignored. This is partly due to lack of effective communication channels and polling systems to automatically retrieve records and a lack of trained personnel who are capable of handling the different software sets needed to retrieve and analyse fault records from different vendors whether they be from relays or stand alone DFR devices. This is exacerbated under ‘storm’ conditions when the number and variety of fault records become unmanageable for manual analysis at a time when protection engineers are engaged in urgent operational driven activities.

Fig 1 shows a typical DFR record from a phase to ground fault that in most cases will be analysed as it is associated with a line trip.



Ability of DFR Devices to Capture Incipient Fault Conditions

To gain the maximum benefit from an installed base of DFR devices it is necessary to examine all records to check the cause of trigger as there have been many instances of a pending serious event that could be averted by early recognition of the symptoms followed by effective remedial action. The DFR fleet can be used for Condition Based Maintenance (CBM) as well as fault analysis if used in the correct way.

Fig 2 shows a DR record when a transformer picked up load on 132KV feeders. The lower 4 traces are the 3 phase and residual currents. It can be seen normal load current begins to flow on the red and yellow phases but the blue phase has an obvious problem as further demonstrated in the residual current. It appears that the CT has an open circuit secondary, a potentially dangerous situation.

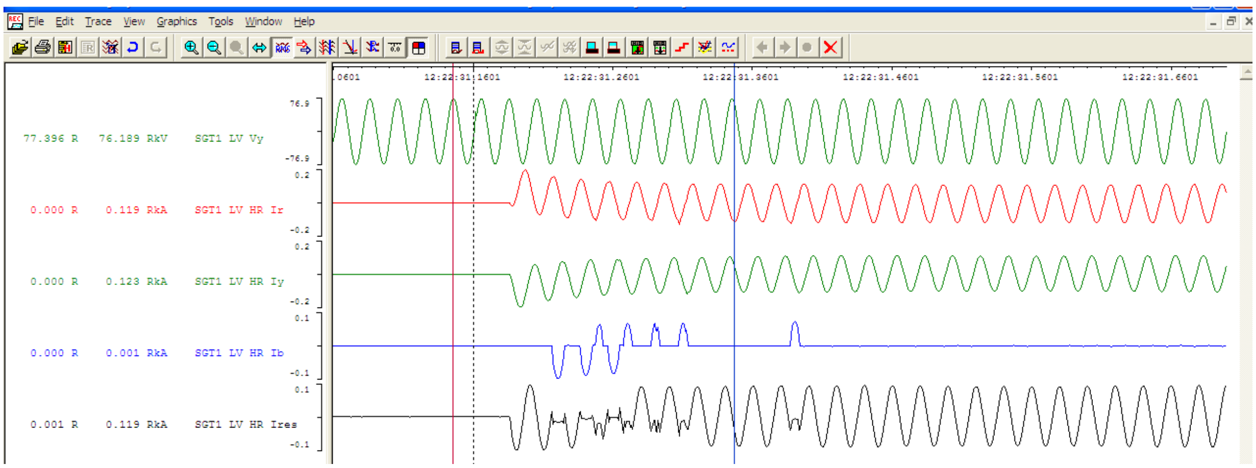


Fig 2 Load Pick Up on a 132KV Transformer showing a Problem on the Blue phase

The advantage of a standalone DFR device is that there is normally an equivalent, longer duration slow scan record where rms values are logged over an extended period. The slow scan record associated with the above event is shown in Fig 3. Cursor measurements indicate that after 680ms the blue phase current reappeared as if normal. Without analyses of the DFR data there would be nothing to indicate that an abnormal event had occurred.

Subsequent site investigation discovered a badly corroded CT marshalling box as shown in Fig 4. Vibrations caused by the circuit breaker operation resulted in intermittent contact of a loose connection resulting in the observed behaviour. The fault was repaired before the CT connection broke meaning that a significant health and safety issue of an open circuit CT was avoided.

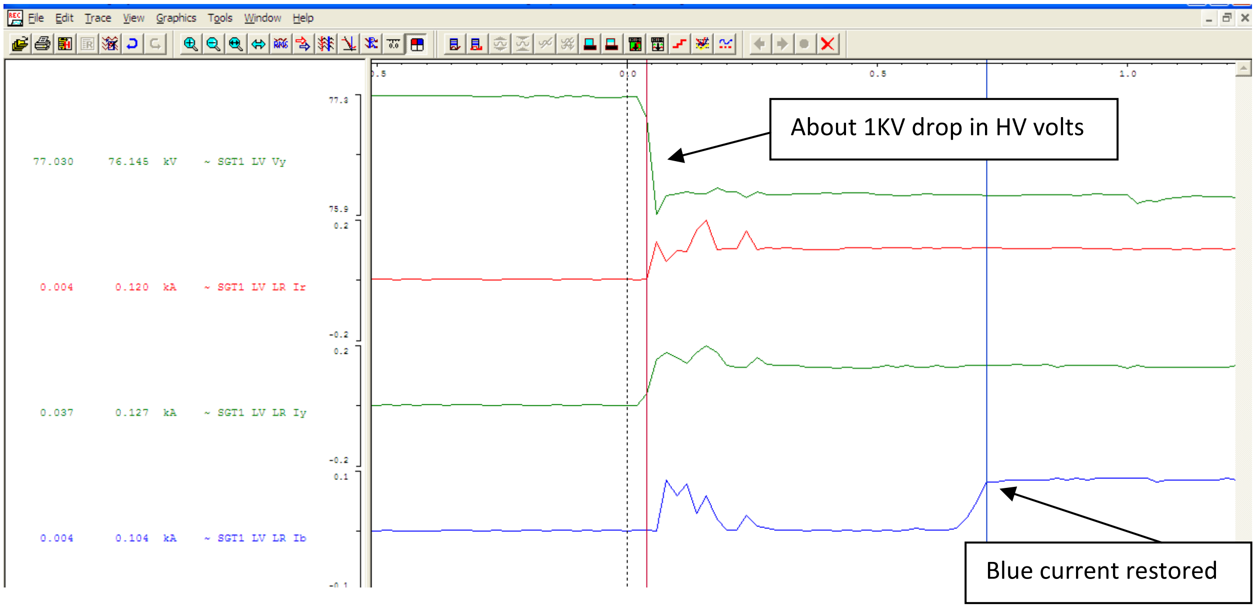


Fig 3 Slow Scan Record showed Blue Phase Current Returned after 680ms

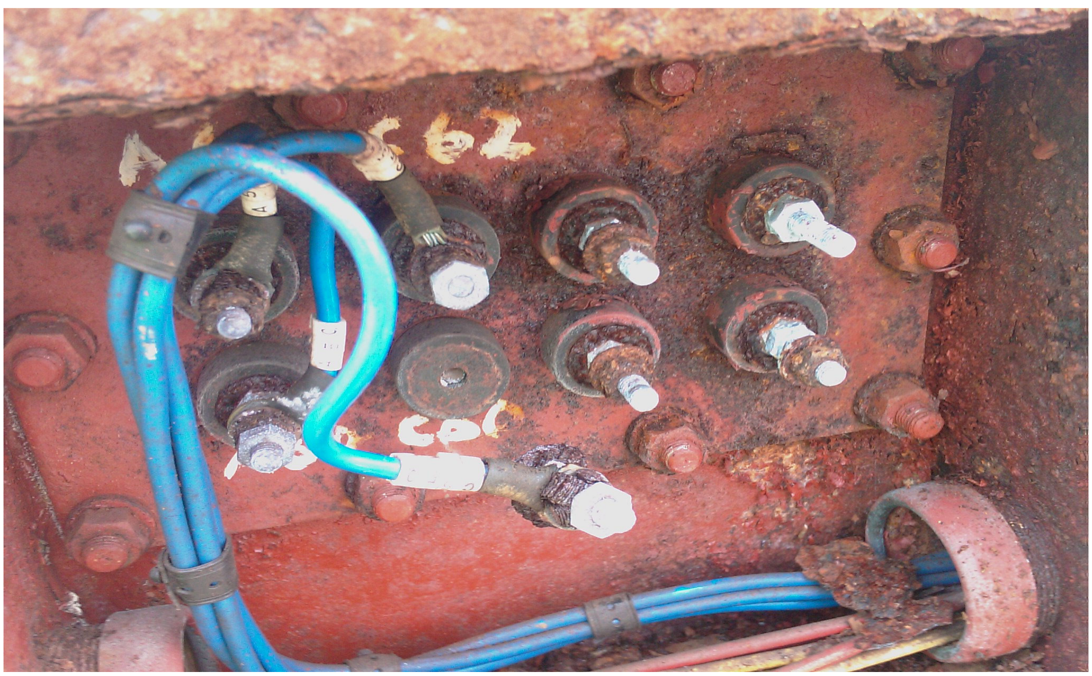


Fig 4 Badly Corroded CT Marshalling Box had an Intermittent Connection

Another problem with an instrument voltage transformer also gave early signs of the pending failure when several DFR records were triggered from a short anomaly in the red phase voltage. One of these records is shown in Fig 5.

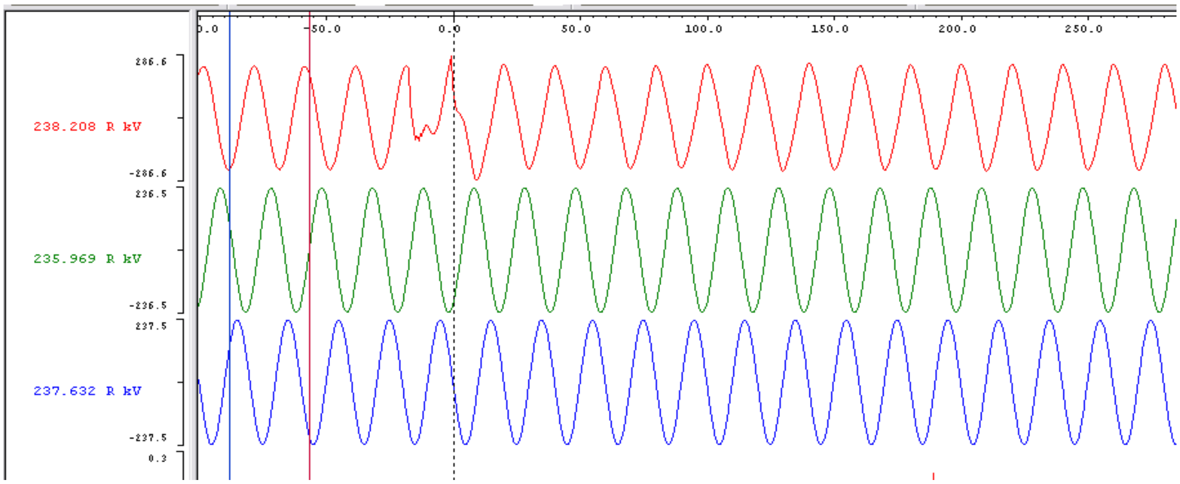


Fig 5 Voltage 'Wobble' on Red Phase giving an Indication of a Pending Problem

It is highly likely that most Utilities would have missed these events unless a dedicated team were looking at all the DFR data. The implication of missing this signal is shown below. Fig 6 shows the DFR record when the VT failed with normal protection operation and circuit trip. Fig 7 shows the effects of the flashover on the transformer, a catastrophic failure leading to a lengthy unplanned outage and an expensive asset replacement.

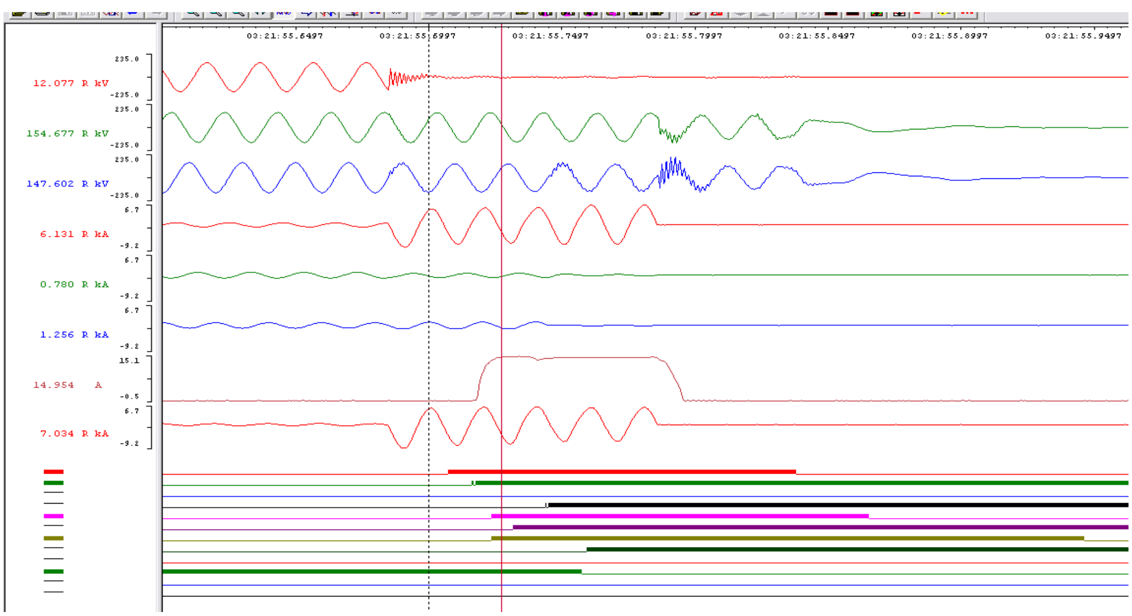


Fig 6 Red Phase VT Failure to Ground and Subsequent Trip

Fig 7 Top View of Failed VT

Other examples of defects discovered from analysis of DFR and slow scan records are:

- Excessive pole spread on a 3 phase circuit breaker
- A stuck breaker that took 8 seconds to trip but thereafter worked properly for subsequent trips
- A circuit breaker where only two out of three poles closed
- Faulty VT secondary circuits resulting in random operation of the overvoltage protection resulting in non linear waveforms. It has been observed that if these random events occur more frequently it can result in a total loss of secondary voltage.

Preferred Utility Practice to Maximise the Benefits of DFR Data

As demonstrated by the previous examples, there is a lot of valuable information available from a DFR system apart from that related to trip operations. Much of this is currently missed by Utilities. The following is the recommended mode of operation when analysing fault records.

- Routine polling and daily analysis of records to extract ‘condition based’ maintenance data as well as assess the ability of the main assets to clear a fault.
- Use the slow scan data for daily events – not just for power system disturbances involving power swing and frequency fluctuations.
- Adopt software to monitor the ‘health’ of the installed base and flag issues. Every time a DFR is remotely accessed there is an opportunity to check for errors that can be reported allowing early remedial action to be taken before important data is missed or lost. High availability of the DFR system is essential to maximise the benefit to the Utility

- Adopt software to automatically analyse DFR records to highlight abnormal occurrences. The biggest issue preventing full analysis and exploitation of DFR records is the lack of experienced engineers to spend time manually looking at all the information. A software tool to automatically analyse DFR records to highlight ‘non standard’ or ‘non compliant’ records will direct and prioritise analysis to reap the maximum benefit. This is especially true after a major system event when there may well be an avalanche of records in a short time.

Automatic Identification of Non Compliant Fault Records

Record analysis software automatically analyses every new DFR record and provides a summary report listing the key parameters and compliance to ‘normal operation’. A full report is available with more detail. Results can be emailed as required. There is no need to study a DFR record to find out what happened.

The first requirement of such software is the automatic collection of DFR records. DFR records can be automatically downloaded from stand alone devices by establishing a scheduled polling job with a specified time interval. Important records with higher weighting, dependent on cause of trigger, can set up an ‘auto comm’ request and be downloaded before the next scheduled poll and analysed within minutes of the event.

DFR records from other DFR vendors or relays can be automatically imported and analysed in Comtrade format from a specified directory.

An example of a summary report is shown in Fig 8. Each DFR record is described in one line of the report. The report has already been filtered on circuit name. Other important information listed is trigger date and time, retained voltage, fault current, clearance time, distance to fault, whether the record is compliant or not, phases affected in the event and fault type.

The list can be filtered on ‘non compliant’ to reduce the number of entries down to those that should be investigated first.

A detailed record analysis report from a phase to phase fault is shown in Fig 9. The graphical DFR record is reproduced to give an overview of what happened but the important information is in the text summary. The fault category is defined as a circuit trip, the phases involved identified as being L2 and L3 and the maximum current on each phase listed. The distance to fault is displayed along with the calculated impedance, total harmonic distortion on each voltage phase and the retained voltage. The event timing table lists the operating times of selected digital inputs indicating relay and breaker operate times. A record is classed as ‘non compliant’ if any of the event operate times are outside preset limits.

Data Analysis / Triggered Recordings

Circuit Nam	Trigger	Retained Voltag	Fault Curren	Clearance Tim	DTF	Compliant	Comments	Fault Type	Fault Category
STHA INK	2008-12-04 00:03:25.468	141.524	0.132	636.250	83.554	☐	Non_compliant	L2L3(5)	Circuit Trip(4)
STHA INK	2008-12-04 00:03:46.581	241.874	0.212	150.781	6446.581	☐	Non_compliant	L1L2L3(10)	Thru Fault(5)
STHA INK	2008-12-04 01:30:28.891	104.416	0.126			☐	Non_compliant	No Fault(0)	No Fault(0)
STHA INK	2009-02-03 08:23:08.771	230.173	0.374			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2009-02-03 08:23:54.052	87.830	0.129			☐	Non_compliant	No Fault(0)	Circuit energised(2)
STHA INK	2009-02-03 13:51:53.968	233.281	0.089			☐	Non_compliant	No Fault(0)	Thru Dip(6)
STHA INK	2009-02-03 13:55:02.307	241.083	0.112	157.969	6380.007	☐	Non_compliant	L1L2L3(10)	Thru Fault(5)
STHA INK	2009-02-03 13:56:12.310	1.608	0.090			☐	Non_compliant	No Fault(0)	No Fault(0)
STHA INK	2009-07-29 12:56:51.708	229.700	0.193			☐	Non_compliant	No Fault(0)	Thru Dip(6)
STHA INK	2009-07-29 14:30:42.928	236.119	0.228			☐	Non_compliant	No Fault(0)	Thru Fault(5)
STHA INK	2009-08-24 10:31:06.218	230.176	0.319			☐	Non_compliant	No Fault(0)	Thru Dip(6)
STHA INK	2009-08-24 11:09:44.803	229.587	0.359			☐	Non_compliant	No Fault(0)	Thru Fault(5)
STHA INK	2009-09-01 08:20:33.708	216.000	0.205			☐	Non_compliant	No Fault(0)	Thru Dip(6)
STHA INK	2009-09-01 13:25:08.082	240.145	0.223			☐	Non_compliant	No Fault(0)	No Fault(0)
STHA INK	2009-11-12 07:02:02.777	8.469	0.098	197.813	6342.408	☐	Non_compliant	L1L2L3(10)	Thru Dip(6)
STHA INK	2009-11-12 07:08:05.671	2.294	0.015			☐	Non_compliant	No Fault(0)	No Fault(0)
STHA INK	2009-11-12 15:21:44.688	242.456	0.089			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2009-11-30 09:08:30.385	243.860	0.093			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2009-11-30 15:37:12.457	239.920	0.092			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2009-12-02 08:41:16.539	239.986	0.201			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2009-12-02 15:17:47.697	241.232	0.092			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2009-12-03 08:48:44.540	239.489	0.305			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2009-12-03 15:07:42.256	240.630	0.092			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2009-12-08 08:11:06.732	240.344	0.099			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2009-12-08 14:40:34.246	238.749	0.090			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2009-12-09 08:02:49.356	242.154	0.097			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2009-12-09 14:50:47.653	239.707	0.090			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2010-09-23 08:44:19.248	14.974	0.014			☐	Non_compliant	No Fault(0)	Thru Dip(6)
STHA INK	2010-09-25 05:01:58.671	1.836	0.014			☐	Non_compliant	No Fault(0)	No Fault(0)
STHA INK	2010-09-25 05:03:34.542	1.853	0.016			☑	Compliant	No Fault(0)	No Fault(0)
STHA INK	2010-09-25 05:04:39.067	231.542	0.104			☐	Non_compliant	No Fault(0)	Circuit energised(2)

Fig 8 Record Analysis Summary Report

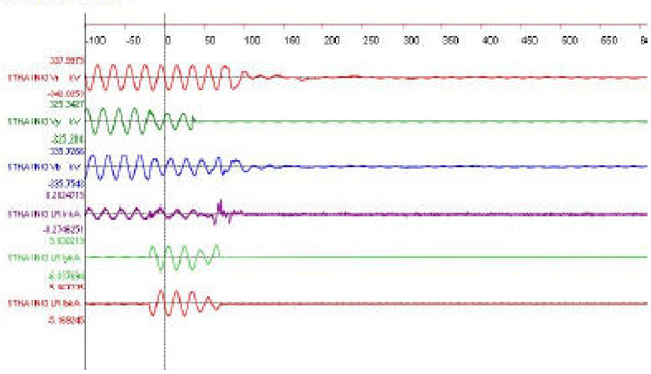
Fault Report

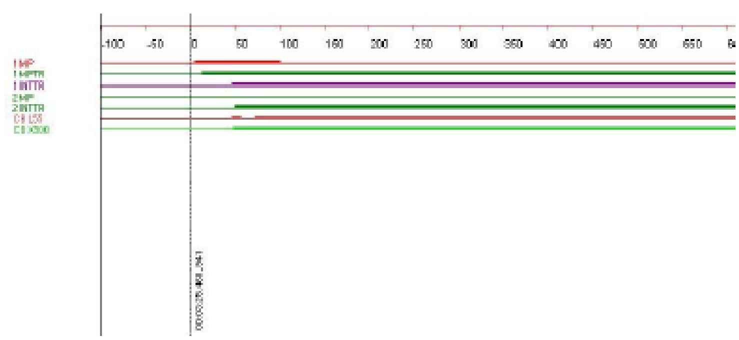
Record Information:

Triggered at: 04/12/2008 01:03:25.469
Station Name: Strathaven 400
Device: [IDMV3] Inverkip
Record length: 709 ms
Cause of trigger: FRSENSOR

Circuit: STHA INK (92.1km)

Analog channels plot:





Fault Category: Circuit trip
Phase: L2L3
Maximum currents: STHA INKI LR Ir= .10kA; STHA INKI LR Iy= 3.94kA; STHA INKI LR Ib= 3.89kA
DTF Result: 82.996km
Fault Z: R=1.607 X=23.261
THD: STHA INKI Vr=1.50; STHA INKI Vy=2.76; STHA INKI Vb=1.65
Fault Inception (T0): 04/12/2008 00:03:25.450
Retained Voltage: 142.13kV

Event Timings:

Event #	Event Name	Activate time (ms) from T0	Compliant Yes/No?
0	1MP	23	Yes
1	1MPTR	31	Yes
2	1INTTR	64	Yes
3	2MP	0	No
4	2INTTR	68	Yes
6	CB L55	64	Yes
7	CB X500	59	Yes

Fig 9 Detailed Report of a Phase to Phase Fault

Unlike the above example of a phase to phase fault, not all DFR records can be analysed so easily. As such the record analysis software has eight categories of fault type as follows:

- Circuit out
- Circuit energised
- Circuit de-energised
- Through-fault
- Circuit trip
- Through-dip
- No fault
- Unknown

The measurement of total harmonic distortion is important to identify abnormalities on the voltage waveforms that indicate a possible defect. Fig 10 repeats the DFR record of the 'wobble' on the VT waveform prior to failure. It is characterised by a high total harmonic distortion that can be used to flag the DFR record as 'non compliant' and worthy of further investigation.

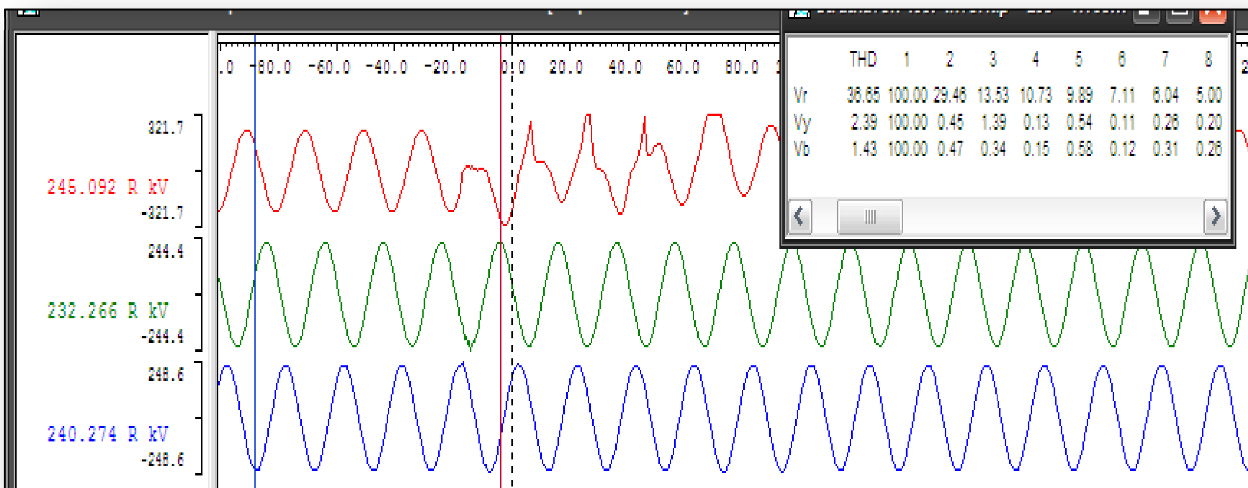


Fig 10 VT 'Wobble' Characterised by a High Total Harmonic Distortion

Automatic analysis of fault records will never be 100% accurate due to their complexity and variability. To date the algorithms have been tested on a data set of 200 records captured during storm conditions all of which have been manually investigated and details of the actual events recorded. So far the success rate of the record analysis software has been 72% and work is continuing to improve this.

Conclusion

DFR and slow scan data should be analysed more carefully to identify incipient problems on the power system as well as investigating circuit trips. Unfortunately, using the installed base of DFR devices for Condition Based Maintenance requires more intensive analysis of all the DFR records. To alleviate operator time and make this practical, automatic record analysis software is now available to flag non compliant events and prioritise the records that require investigation first.

Authors Notes

David Cole obtained an honors degree in Electrical and Electronics Engineering followed by a two year graduate training program at a UK Distribution Company. He then spent three years at the High Voltage Laboratory of BICC Power Cables developing a method of locating partial discharge sites in drum lengths of polymeric cable using travelling wave techniques and four years of applications engineering with a company specializing in underground cable fault locating. He has been with Qualitrol for twenty five years working with fault recorders, sequence of events recorders, circuit breaker test sets and travelling wave fault locators. He is currently a Senior Technical Applications Specialist for Qualitrol's IP range of products. David is a member of the IET and has authored several papers.

Colm White obtained an Honours Degree in Electronics, Mathematics and Physics in 1980, subsequently joining Circuits and Systems Design two years later. Whilst that organisation has grown and changed ownership over the decades, and is presently Qualitrol LLC, Colm has been there from the start, involved with almost all major projects from CSD, Hathaway and Qualitrol involving recording instrument platforms. Now Chief Engineer, Colm's initial years were spent developing specialised hard real time firmware for various recording instrument platforms. This includes the five generations of fault recording instruments, 3 generations of travelling wave instruments and their various specific customisations to end-user requirements. He has travelled extensively to power utilities world-wide with his pragmatic and fact based approach to the use of electronic instrumentation in helping solve customer problems.

Peter Glover received a Bachelor of Electrical and Electronic Engineering Degree from Queens University Belfast in 2003. From University Peter joined Qualitrol where he still works today as a Senior Applications Engineer Team Leader.

Peter has amassed 11 years experience in the Power Industry focusing on Transmission System Fault Recording. He has travelled extensively working in substations on 4 continents and on many high profile projects such as GCCIA and England-France HVDC Interconnector.