SEPTEMBER 2020 • POWER GENERATION

FAULT RECORDING IN A UK UTILITY

Deployment and Performance of a Large Scale Fault Monitoring System During Storm Conditions

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INTRODUCTION

This Utility in the north of the UK is a vertically integrated company owning and operating transmission and distribution from 400KV to 400/240V and serving 3.5 million consumers. The infrastructure consists of 92,100 substations, 42,550Km of overhead line and 68,670Km of underground cable. The cost to replace these assets would be in excess of £10 billion.

The Utility has made a strategic decision to invest in monitoring equipment and use the resultant data to evaluate plant and network performance and identify defects and weaknesses in the system to allow early remedial actions to be taken. Fault recorders were first introduced to the transmission system in the 1980s and they now have a fleet of 380 devices. Units installed since the early 1990s are multifunction devices offering conventional fault recording, slow scan monitoring, power quality recording and, more recently, synchrophasor measurements . Real time values of power, voltage and current are also transmitted to the substation RTU via modbus or 61850 protocols for SCADA use. This replaces the need for separate transducers and the investment for regular maintenance and calibration. Recorders are present in nearly all 400KV, 275KV and 132KV substations monitoring lines, transformers and circuit breakers. Units are also installed in many generating stations from large nuclear sites to small 30MW windfarms.

This cost effective, single installation, multifunction approach gives a wide range of data used by protection engineers, plant maintenance engineers, system operators and system planners. Protection and plant maintenance engineers mainly use fault records, the system operators use the triggered and continuous slow scan data to study low frequency oscillations, effects of frequency disturbances and power swings and the system planners use the power quality data for harmonic surveys and load flow analysis to review system performance and assess the impact of new embedded generation.

A single Master Station is used to poll all the recorders every night to collect data. This has been traditionally done via multiple modem connections over telephone lines but the use of Ethernet is growing as the IT infrastructure is expanded. All data is reviewed the following day and reports sent to the relevant departments.

The use of ‘stand alone’ multifunction recorders has advantages over the reliance of relays. The recorders monitor the entire protection scheme from relay to trip relay to circuit breaker operation. They are independent and therefore always produce a record even when the relay malfunctions. The quality of the data is also much better with higher sampling rates, more flexible record lengths and enhanced triggering functions. The real value of the stand alone device is the variety of the different data types giving the ability to analyze disturbances, both fast and slow, more thoroughly. A single, easy to use software is also advantageous as opposed to operators having to learn to cope with multiple packages from a variety of relay vendors.

Accurate distance to fault results are vital to ensure speedy repairs of permanent line trips and the location of intermittent faults to allow planned maintenance to be undertaken. The Utility has a fleet of 60 traveling wave fault locators to augment the impedance based algorithms contained within the fault recorders. This system guarantees maintenance crews are sent to the right tower every time.

THE WINTER OF 2009 / 2010

The winter of 2009/10 produce some of the worst weather conditions in UK for 30 years. Severe ice and snow storms wreaked havoc across the country causing major disruption to infrastructure. There were many incidents on the power system from December 2009 to March 2010. This paper will look at a specific storm that occurred between the 24th and 26th of February. In this particular storm up to 61cm of snowfall was recorded and temperatures as low as -19.2°C. Strong winds also contributed to the problems with gale force gusts recorded on the western coast. Across all of Scotland 45,000 homes were without power for several hours and drivers on the main A9 road were stranded for up to 17 hours due to the extreme snow and fallen power lines.

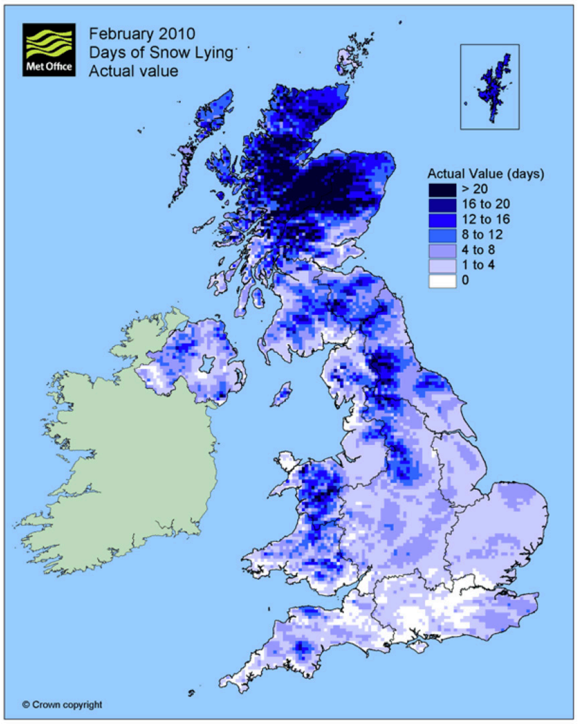

Figure.1 – Weather Map of UK

SEVERE SNOW AND ICE STORM - THE FAULTS ON 25TH FEBRUARY

Table 1below shows the fault activity for the 25th of February on a 132KV network consisting of 4 substations and 10 circuits. In total there were 24 faults (1 fault seen by 2 recorders).

Substation	Line	No. Faults	Successful DAR	Unsuccessful DAR	Phase to Phase	Phase to Neutral
WH	SY1	8	8	0	8	0
WH	SY2	1	0	1	1	0
WH	HB	1	1	0	1	0
WH	SL	0	0	0	0	0
SL	WH	0	0	0	0	0
SL	SY	9	7	2	8	1
BB	BE 1	1	1	0	1	0
BB	BE 2	1	1	0	1	0
HB	WH	1	1	0	1	0
HB	SY	3	2	1	3	0
		25	21	4	24	1

Table.1 Faults on the 25th of February

The Utility uses a single shot delayed automatic reclosing scheme with a dead time of 10 seconds, a variable wait time from 1 to 10 seconds and a reset time after reclosing of 4 seconds. Of the 24 faults, 20 were successfully auto reclosed (81.8%) and 4 were persistent and caused protection lock out. Twenty three out of the 24 faults (95%) were phase to phase, there was one phase to ground fault. The high incidence of phase to phase to phase faults was due to the high winds and the effect of snow and ice on the conductors.

A single line diagram of the 132KV network is shown below in Fig 2. Most of the faults occurred on 3 lines.

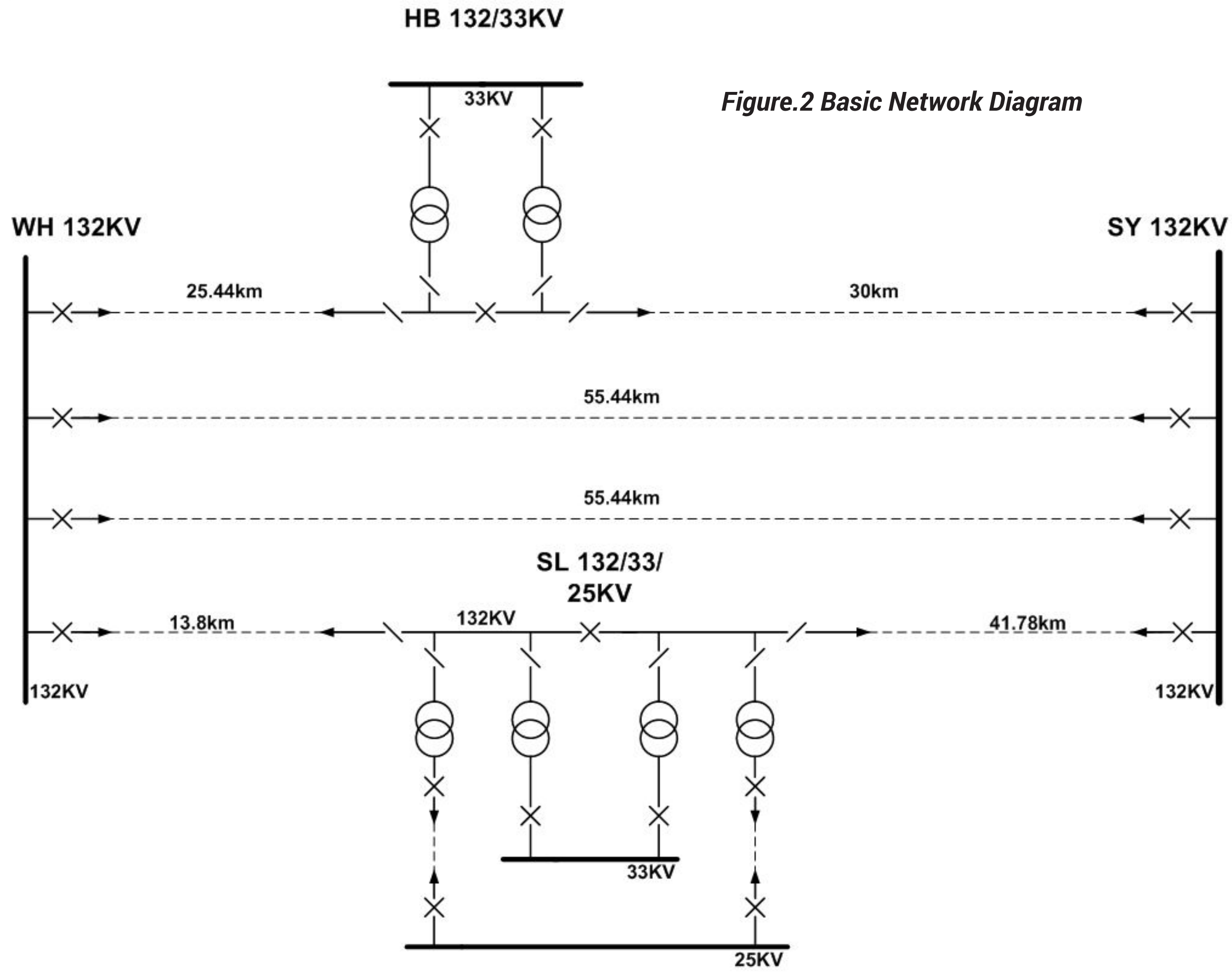

Figure.2 Basic Network Diagram

Fault and triggered slow scan records from the relevant recorders were analyzed to examine the fault activity in more detail. Fig 3 shows the minimum voltage, maximum fault current and clearance time for each of the 8 faults at WH substation on the SY1 circuit. As can be seen all were cleared successfully in 79 to 91ms with fault currents ranging from 2.1 to 3KA.

Fig 4 shows a similar situation for 8 of the 9 faults at substation SL on the SY circuit. However, the first fault of the day had a fault clearance time of 8 seconds indicating a sticking circuit breaker. Subsequent circuit breaker operations were successful. This will be analyzed in more detail later.

Fig 5 shows the results for the 3 faults at substation HB on the SY circuit. Note the relatively slow clearance time of 120ms for the first trip as opposed to 70ms for the next two. Fault current and minimum voltages were similar for all three faults indicating a slow first trip of the circuit breaker.

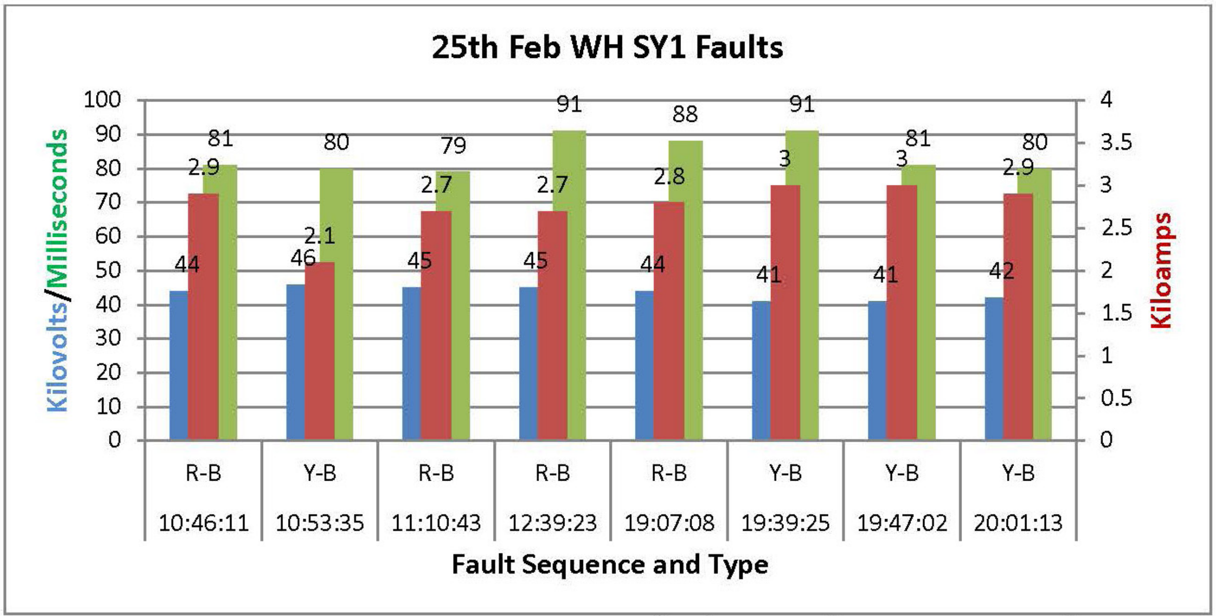

Fig 3 25th February Faults at Station WH on line SY1

🟦 Retained Voltage 🟥 Fault Current 🟩 Clearance Time

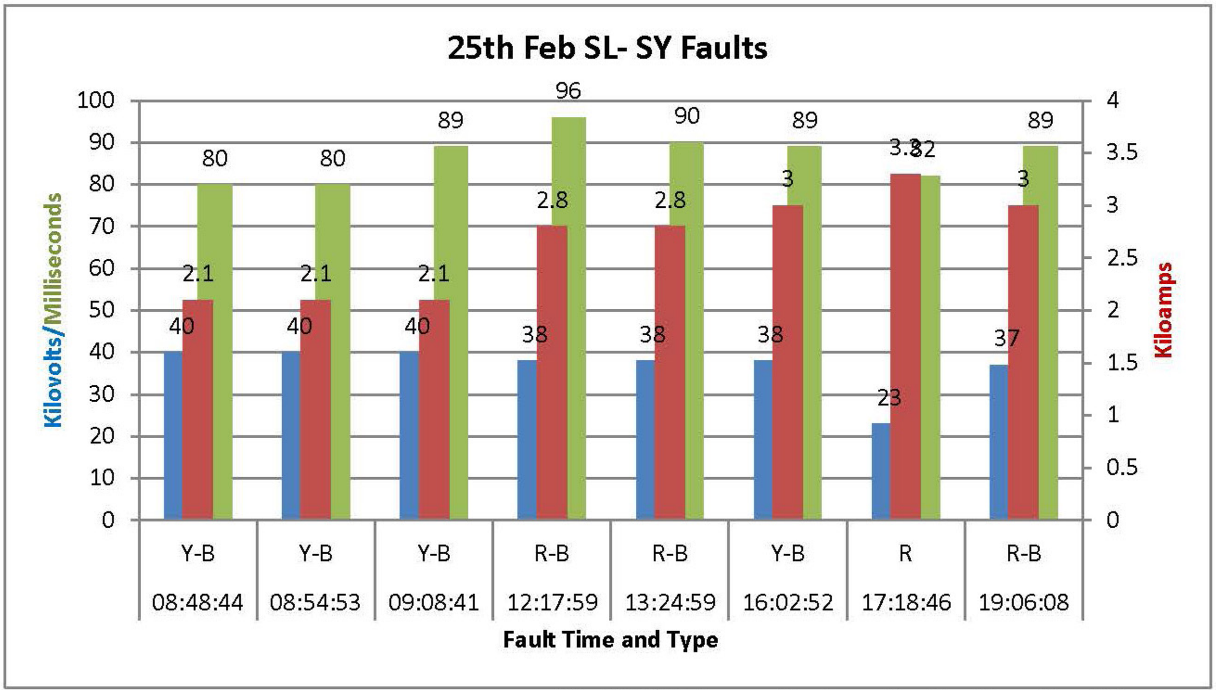

Fig 4 25th February Faults at Station SL on line SY

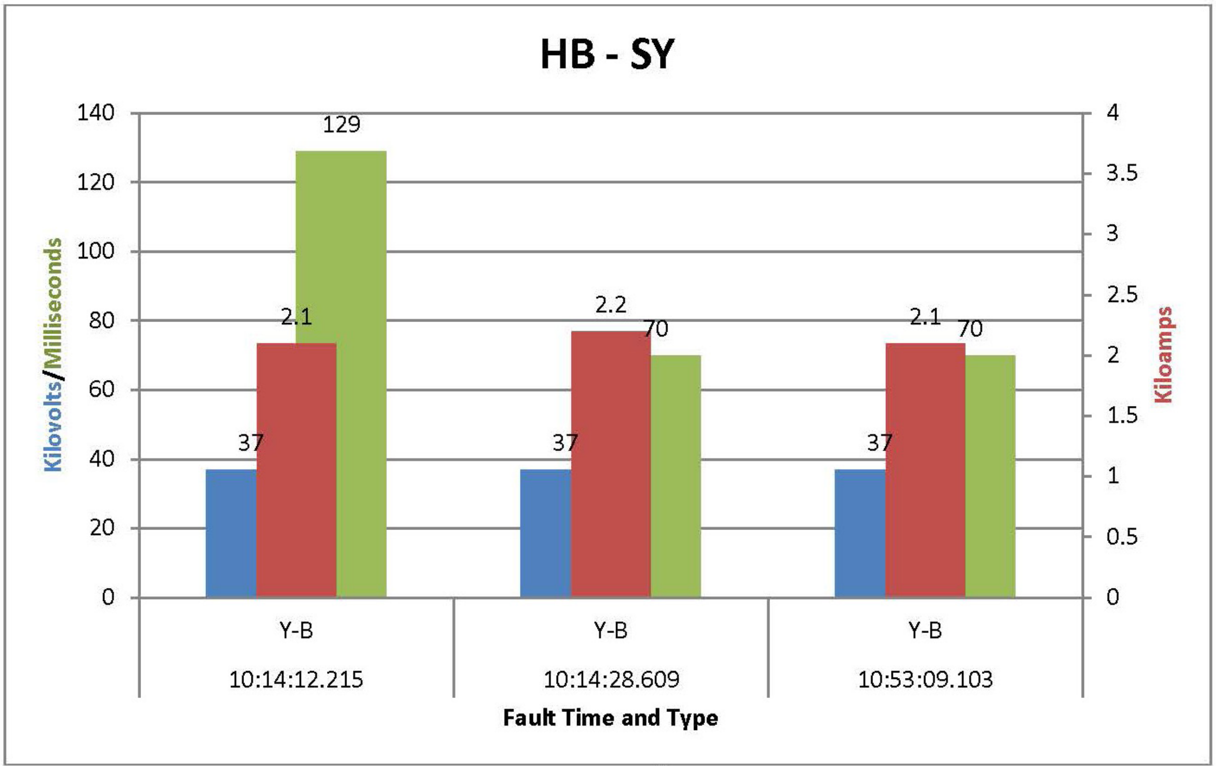

Fig 5 25th February Faults at Station HB on line SY

EIGHT SECOND CLEARANCE TIME

The first fault of the day that occurred on the 25th on the SL to SY line was only partially cleared by the protection. The fault was a phase to phase fault caused by snow loading on the line and high winds. A more detailed single diagram of the network is shown in Fig 6. CB1, CB5 and CB3 all operated within 120ms of fault inception, however CB2 remained closed and continued to back feed the fault until it self extinguished almost 3 seconds later. A further 5 seconds after this CB2 finally operated.

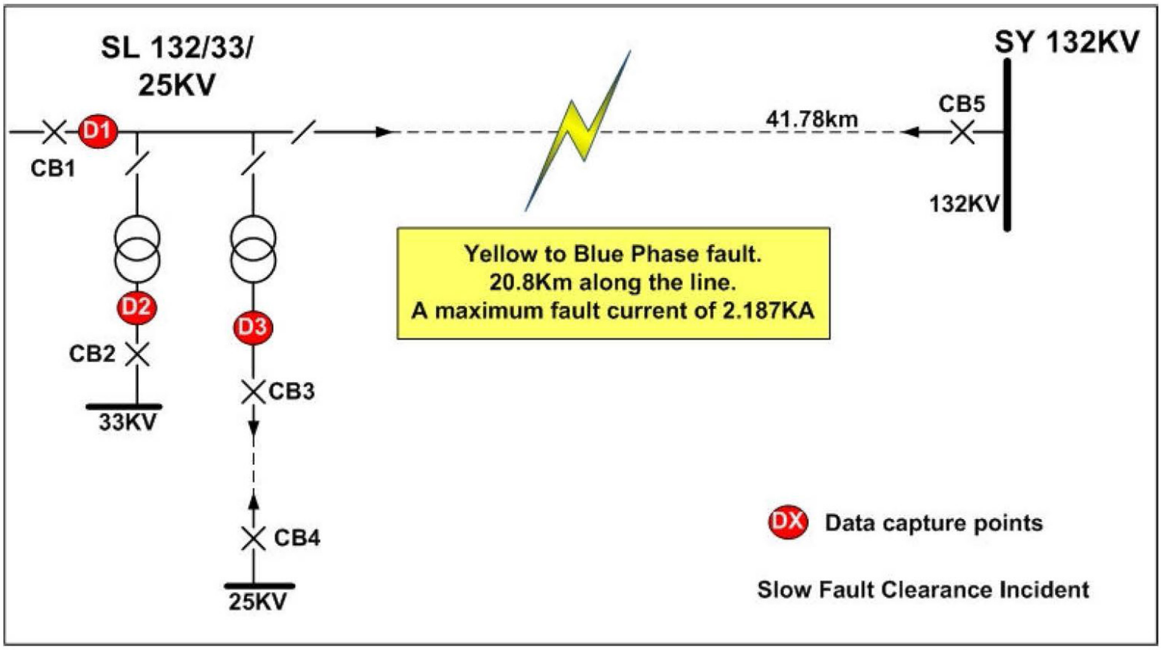

Fig 6 Basic network diagram of fault

The triggered slow scan record from SL (Fig 7) shows the full duration of the event from fault inception to the successful auto-reclose approximately 12 seconds later. Note that the phase current measured at D1 is the summation of the line current and the 2 HV transformer currents. Only single phase quantities are available from D3. The record shows fast clearance of the main fault current by operation of breakers CB1, CB5 and CB3. However reduced fault current continued to be fed into the fault from the closed D2 circuit breaker. The current reduced to zero after 3 seconds when the phases parted and the arc extinguished but CB2 did not open until another 5 seconds had elapsed collapsing the volts measured at D1. CB5 auto reclosed after 12 seconds and CB1 after approximately 15 seconds.

TM = 25/02/2010 08:43:31.4396 TR = 25/02/2010 08:43:48.6196 TM-TR = +0 00:00:17.1800

Fig 7 TSS Record showing full fault duration and Auto Reclosure

It would not have been possible to fully analyze this event using fault records from the relay as the record lengths would have been too short. The high speed fault record shown in Fig 8 shows the initial events at fault inception. The effects of the delay in the operation of breakers CB1 and CB3 can be clearly seen. The continuing current at D2 clearly shows that the breaker has remained closed. Note that to obtain this record from relays would have meant downloading and merging 3 separate records assuming they were all time synchronized. All the data is in one synchronized record in the stand alone recorder making analysis much easier and quicker.

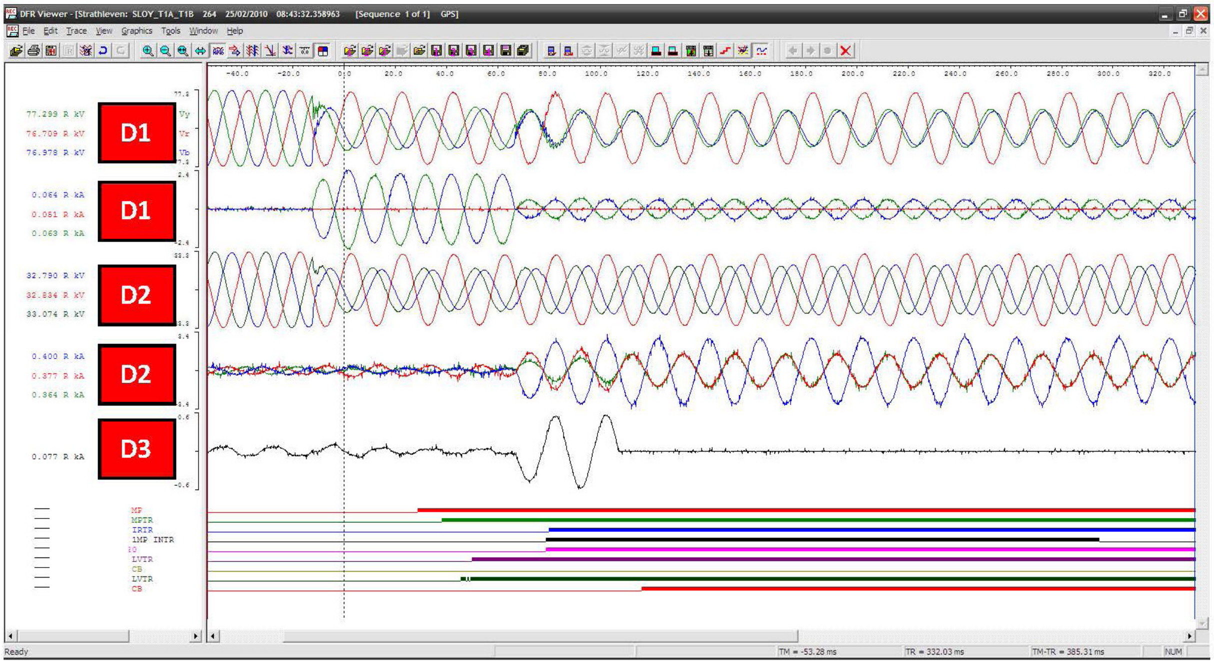

Fig 8 DFR Record of Fault Inception

THE FAULTS ON 24TH FEBRUARY

In total there were 8 distinct faults on the 24th on the same 132KV network as depicted in Fig 2. All were phase to phase. A summary is given in Table 2. There is no Delayed Auto Reclosing on any of these lines.

Substation	Line	Voltage	No.Faults	Phase to Phase	Phase to Neutral
HS	SC 1	132KV	1	1	0
HS	KW-SC-MH 2	132KV	4	4	0
HM	SC	33KV	2	2	0
AC	G1	33KV	3	0	3
		Total	10	7	3

Table 2 Faults on the 24th of February

There were faults on 2 different voltage levels 132KV and 33KV. Fig 9 below shows an overview of the faults that occurred on the KW-SC-MH-2 line at HS. All fault clearances looked to be successful.

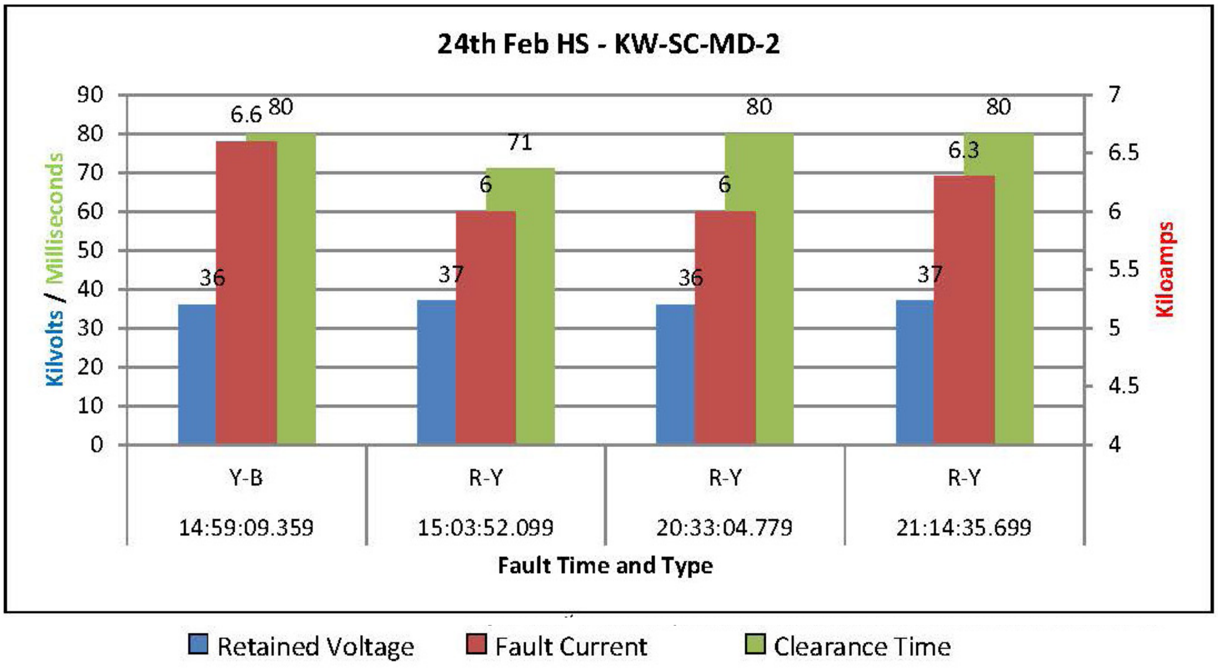

Fig 9 24th February Faults at Station HS on line KW-SC-MD-2

POLE STAGGER

Detailed examination of the first fault at 14.59 revealed excessive pole spread when the circuit breaker operated. Note that the red phase trace has been magnified and is on a different scale to other phases.

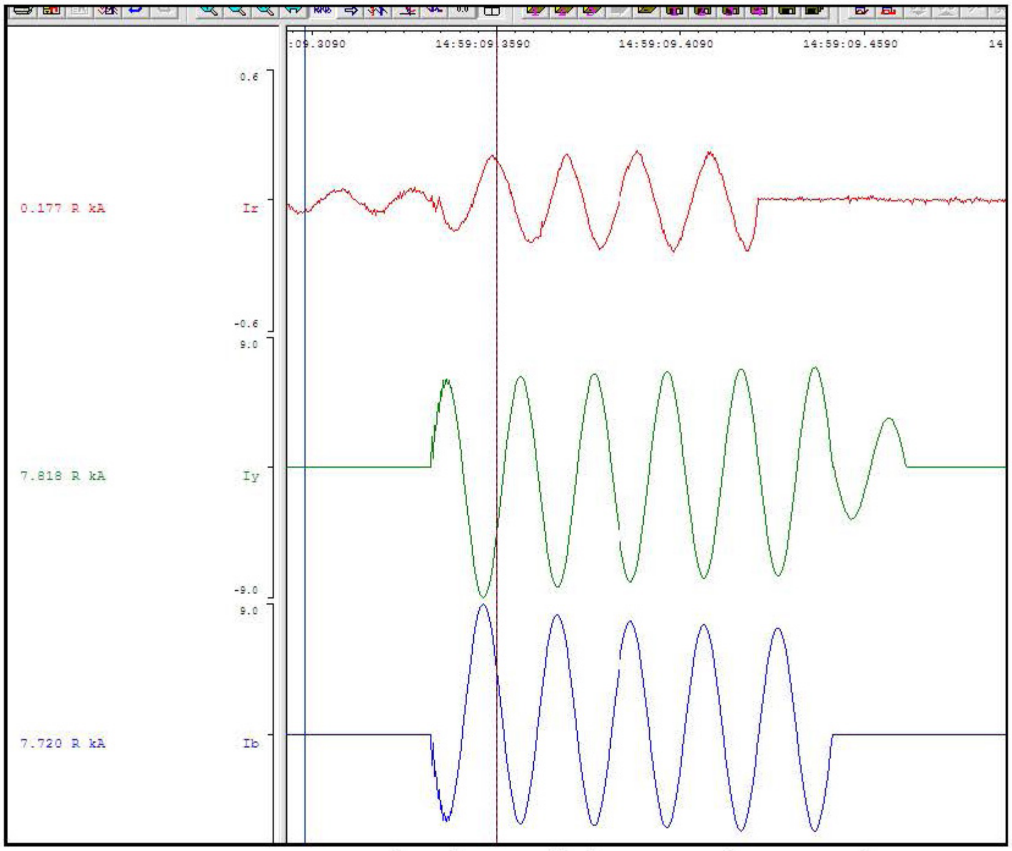

Fig 9 Circuit Breaker clearing fault current showing pole stagger

It can be seen that each of the current reduces to zero at a different time. The red phase is the first to be extinguished, then the blue phase 20.16ms later and finally the yellow phase a further 20ms later. This resulted in a large spike in residual current which latest for a cycle. See Fig 10.

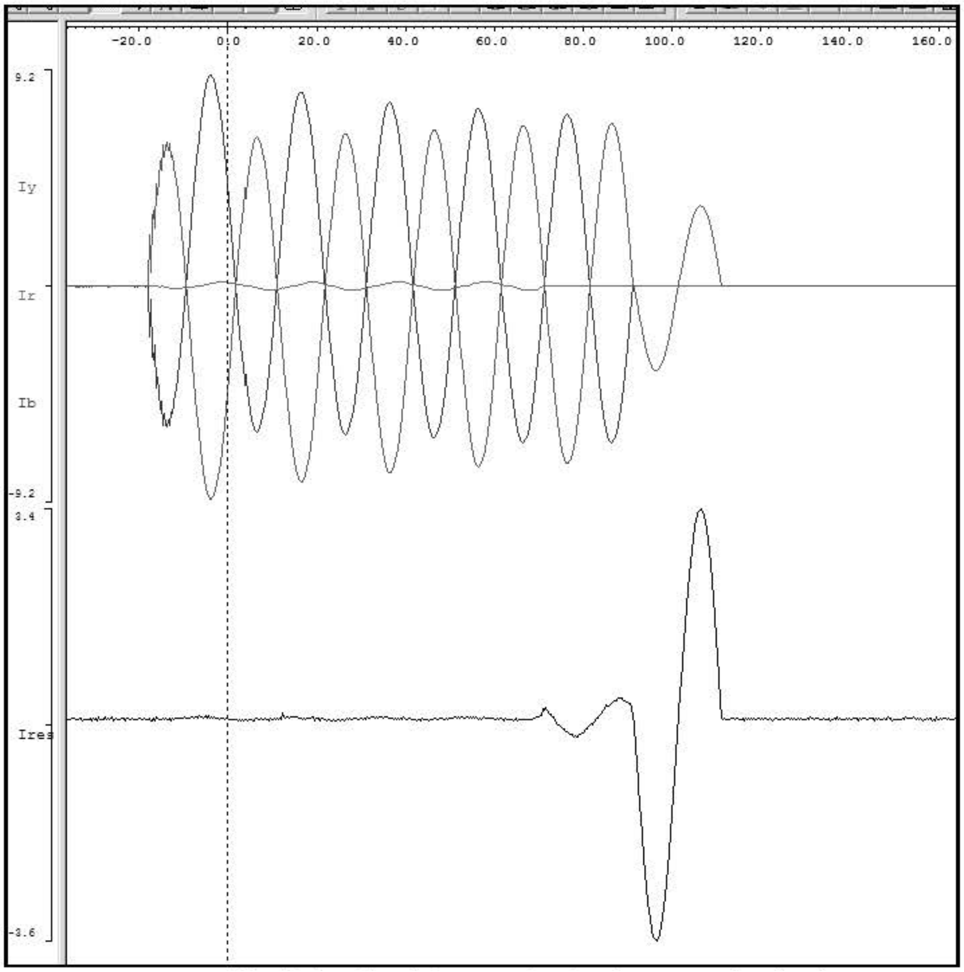

Fig 10 Residual Current in circuit as result of pole stagger

Note that the same effect was not seen in subsequent operations suggesting that it was caused by a sticking mechanism cleared after the first operation. It does suggest maintenance is required.

OTHER APPLICATIONS OF FAULT RECORDER DATA

Geomagnetically Induced Currents (GIC) in Transformers and Lines Sun spot activity results in streams of ionized particles being thrown out into space, some of which are captured by the earth's magnetic field and induce DC currents in the earth's surface that can enter large utility transmission networks via grounding points on transformers and transmission lines. The effect is more pronounced on east west lines and peaks every 5 years. The result is a DC current that can be detected in transformer neutrals. The effect is to drive the core into saturation causing local heating and hot spots that can adversely affect transformer life. In extreme cases the transformer can trip and lead to black outs as happened in Canada a few years ago.

Geomagnetically induced currents flowing in a transformer can be detected in the ground point of the transformer and the result of saturation within the core can be detected by measuring even harmonics in the transformer currents. Figure 11 shows how a multi-function recorder can be used to detect and record geomagnetically induced currents.

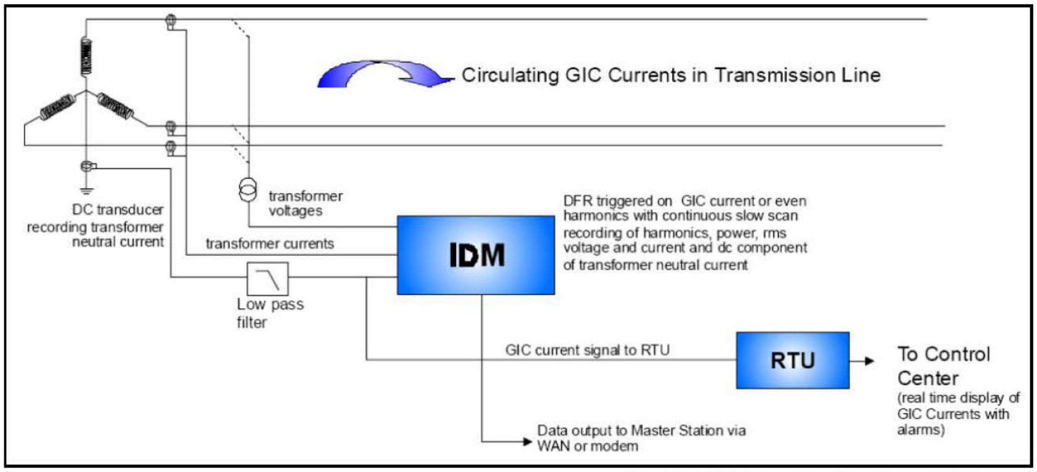

Fig 11 GIC Monitoring in a DFR

Fig 12 below shows some recorded data from the one of the Utility's GIC monitors. During this storm there were burst of GICs that lasted for minutes peaking at 13Amps. During sustained storms the Utility takes steps to reduce transformer load to avoid overheating.

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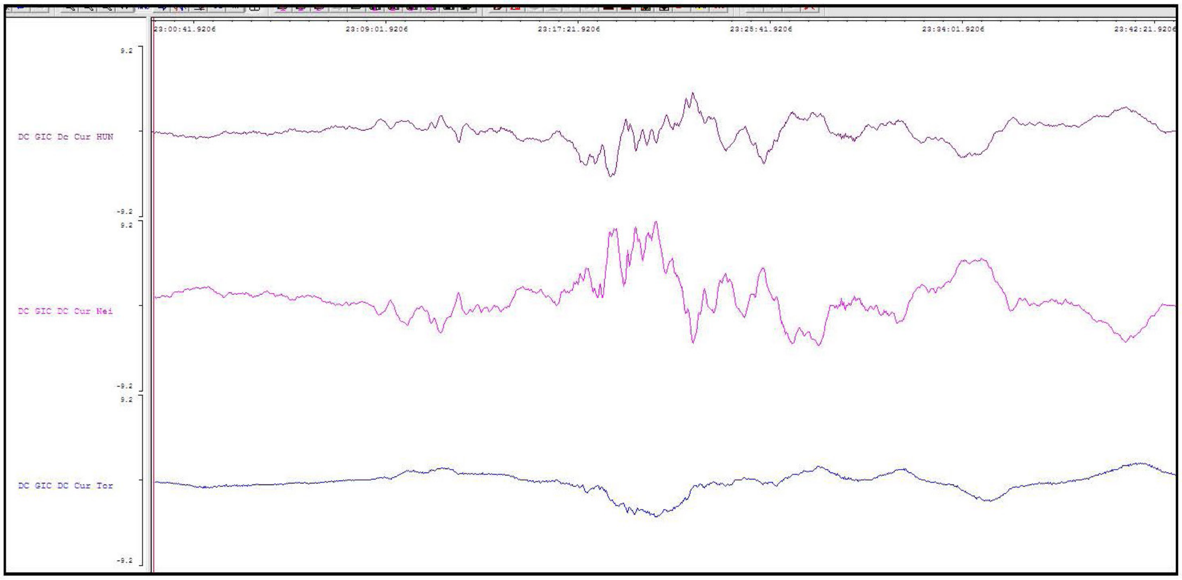

Fig12 GIC Data

CIRCUIT BREAKER CONDITION MONITORING

The versatility of a stand alone fault recorder makes it ideal to monitor circuit breaker performance. By adding the trip coil current, DC battery voltage and some extra auxiliary contacts it is possible to emulate the function of most dedicated on line circuit breaker monitors. The Utility has done this and an example of a trip operation showing trip coil current and auxiliary contact operation is shown in Fig 13. Fig 14 shows the entire record with all analog and digital channels.

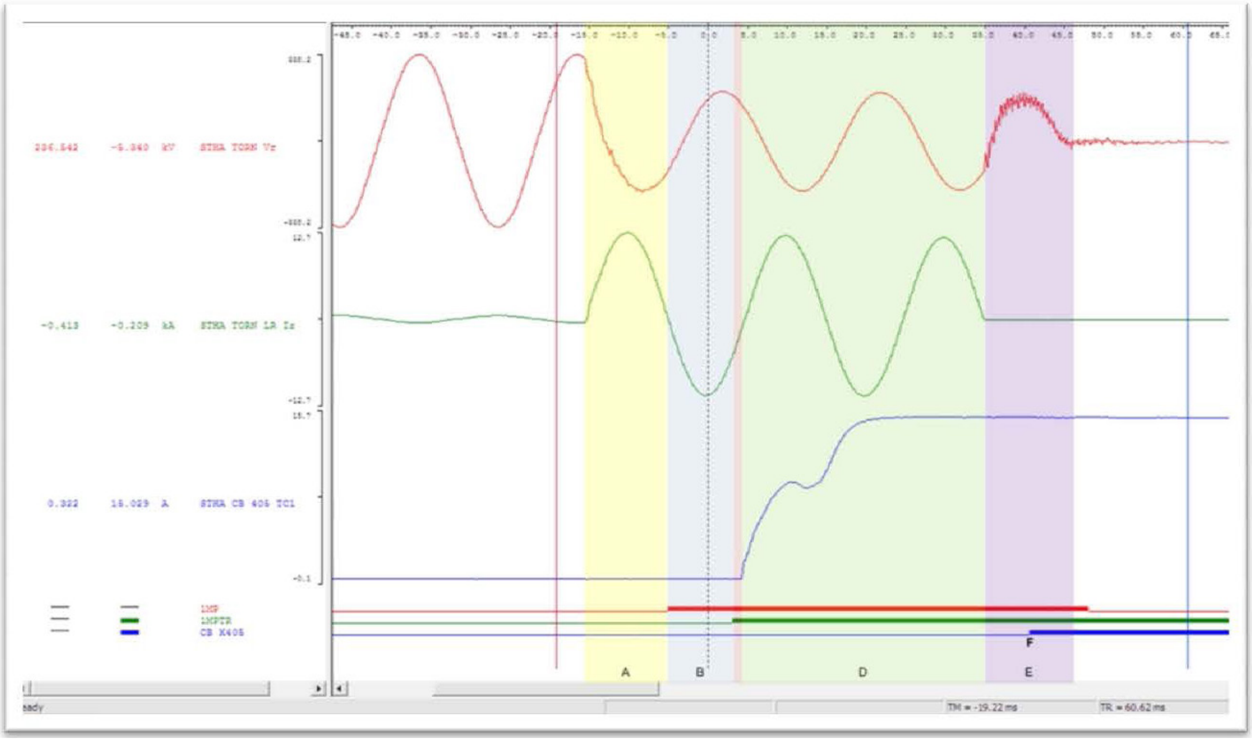

Fig 13 Fault with Trip Coil Current Profile

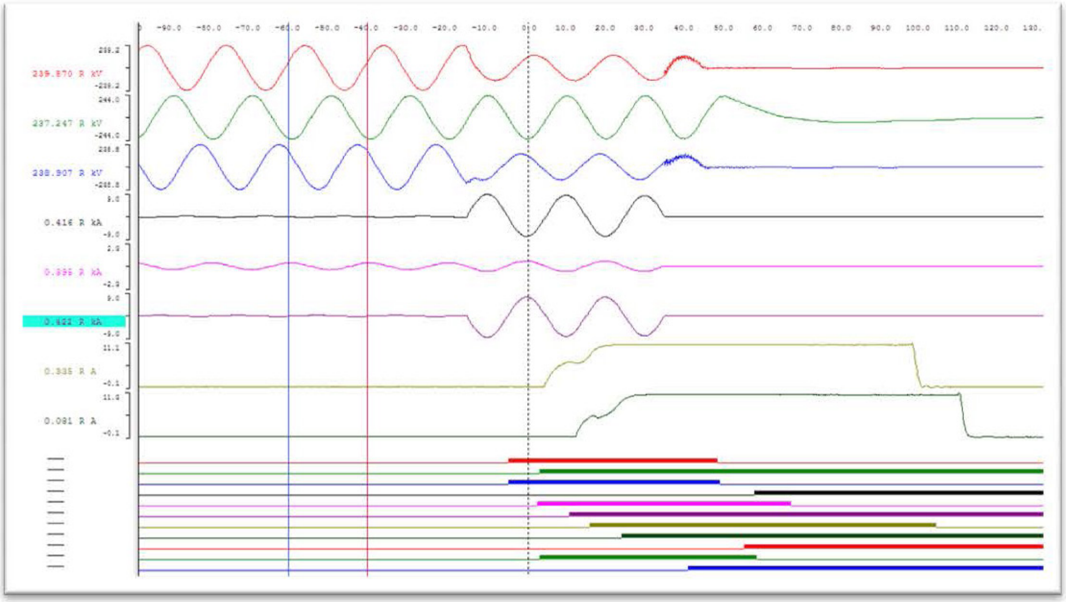

Fig 14 Fault Record Example

Changes over time in the shape of the trip coil current profile and the operation of the auxiliary contacts indicate a change in the breaker behavior and gives early indication of pending problems. Online monitoring is becoming more important as maintenance periods are being extended and there is more chance of mechanical faults developing.

Problems Detected Using this type of Breaker Monitoring Include:

- Burned or damaged operating coils
- Sticking coil armatures
- Auxiliary contact mis-adjusted / bouncing
- Defective contacts in breaker control circuits
- Protection Relay contact bouncing
- Battery charger and DC supply problems
- Main contact bouncing
- Defective dashpots
- Slow breaker mechanisms
- Bearing problems

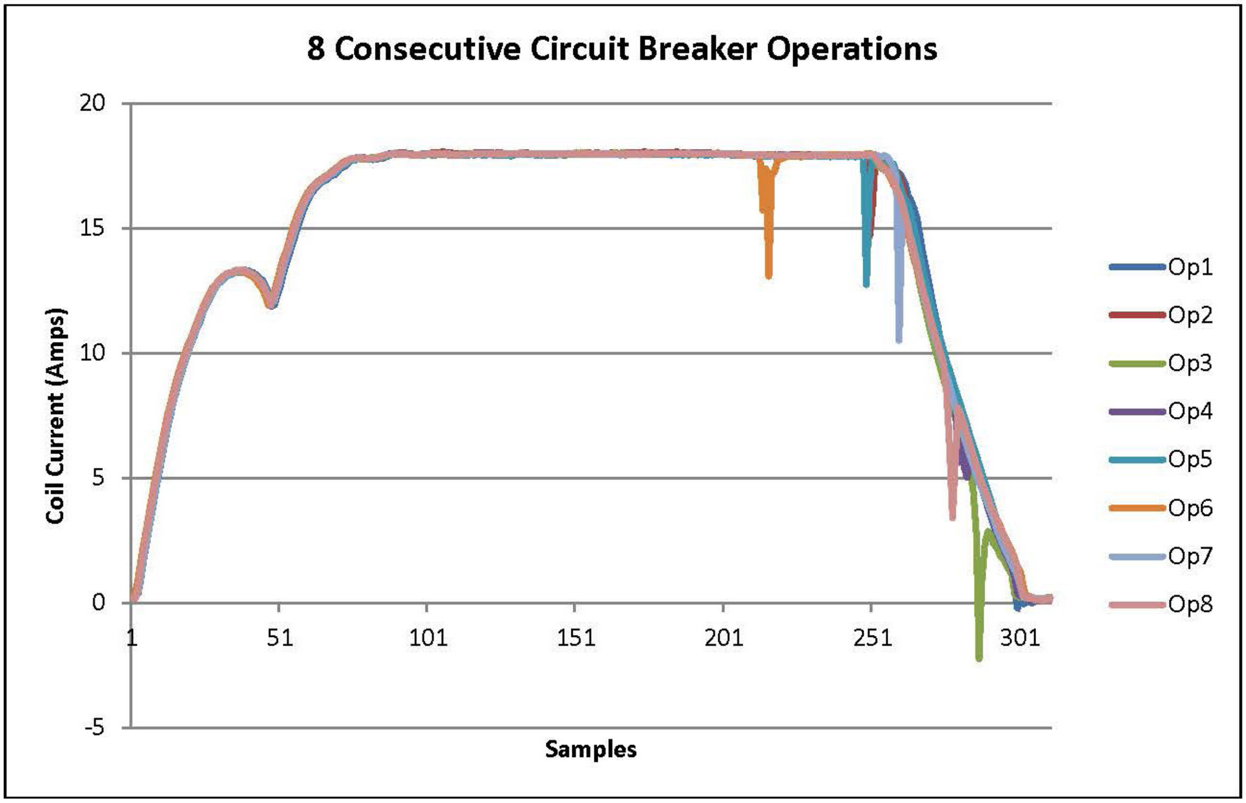

Fig 15 Circuit Breaker trip coils from 8 operations

Eight profiles from consecutive circuit breaker operations from the 25th of February at substation WH for the SY1 line show no significant differences apart from some spikes on the current decay that could be caused by arcing on an auxiliary contact. Changes in the latch mechanism or breaker operate time would result in a different shape.

VT ISSUES

Another phenomena recorded by the Fault Monitoring System during the February storm were several CVT perturbations as seen in the voltage traces in Fig 16.

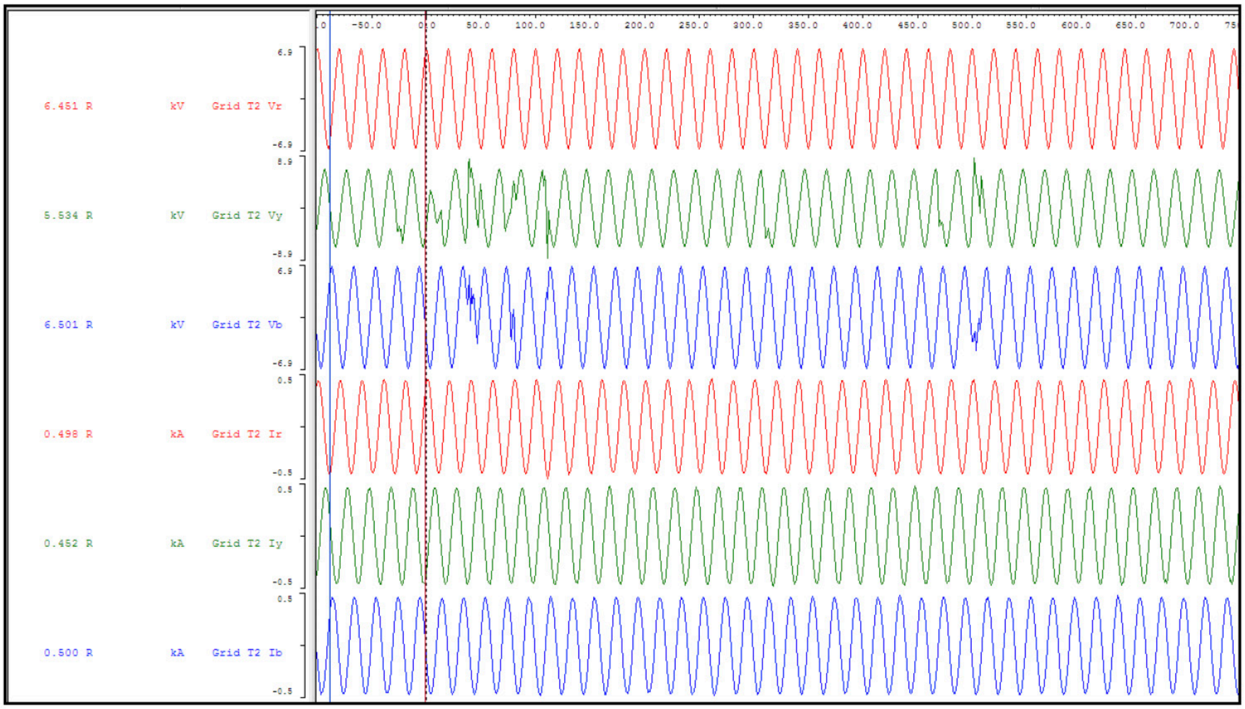

Fig 16 CVT Issues Captured by the Recorders

The recorder triggers on under voltage otherwise the Utility would not know this was happening. It would certainly not be detected by a relay. The cause is transient operation of the over voltage protection circuit on the secondary of the CVT. It has been detected on many different types of devices and if it gets too repetitive or severe then a line outage is organized and CVT maintenance undertaken. If left it could result in the loss of one or more phase voltages that would drastically affect protection performance.

CONCLUSIONS

This paper has described the fault monitoring system used by one UK Utility and the value it brings to the day to day operation of the electrical system. The versatility of the multi function devices and the ability to collect and analyze different types of data with one software package fully justifies the use of stand alone systems as opposed to reliance on protection relays. Future developments will include the introduction of enhanced data processing software to automatically analyze fault records and minimize the need for manual intervention

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