AUGUST 2020 • POWER GENERATION

HOW TRAVELING WAVE TECHNOLOGY IS LOCATING THE FAULT SITE

Investigation of Fault Activity on a 132KV Teed Circuit in Scotland

Scottish and Southern Energy (SSE) is responsible for generation, transmission and distribution of electricity in the north of Scotland. The system in Scotland is predominantly rural with the bulk of the transmission on 132KV double circuits. One of these circuits with a tee connection to a transformer station feeding local load, showed increased tripping activity from 2006. Thereafter an emerging pattern of increasing faults could not be fully explained by the foot patrols and helicopters sent to investigate. The distance to fault on the tee circuit could not be accurately identified for a number of reasons outlined in this paper.

This paper analyses the faults by time of year, time of day and phases affected in an attempt to categorise the fault types and provide insight into possible causes. It also describes the remedial action SSE undertook to improve performance and a modification to an existing traveling wave based fault location system to provide fault location in the tee section where all the unexplained trips were allegedly occurring.

THE SLOY, WINDYHILL, DUNOON TEED CIRCUIT.

This circuit was constructed in the 1950s as a double 132KV overhead line using a 'light' construction on steel towers. Unexplained fault activity increased from 2006 and was found to originate on the Dunoon tee'd section. The terrain the tee traverses is wooded with hills and valleys with a long span crossing a loch. The maximum elevation is 370m. There are several sections close to the sea. A simplified line diagram of the complete circuit is shown in Figure 1 and one of the towers in Fig 2. The section lengths have been refined using traveling wave measurements over the past year.

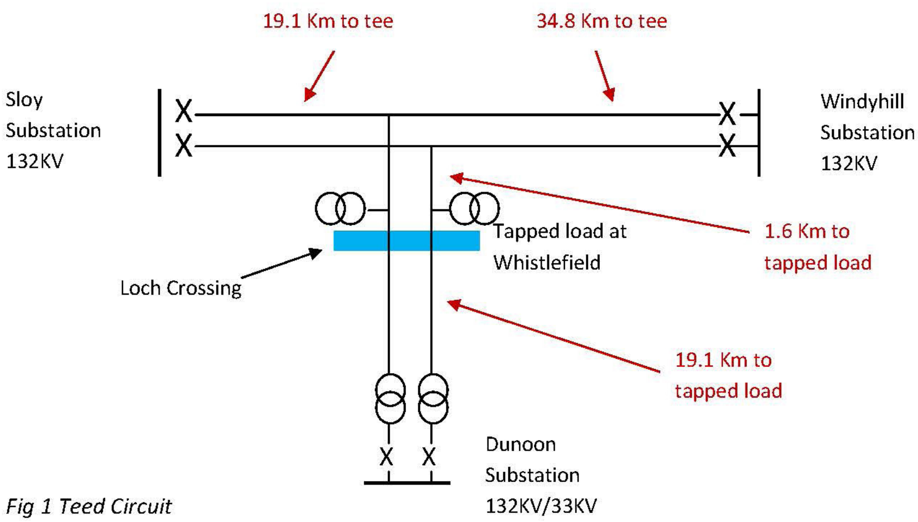


Fig 1 Teed Circuit

Fig 2 132KV Tower on the Dunoon Tee

The 132KV circuits have distance protection in operation at Sloy and Windyhill and directional over current at Dunoon to trip the low voltage transformer breakers.

FAULT ACTIVITY

The history of line trips on the complete circuit from 2005 to 2012 is shown in Table 1. Over that period there were a total of 85 trips of which 33 were linked to weather conditions or external influences and 55 to unknown causes. Of the 85 trips, 79 of them successfully auto reclosed (temporary fault) and 6 resulted in a lockout condition (permanent fault). Traveling wave based fault location equipment up to 2012 had been effective on the main Windyhill to Sloy lines but there were no credible results available for the Dunoon teed circuits. From the data it appeared that most of the unexplained temporary faults occurred on the Dunoon tee with the faults evenly distributed across both circuits.

The rise in fault activity was a cause of concern for SSE as the 33KV primary substation at Dunoon is a critical asset serving approximately 20,000 consumers.

Year	Line Trips	Month	Notes	Fault
2005	3	June	Cause unknown	Temporary
2006	2	March	Poor weather conditions	Temporary
	1	July	Cause unknown	Temporary
	1	October	Cause unknown	Temporary
2007	1	January	Cause unknown	Permanent
	2	July	Cause unknown	1 x permanent – 1 x temporary
2008	3	January to March	Cause unknown	Temporary
	6	June to August	Cause unknown	Temporary
2009	2	January to March	Poor weather	Temporary
	10	April to July	Cause unknown	2 x permanent
2010	9	February	Storm conditions	1 x permanent – 8 x temporary
	13	March	Snow storm on one day	Temporary
	4	June to September	Cause unknown	Temporary
	1	December	External events	Permanent
2011	1	February	Cause unknown	Temporary
	10	July to September	Cause unknown	Temporary
	2	October to December	Poor weather	Temporary
2012	4	January to February	Poor weather	1 x permanent – 3 x temporary
	10	May to August	Cause unknown	Temporary

Table 1 Fault Activity from 2005 to 2012

ANALYSIS OF FAULT ACTIVITY

SSE evaluated the trips in an attempt to better understand the issues. The analysis was conducted on the temporary faults not linked to weather related incidents.

Figure 3 shows the distribution of faults of GL1 and GL2 by time of day. The distribution on both circuits is similar and it can be seen that more occur during the night particularly between 4am and 6am in the morning.

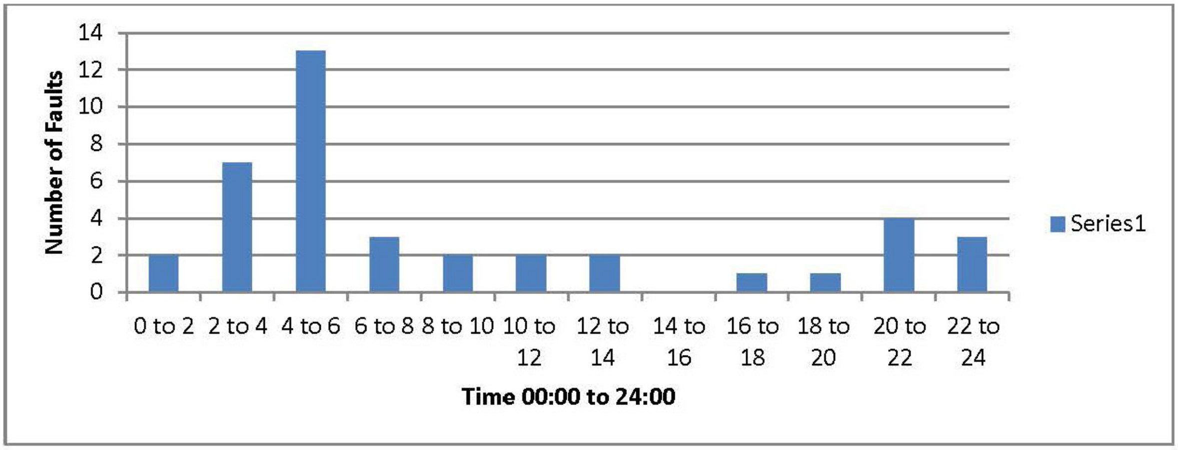


Fig 3 Distribution of Faults by Time of Day

Figure 4 shows the distribution of faults by time of year. It can be seen that most occur between June and September with the number rising annually.

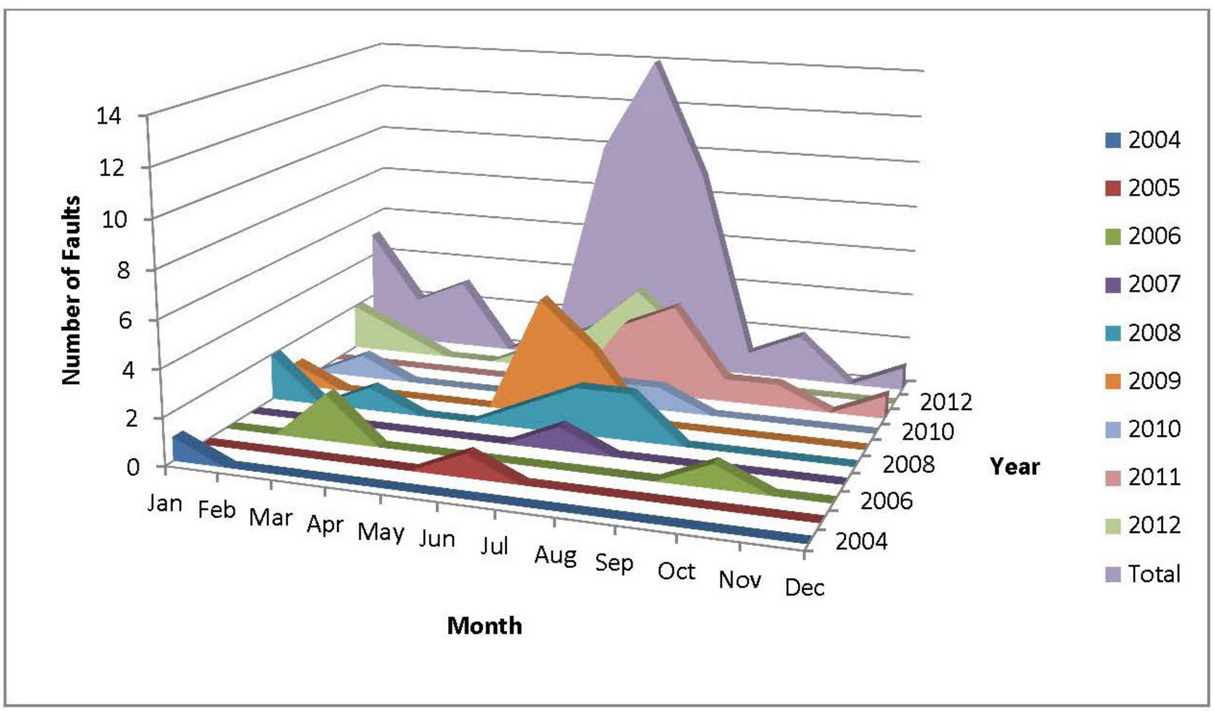


Fig 4 Distribution of Faults by Time of Year

The last analysis examined which phases were involved in the faults. Again the distribution on the two circuits was similar. Only the faults from GL1 are shown. Figure 5 is the distribution of faults affecting the top red phase and figure 6 the distribution of faults on the middle yellow phase.

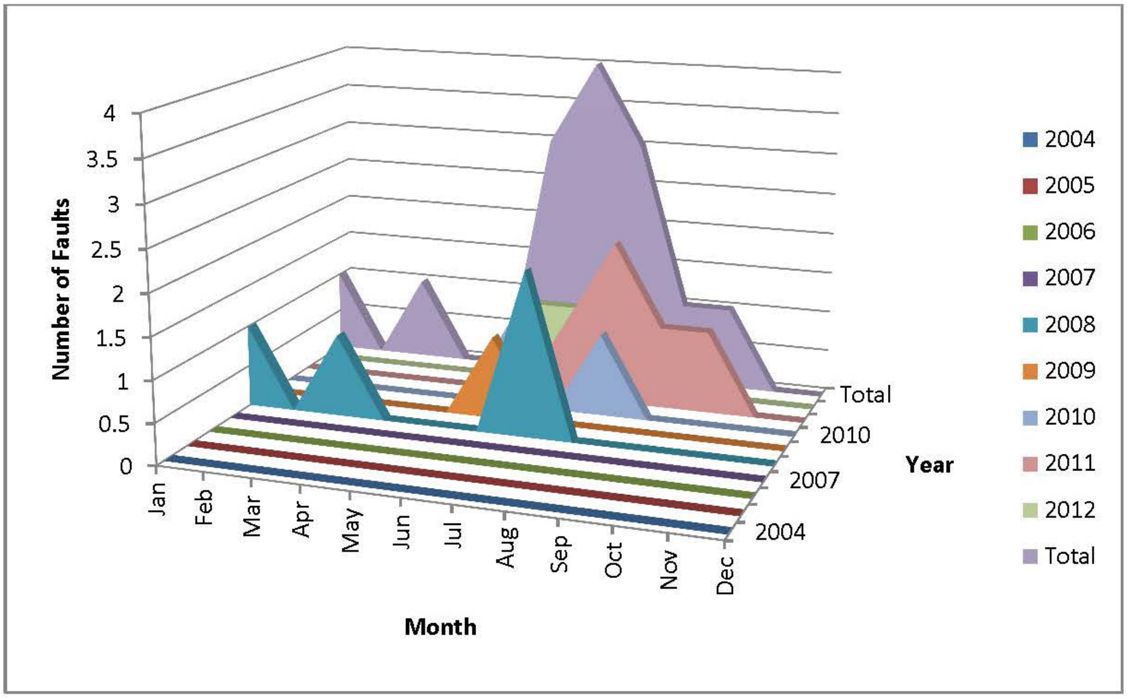


Fig 5 Distribution of Faults on GL1 Top Phase

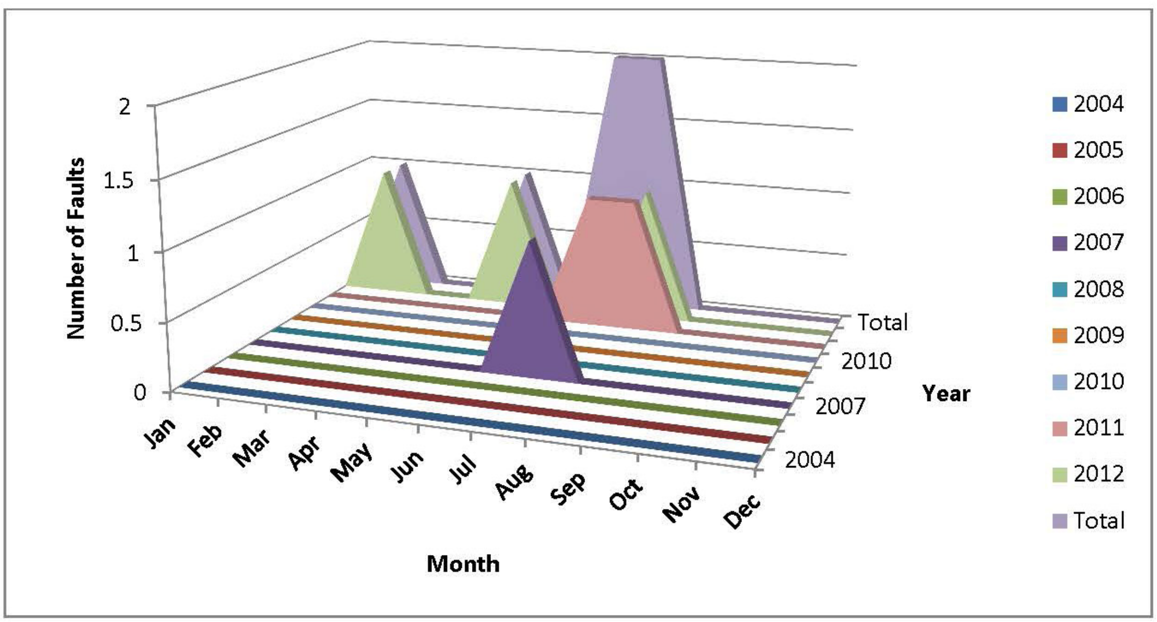


Fig 6 Distribution of Faults on GL1 Middle Phase

Most faults occurred on the top phase with about 50% on the middle phase and very few on the lower phase. In the analysis SSE considered the following:

- The possibility that a build up of pollution and salt on the original glass insulators was causing flashovers during the night and early morning when dew and mist were prevalent. The time of day would support that hypothesis but most faults would be expected on the lower phase where the dampness would be more prevalent. This was not the case.
- Wind driven saline solution in the coastal location around the loch and Dunoon could also be a contributory factor. The wind direction is mostly from the south-west but the micro climate around the line is known to generate winds from other directions.
- Reduced lightning performance due to higher earth impedance caused by a worn earth wire and aging fittings is a possibility but the incidence of lightning linked to fault activity could not be proven. Inspections did reveal evidence of discharge damage consistent with lightning impulse but due to the location and age of the equipment this was not thought to be the cause of so many line trips in recent years.
- Bird interference and fouling of the insulators was considered the most likely problem especially as a new landfill site (burial of domestic waste) became operational in 2006 at a site close to the line and about 2km from Dunoon. These sites attract birds and can generate wind blown debris. The incidents of faults, evening and early morning, mostly in the summer months and most on the top phase, support this theory. However, although some evidence of bird fouling was found it was not significant and there have been no discoveries of feathers or bird remains close to the line.
- The lack of effective fault location on the Dunoon tee meant it was not possible to identify the spans or towers where the fault activity was occurring thereby hindering confirmation of the root cause.

SCOTTISH AND SOUTHERN REMEDIAL WORK

In 2004, before the increasing instances of line trips with unknown causes, SSE had replaced insulators and added support stays to limit conductor movement in an attempt to improve performance on an exposed section of the line of route. This was successful in stabilizing fault activity at that time. The 'new' fault activity since then was not believed to be in this section of the line.

The following work has subsequently been completed:

- An independent structural survey was undertaken in November 2009 and concluded that the towers were still fit for purpose. However, conductor loading could not be introduced without a more extensive structural assessment which ruled out the possibility of increasing the conductor size to accommodate prospective wind farm connections, at least in the short term.
- SSE appointed an independent assessment of sample 132kV insulators. The results were published by the University of Manchester in February 2010. The conclusion was that the sample insulators were of a condition commensurate with age and location but the associated small part support steelwork was showing clear sign of metallurgical stressing. SSE decided on the balance of economic considerations that all original insulators on the branch were to be replaced by slightly smaller ones (to reduce the kinetic envelope) and with a longer creepage path to minimise the possibility of phase to ground faults.
- In August 2012 an intrusive investigation carried out by SSE discovered lightning damage at various locations along the tee circuit. It was decided to replace the earth wire and associated small part steelwork to improve performance against lightning.

- In 2013 it was decided to install bird deflectors on 7 towers close to the landfill area. This was a difficult decision as although birds were considered a probable cause of faults at the landfill site the spikes on the deflectors can snag windblown debris, especially plastic bags, and cause other problems.
- In 2013 it was decided to add voltage sensors to test taps on the HV bushings of the transformers at Dunoon to implement double ended traveling wave fault location that extended down the tee when combined with results from existing units at Sloy and / or Windyhill.
- The condition of the conductors was assessed to be good from SSE records and this was confirmed in 2014 by on site measurements. This supported the decision not to replace the conductors.

By the end of 2012 a scope of work had been defined. The towers were structurally acceptable, the earth wire would be replaced like for like, all of the original 132KV insulators would be replaced and small part steel work changed. During the completion of this work the new traveling wave sensors would be fitted to the transformer HV bushings at Dunoon, bird deflectors fitted near the landfill site and the towers repainted.

After planning and budgeting the above work was completed in phases during 2013 and 2014. Figure 7 shows a tower fitted with bird deflectors.

Fig 7 Bird Deflectors Fitted to a Tower near the Landfill Site

Note that faults continued to occur during the planning stage and despite aerial surveillance from helicopters and foot patrols over difficult terrain the cause remained elusive.

There is some evidence to indicate that birds are no longer roosting on the towers as a result of the deflectors but there is a suggestion that the bird deflectors have captured some wind borne debris. On balance the results of installing bird deflectors since March 2013 to date have been more positive than negative. Since completion of the above work the number of line trips with unknown causes has decreased significantly but further time is needed to confirm that this is due to the remedial works.

FAULT LOCATION INSTRUMENTATION

The distance relays at Sloy and Windyhill both have impedance fault location functionality but the results on this teed network have been erratic for reasons previously outlined. The use of double ended traveling wave (TW) fault location is widely used in Scotland for accurate, consistent fault location on the overhead lines. In this instance, TWS devices were installed at each end of the teed circuit at Sloy, Windyhill and Dunoon. The standard technique is to capture the current component of the fault induced traveling wave on the secondary side of the protection CT via the use of split core linear couplers. Results using this method are good but it does assume that the terminating impedance of the substation is low compared to the surge impedance of the line. This usually means that one or more lines must be connected to the busbar as well as the line being monitored. This was true for the Sloy and Windyhill ends of the circuit and these devices combined well to give good results for faults on the main line. However, the lines at the end of the tee at Dunoon terminate directly onto transformers and the resultant high impedance means that measuring current was ineffective. The result was that faults on the Dunoon tee that triggered the TW devices at Sloy and Windyhill returned a distance to fault at the tee connection. Figure 8 gives an example of a TW result on a fault on 14th March 2006 where the fault location appears to be at the tee point. This is indicative that the actual fault location was down the tee. Note that the line length of Windyhill to Sloy used at that time was 55.5Km. This has subsequently been amended to 53.9Km. When the new line length is used with the original time tags the revised distance to fault is within 300m of the tee connection as defined in Fig 1.

The TW waveforms indicate a phase to phase fault confirmed by the fault recorder trace from Windyhill for the same incident shown in Fig 9. The lack of accurate fault location on the Dunoon tee was a major hindrance in establishing root cause of the line trips and proved very costly in helicopter use 6,000 GBP per day and extended foot patrols costing hundreds of pounds.

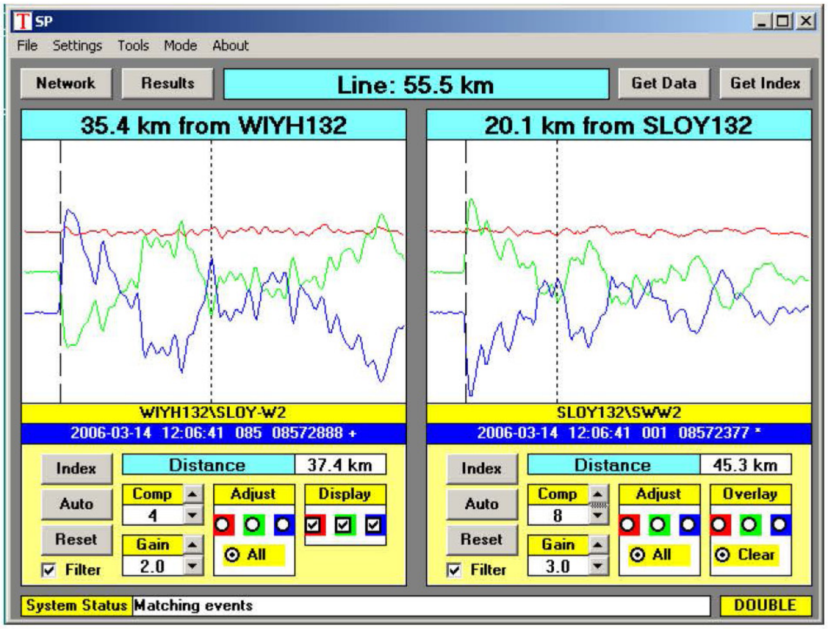


Fig 8 Travelling Wave Result for Phase to phase fault in March 2006

Corrected result is 19.38Km from Sloy and 34.5KM from Windyhill when a corrected line length of 53.9Km is used

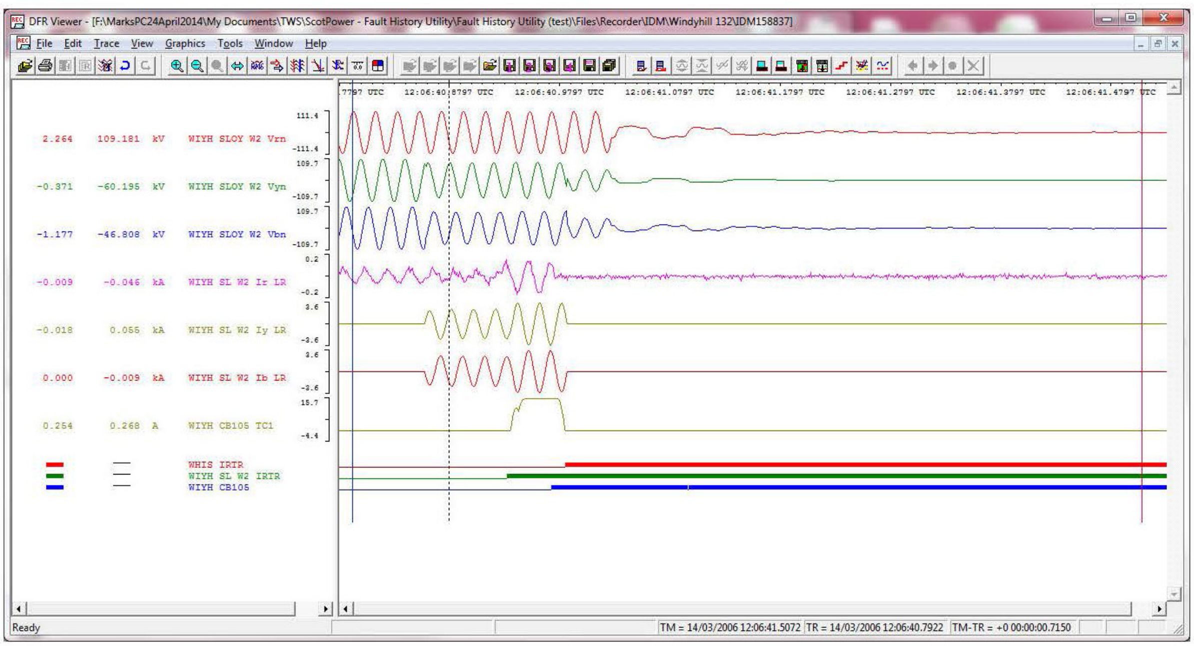


Fig 9 Fault Record from Windyhill for the March 2006 fault

Part of the SSE initiative to improve the circuit availability was to replace the current sensors at Dunoon with 'voltage' sensors in the form of couplers connected to the tapping points on the transformer HV bushings. These couplers, measuring the current to ground through the bushing capacitance as a result of the transient voltage, were fitted in September 2013 during line outages. Although the two 132/33KV transformers at Dunoon are identical there were two different types of bushing fitted meaning two different coupler designs had to be deployed. The couplers are shown in figure 10.

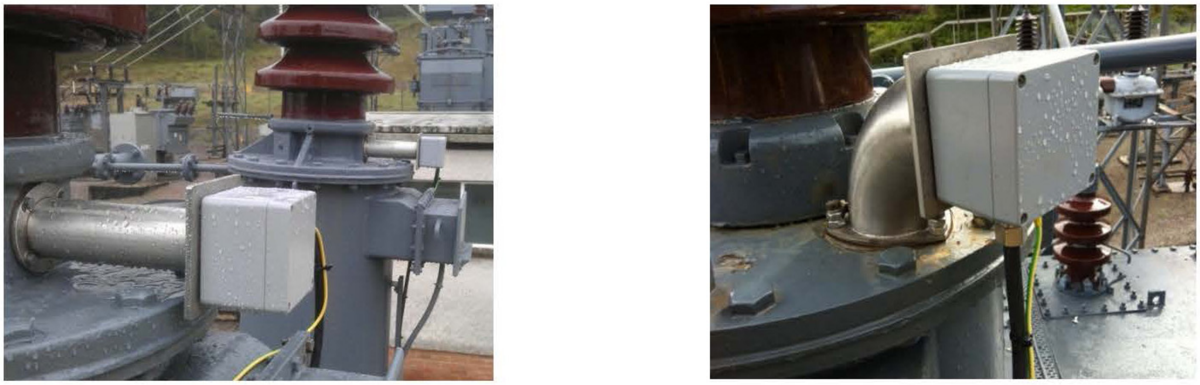


Fig 10 Adapters Fitted to the Bushing Taps to Allow TW Fault Location

Figure 11 shows the waveform captured on 18th September 2013 from the TWS at Dunoon when the tee'd circuit was energised by closing the circuit breaker at Windyhill. After adjusting the trigger point the opposite polarity reflection from Whistlefield can be identified 19.21Km from Dunoon proving correct operation of the bushing coupler assembly. Whistlefield produces a relatively large reflection because short underground cables are used to connect from the lines to the transformers creating a significant impedance change.

Fig 11 Energising GL2 from Windyhill

FAULT LOCATION RESULTS

The bushing couplers fitted to the transformers at Dunoon are proving to be a good signal source for traveling waves meaning there is now full three ended coverage of the tee'd circuit. The first trip after commissioning was on 5th December 2013 on the GL1 circuit and was located 9Km from Sloy on the main line. Figure 12 shows the graphical result from the analysis software. In this view all the different 2 ended possible results are marked with the X showing the actual fault position.

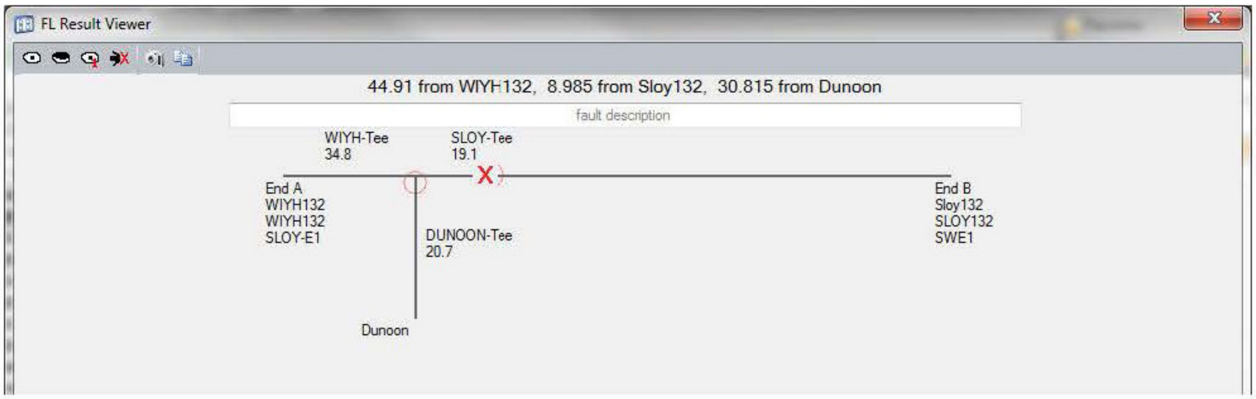


Fig 12 Results from Trip on 5th December 2013

Two other trips occurred in 2014 both of which were on the Dunoon tee section and both of unknown origin. The first was on the 14th May at 23.02. It occurred on the top phase (red) of the GL1 circuit and the TW system located the fault at 1Km from Dunoon as shown in the double ended measurement from WIndyhill to Dunoon in Fig 13.

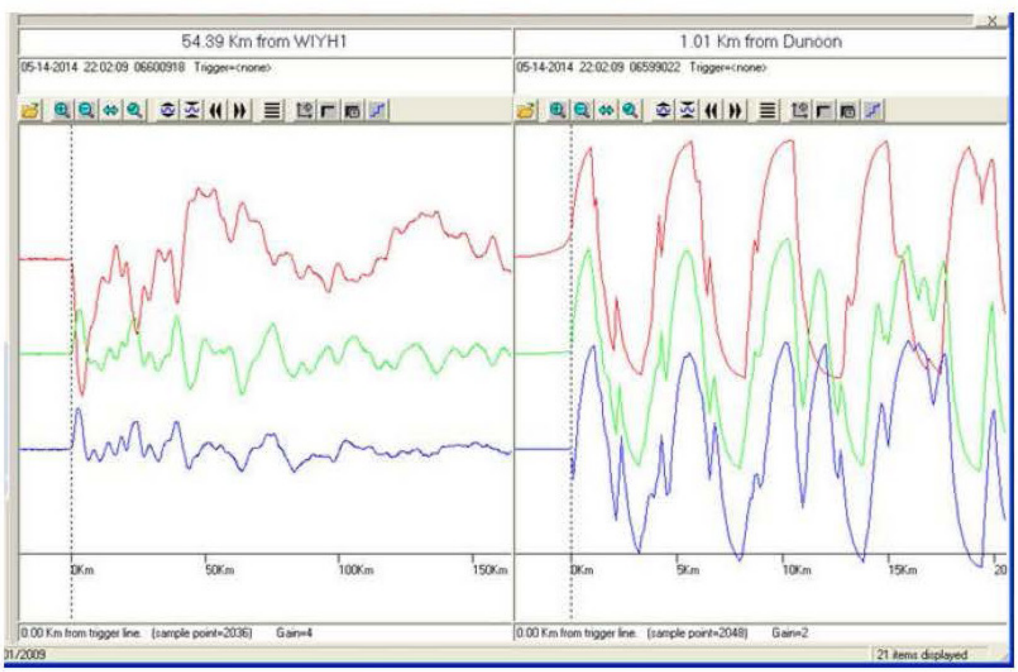
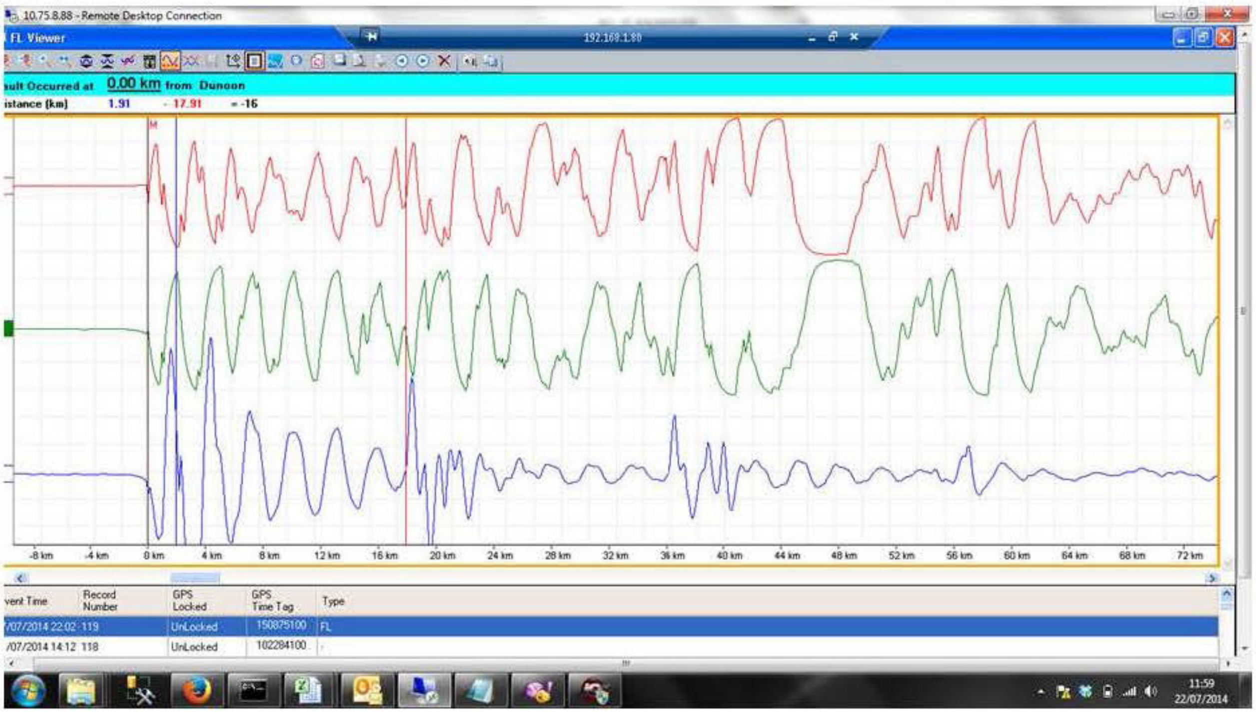


Fig 13 Fault Location from on 14th May 2014

Note that the time shown is 1 hour early as the daylight saving function was not enabled

The second fault occurred on the 17th July at 23.02 on the top phase (blue) of the GL2 circuit. The Windyhill section of the circuit was out of service for maintenance and the TW device at Sloy had been taken off line meaning only a manual single ended analysis of fault location was possible from Dunoon. The single ended manual analysis puts the fault close to Dunoon, less than 2Km. The clear reflection of opposite polarity that can be identified (where the red vertical cursor is placed) is 17.91Km out. If the fault was high impedance then this could be the reflection of the fault generated transient from Whistlefield meaning 17.91Km is the distance back from Whistlefield. This would place the fault about 1Km from Dunoon.



Both faults were in the same vicinity just outside the area protected by the bird deflectors and work is now concentrated in this small area to try to identify the cause. The occurrence of the faults at the same time is also interesting.

SUMMARY

The rising number of unexplained line trips on the Dunoon teed circuit seems to have reduced following the remedial work carried out by SSE on the lightning wire, insulators and small scale steel work but more time is needed to confirm this. Upgrading the traveling wave fault location system to give full coverage across the complete circuit has been successful in locating the fault sites when trips have occurred. Although these faults were in the same vicinity no cause has yet been determined but the search area has been narrowed. This has resulted in reduced costs on line patrols and the confidence to deploy more intrusive investigations across one or two towers only. Having accurate operational fault location available will allow more focused actions in the future should fault activity persist.

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 traveling 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 traveling 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.

Ron Garrett is Chartered Engineer. After gaining a degree in Electrical and Electronics Engineering he went on to work as a consulting engineer in design, construction and project management mainly in the power industry. He is a member of the IET and IEEE and is presently working in project management with SSE in the Transmission Department.

QUALITROL®
Defining Reliability

FOR MORE INFORMATION ON
PRODUCTS AND SOLUTIONS

Contact us info@qualitrolcorp.com