LOSS OF MAINS PROTECTION RELAY PERFORMANCES WHEN SUBJECTED TO NETWORK DISTURBANCES / EVENTS

Andy BEDDOES*, Peter THOMAS#, Mark GOSDEN†
***EA Technology – UK, # Scottish Power – UK, † Manx Electricity Authority – Isle of Man**
Andy.Beddoes@eatechnology.co.uk

SUMMARY

Loss of Mains protection (LOM) is the requirement for the connection of Generation to the UK distribution network. Its role is to prevent the generator from accidentally energising an electrically isolated section of network. Such requirements are derived from Statutory Regulations, and the method of achieving it are described in Engineering Recommendation G59/1 and Engineering Technical Recommendation 113 - often referred to as ETR 113 [1,2].

There is however a general concern, within the power system fraternity, that the existing generation of LOM protective relays are unduly influenced by, and sensitive to, network disturbances. Whilst standard settings [1,2] are used, the level of sensitivity has been found to be primarily determined by the type and make of protection relay used. This can directly impact on the level of 'false tripping' for connected distributed generation, which in turn increases maintenance requirements, reduces their availability, and can affect the overall performance of the distribution network.

This paper presents an overview of the high level performance of several Loss of Mains protection relays. Real network disturbances were used in the testing, captured using installed data loggers, and a range and variety of network disturbances were used and applied to the relays. These disturbances were not true LOM events and so enabled the performance and immunity of the relays to be evaluated under controlled conditions.

INTRODUCTION

The impact on the performance of generator's LOM protection from network disturbances is of concern to both generators and network operators. As Distributed Generation and its penetration within the distribution system grows (UK targets of 10% from new and renewable for 2010 and 10GW of installed CHP), adequate and reliable generator protection is clearly of paramount importance.

There are high expectations for Distributed Generation within the distribution system, especially when Wind Power and the penetration levels required to meet the UK Government Targets are considered. Most large scale Wind Projects are likely to be connected at 132kV or higher due to their large connected capacity and LOM achieved by more secure means (intertripping). Nevertheless a substantial number will rely on LOM protective relays and it remains important to ensure that both generator and network interact as effectively as possible, with protection systems interacting without maloperation.

The concern over the performance of Loss of Mains protection relays when subjected to network disturbances was such that a group of leading UK and Island Network operators commissioned an investigation into their performance under EA Technology's Strategic Technology Programme as part of the optional Module 5 – Distributed Generation.

NETWORK DISTURBANCE

The use of accurate network data is important in any modelling and investigative work. To this end real network disturbance data / waveforms were captured from a Power Quality (PQ) data logger. Its location was on a 33kV Distribution Network adjacent to an existing established Wind Farm (at the Wind Farm's Point of Common Coupling). The voltage trigger setting for the installed PQ logger was ± 10% of nominal, with a current trigger setting of 20% overcurrent from nominal and 50% magnitude rate of change trigger over 8 cycles. Over a two year monitoring period (2000 and 2001), over 1000 events were captured.

Correlation With National Disturbances

Information from National Grid on UK system frequency deviations were obtained for the year 2000 and 2001. This information provides dates, times and magnitude of frequency deviation (outside the operational limits of 50Hz ± 1%). The results in Figure 1 show the trend over a 4 year period for the reported frequency deviations (positive deviations are illustrated for simplicity).

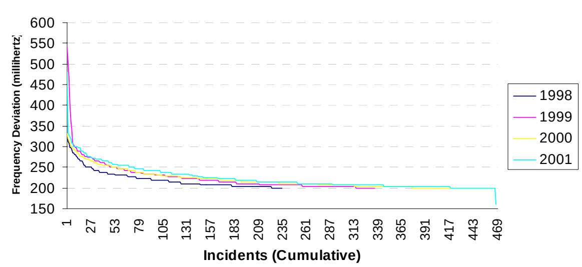

Figure 1 - Positive NGC Frequency Deviations

For the two year monitoring period the data logger was installed, it was observed from the generators SCADA log that a total of 92 'G59' protection trips happened. From the event timestamp none of the 'G59' protection trips correlated to National Grid's system frequency deviations, with the PQ logger capturing the local disturbances at the time of trip (with none of the captured disturbances showing a voltage approaching zero for anything more than a few cycles). The trips therefore observed and captured for the site were as a result of local network disturbances and **not** national power system frequency deviations.

SCADA Log and Captured Disturbances

The captured data was post processed to calculate the Vector Shift of the voltage waveforms captured. Analysis was carried out which minimised the difference between the square of both ideal and measured sinusoids. When using this method, the vast majority of the calculated Vector Shifts (~ 85%) were of the order of 6 degrees or greater and for one phase only. The remaining 15% of events were less than 6 degrees.

A significant number of multi-polarity three phase Vector Shifts were observed and suggested that a simple change in the 'detection' criterion (single or three phase shift detection) for when to trip or not to trip a LOM protection relay using a Vector Shift technique could dramatically influence the potential number of 'false' trips. UK DNO's do not recommend single phase Vector Shift LOM detection.

PROTECTION RELAY TEST RIG

With the results from the previous section showing some interesting observations, it was considered necessary to test the performance of the LOM protection relays directly. To achieve this a relay test rig was developed to enable a controlled environment for the testing and analysis of the sensitivity of the LOM relay's settings.

System Overview

The diagram below shows the structure of the test rig. This permits a digitally sampled signal to be synthesised and output as an analogue signal. Data can be added to the signal (post or pre trigger) and enables the relays under test to settle down as they require a steady input signal for a few seconds before any relay protection functions are enabled.

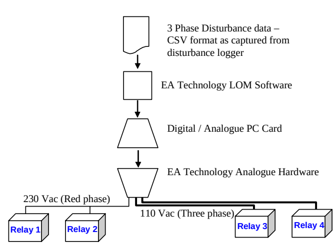

Figure 2 - Loss of Mains test rig overview

This system can re-synthesise the captured disturbance (or any digitally created one) and output it at either 110Vac or 230Vac both single and three phase since different protection relays have different input voltage configurations.

Software Development

The LOM Test software is part of the LOM Tester System. Its main function is to convert the real fault data that has been collected and stored (digitally) into a real-time analogue output. This enables the captured waveform to be applied to LOM relays to test their performance and operation within a controlled environment. Relays other than LOM can be tested using the rig.

The software reads in fault data in specific text formats, converts and scales the data into the range for the underlying analogue output card (+/- 10V) and then displays the data graphically on screen. The data can then be 'played' to the card appearing on the analogue channel outputs. This is then passed through an additional hardware stage (filtering, amplification and buffering) before being applied to the relays under test.

Key Issues

One of the main issues in developing the software was in the synthesis of a "lead-in" and "lead-out" waveform. This is necessary since the data obtained from the disturbance logger normally only starts a few cycles before the trigger point. With a 'lead in' and 'lead out' pre-amble function, the original data within the pre and post trigger periods can be extrapolated in order to stabilise the relay before and after the actual fault data is applied to the relay. This is illustrated below in figure 3.

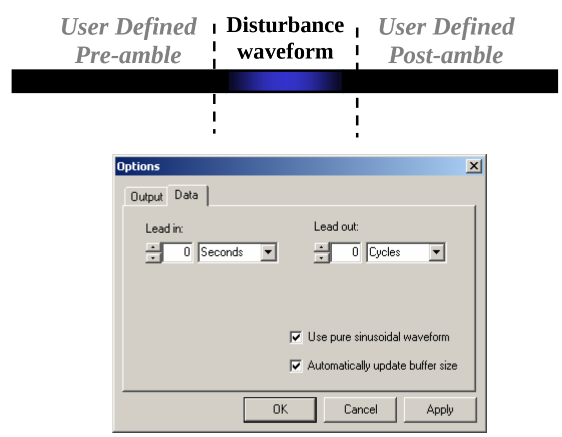

Figure 3 - Setting the lead in and lead out in the software

It is critical that no false disturbance is introduced at this transition stage and the correct implementation of this was a key focus in the development of the software. The user can define the pre and post amble periods in either cycles or seconds as required by the relay under test. The lead-in data can be generated either by repeating the first few cycles of the boundary cycles or applying a best-fit pure sinusoid of the required length.

The pure sinusoidal waveform option was provided because it was found that a phase drift often occurred when the original data was used as lead in or lead out information. This option provides for a much smoother transition. The LOM Tester software runs on a PC running any compatible Windows OS and utilises a National Instrument analogue output card (a PCI 6711 was used for this development) installed and set up.

Disturbances Used in Relay Testing

Out of the 90 or so disturbance records outlined earlier and from excluding similar events, a set of 50 records was used for the tests in this project. An example of a typical disturbance from the data set is shown below (taken from the LOM Tester Screen).

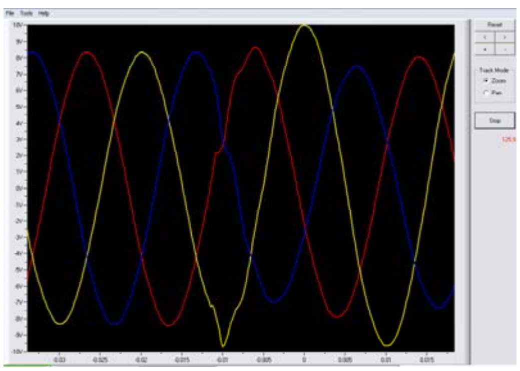

Figure 4 - Typical disturbance from data set used

A Real Loss of Mains Event

As outlined earlier the network disturbance data applied throughout the testing of the LOM protection relays is acknowledged **not** to contain any true 'Loss of Mains' events. It could therefore be construed that by definition a Loss of Mains protection relay should not trip for any of these events. Therefore the tests give an indication and insight into the performance and sensitivities of the relays when subjected to real network disturbances.

In such circumstances, there is no specific requirement for Loss of Mains protection to operate (since no Loss of Mains event has taken place) unless the G59/1 protection protocols require it (e.g. under / over voltage or neutral voltage displacement for example). It is fair to say that "True" Loss of Mains events are rare, but under such circumstances present protection protocols (G59/1) require that the generation must be disconnected from the network.

A Real Loss of Generation Event

On the 26 May 2003 both Sizewell B PWR generation units tripped simultaneously in the UK. This resulted in a total loss of 1175MW, causing the system frequency to go outside of the statutory limits for 12 seconds. Such incidents become reportable when the excursion is more than 60 seconds.

Some 50MW (a relatively small amount) of distributed generation was understood to have tripped off during this event because of the automatic operation of rate of change of frequency protection relays. However, whilst this event was not a significant loss of generation on this occasion, if the long-term increased levels of distributed generation envisaged from government renewable targets were in place, such tripping of connected distributed generation could have a significant impact on the overall stability of the network.

With the use of the LOM test rig, the sensitivity of LOM relays to this 'National observed event' could be 'safely' evaluated within a controlled environment to determine how the relays may have responded.

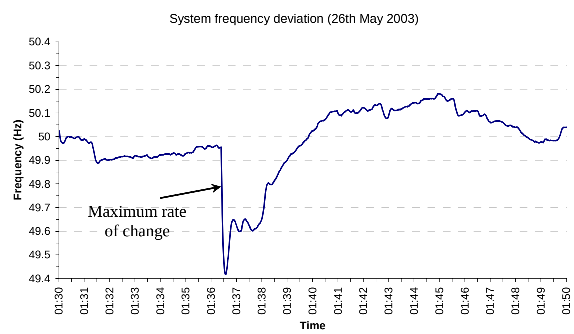

Figure 5 - System frequency deviation on 26th May 2003

No voltage waveforms were captured for this event but it is possible to re-synthesise an ideal voltage trace based on the network frequency data and the monitored voltage level at a network Bulk Supply Point (illustrated below).

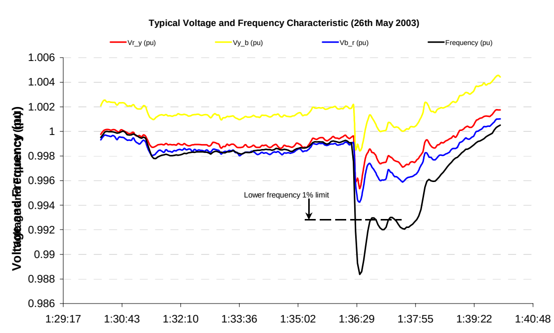

Figure 6 - Voltage and frequency profile for a BSP at time of frequency disturbance

Such an event is rare in the UK and using the data within figures 5 and 6 a re-constituted sinusoidal three-phase waveform was created on a cycle by cycle basis for the 30 to 40 second window of interest.

This re-constituted three phase voltage trace was then applied to the Loss of Mains relays to observe their response.

Although the voltage profile in Figure 6 is unique for the part of network it was measured, it is considered sufficient for these purposes in the absence of any sampled voltage data. It is also interesting to observe that the voltage characteristic follows the frequency response. This illustrates that this was a "National" observed phenomenon since both data sets were measured in very different geographical locations.

RELAY TESTING METHODOLOGY

Some 11 Loss of Mains protection relays from 7 different manufacturers were tested with the captured 50 unique network disturbances applied to the relays using the LOM test rig and developed software. The re-synthesised network event as result of Sizewell B PWR tripping was also applied to the relays using the test rig.

For the relays with 'G59/1' multi-function protection capability, all G59/1 protection functions were disabled with the exception of the LOM protocol. This ensured that only the sensitivity of the respective LOM algorithms were tested.

For each LOM relay, the LOM setting (ROCOF or Vector Shift) was slowly increased from the relay's minimum setting to the relay's maximum setting.

RESULTS AND OBSERVATIONS

Vector Shift Performance

The plot below illustrates the sensitivities observed from the network disturbances applied to the Vector Shift LOM protection relays. The vector shift setting (in degrees) is illustrated along the x-axis, with the number of trips on the y-axis indicating for how many network events (from the 50 applied) a specific relay tripped at that particular setting.

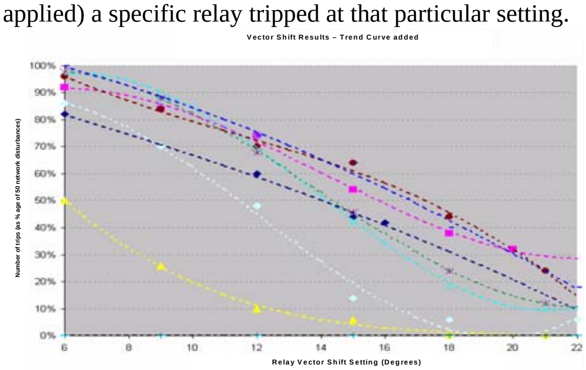

Figure 7 - Vector Shift Results

Vector Shift Results Observations

- The best performances were from two relays when set to "three phase" detection mode. These relays are seen never to trip for any of the network incidents.
- When the same two relays were set to "single phase" mode (default manufacturers setting) they become some of the worst performing relays.
- From a trend line analysis of the results, it is observed that the vector shift algorithms perform within a similar characteristic band, with an approximate 20% band margin in number of trips.
- A third vector shift relay appears very discriminatory against the network events. A setting of 12º was only seen to trip for 10% of the network incidents. This compares to 75% tripping on events for the identical vector shift setting on the other relays tested.
- To achieve the same level of discrimination of the third relay when set at 12º, the remaining relays would have to be set at or close to their maximum vector shift setting. This action, in order to achieve the same level of performance across the range of relays tested, clearly demonstrates the wide-ranging performances for the "same" relay setting.

ROCOF Performance

The plot below illustrated the ROCOF relay sensitivities.

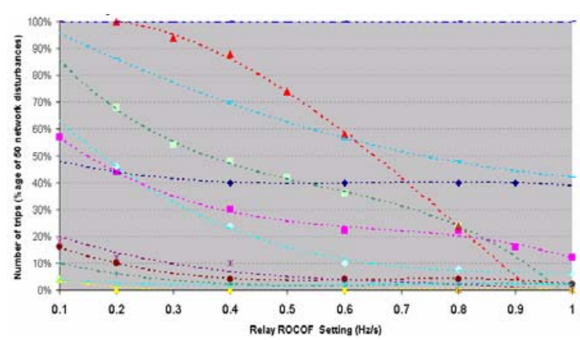

Figure 8 - ROCOF Results

ROCOF Results Observations

- The ROCOF relays are seen to give a more varied performance when compared to the Vector Shift relays.
- An important function, where available for some of these relays, is the "number of cycles" setting which the internal ROCOF algorithm uses. In the case of one relay, a delay timer was utilised in the programmable scheme logic (set by manufacturer to 0.5 Sec).

- The best performing ROCOF relays were seen to be those incorporating a delay time when compared to the next best performer.
- The results show that for one relay increasing the number of cycles within the detection algorithm improves the relay's discrimination at the low end ROCOF settings.
- The results show that a transient type vector shift network disturbance significantly influences the performance of a ROCOF relay, with a noticeable varied performance across the range of manufacturers.

Re-synthesised Loss of Mains event observations

For the re-synthesised Loss of Mains event (from 1175MW loss of generation), some of the key observations were:

- A vector shift setting of 4° would be sufficient discrimination for this event and with most of installed vector shift relays likely to be set at 6° or higher [2], it would have been unlikely that they would have operated based on this reconstructed event.
- The ROCOF performance however differs in that a wide range of settings are seen to trip the relays. The maximum linear change in frequency over a 1-second period, calculated from the NGC recorded frequency data, is 0.1 Hz/s. Theoretically, anything set above 0.1Hz/s should not trip.
- All of the ROCOF relays, with the exception of three which failed to trip for this event on **any** setting, operated for this event.
- For a 'typical' Loss of Mains relay set to 'typical' settings, it is likely that a ROCOF relay would have operated for this "loss of generation" event. However, it is likely that a Vector Shift relay (indicated from these tests) would have been immune to this event and not perhaps have operated. The reason for this is that the generator trip caused a relatively 'slow' drop in frequency with no sudden voltage vector changes.

SUMMARY AND CONCLUSIONS

From the controlled tests carried out for this project, the results clearly demonstrate that in order to achieve a similar level of protection discrimination when using a Vector Shift or ROCOF Loss of Mains protection protocol, different settings have to be used for the present generation of relays.

This spread of settings is seen to be at its widest when ROCOF relays are used. Indeed, some of the relays tested have a minimum permissible relay ROCOF setting of 0.2Hz/s. The setting recommended in ETR 113 is 0.125Hz/s, and so these relays will always remain set above this value.

This clearly has implications for medium sized generators on the distribution system. For example two generators connected at similar locations geographically and set to the same LOM trigger setting using the same protocol, but using relays from different manufacturers, will perform very differently despite seeing the same network disturbances.

Based on the results from this work, the results show that using 'G59/1' settings (12 degrees) a high number of trips would arise from most Vector Shift relays. Since the data is understood to contain no known true Loss of Mains events it brings into question the validity of applying a vector shift protection protocol for Loss of Mains applications. Most relays are clearly 'over' sensitive to remote network events.

Without an in-depth understanding of the internal algorithms the relays use, some internal scheme logic linking the ROCOF and Vector Shift functions could be possible for joint protocol LOM protection relays and may improve their performance. This however would need careful consideration.

It seems logical that the ROCOF principle is probably the best suited approach to help 'Truly' detect a Loss of Mains event from that of transient network vector shifts and disturbances.

There are seen to be significant differences (and functionality) in the performance of the ROCOF relays tested. This is probably due to the different interpretations and algorithms used and demonstrates that a "Standard" ROCOF algorithm or perhaps a defined performance curve would ensure such performance differences for "like" relays are minimised.

The protection of Distributed Generation is an important part in its connection and interaction with the Distribution Network. When considering the likely structure, evolution and requirements of the "future power network", it remains clear that a ratification of the present Loss of Mains protection protocol and requirements are necessary. The Energy Network Association are currently looking into producing a standard for Loss of Mains protection.

Acknowledgements

This report is published with the permission of the EA Technology Director of Research and Development. The project is funded by the Electricity Companies participating in Optional Module 5, Distributed Generation of the Strategic Technology Programme (STP). The authors would like to acknowledge the contributions from the relevant protection relay manufacturers and also wish to thank Scottish Power / Manweb for the provision of network data.

REFERENCES

[1] Engineering Recommendation G59/1, Energy Networks Association

[2] Engineering Technical Report No.113, Energy Networks Association