A TRIAL OF ALTERNATIVES TO DIRECTIONAL OVERCURRENT PROTECTION ON GRID TRANSFORMERS TO IMPROVE THE NETWORK CAPACITY TO ACCOMMODATE REVERSE POWER FLOW

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ABSTRACT

This paper will focus on the role of directional overcurrent (DOC) protection and will provide an overview of options for alternative solutions to replace this scheme. This includes an analysis of their suitability and impact from a technical perspective. The paper will share the UK Power Networks experience, decisions and trial results to manage with the reverse power flow issues in an area of Cambridgeshire, UK, as part of the Flexible Plug and Play project [1].

INTRODUCTION

The Flexible Plug and Play (FPP) project was a Second Tier Low Carbon Network Fund (LCNF) project that aimed to enable the connection of Distributed Generation (DG) onto constrained parts of the electricity distribution network without the need for conventional network reinforcement. One of the constraints under investigation included the limiting factors affecting the reverse power flow into the 132kV network, both in this area and the wider network, as a result of the setting of the Directional Overcurrent (DOC) protection on the transformer incomers. This form of protection assumes a certain direction of "Normal" power flow for stability and is set to detect and clear faults on the remote end of the higher voltage network. The setting of the protection, limits the amount of power allowed to flow upstream through the transformer and, as this setting is often lower than the full plant capacity, it prohibits the full utilisation of the thermal capacity of the network.

This paper provides results following an earlier paper submitted for the IET DPSP 2014, titled "An Investigation into Alternatives to Directional Overcurrent Protection on Grid Transformers to Improve the Network Capacity to Accommodate Reverse Power Flow" [2] in which options for modifying/replacing the existing DOC protection schemes or settings in the context of enabling greater levels of reverse power flow in distribution networks were examined as a precursor to the trial.

THE NETWORK CONSTRAINT

The DOC protection scheme under investigation was applied following the principles established in ENA TS 41-15 [3]. In the application examined, this scheme was applied on the 33kV side of the transformers to provide back-up protection to an intertripping system, which would isolate the transformer following a fault on the 132kV network.

The network constraint imposed by the DOC protection system can be illustrated by considering the present response to a 132kV fault. Taking the example at March Grid, for which the network is shown in Figure 1, and applying a fault on Circuit 2, the protection systems are designed and set to be sensitive, but equally discriminative, to such a fault.

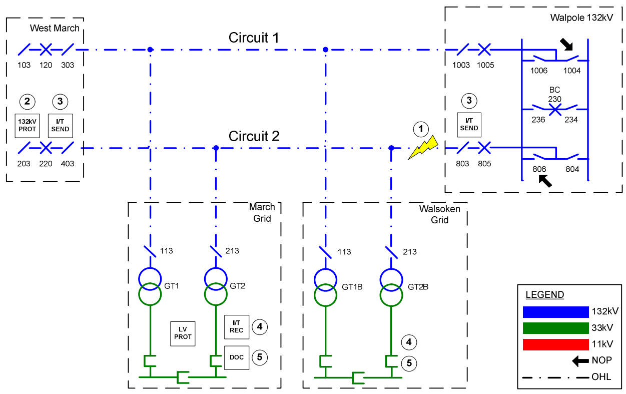

Figure 1: Sequence of events after a 132kV Fault

The typical expected sequence of events is shown within the figure and can be summarised as follows:

1. Fault develops on Circuit 2 of the 132kV network;
2. The 132kV protection will detect the fault and trip CB 805;
3. As the fault is back-fed through the back-energised grid transformers, an intertrip signal is sent;
4. The intertrip signal is received and trips the lower voltage incomer circuit breakers of all of the grid transformers connected to Circuit 2;

5. If the intertrip fails, the power will continue to flow into the fault through the back energised transformers. The DOC protection schemes on these transformer incomerswill should have already detected the fault and will now trip their perspective local breakers.

For the system to remain stable, the reverse power flow must not exceed the DOC setting. As such, the levels of generation are limited to ensure that the power flow onto the 132kV network does not exceed 80% to 85% of the DOC current setting.

The firm N-1 capacity and DOC settings at March Grid are 787A and 600A and at Peterborough Central are 1,050A and 640A. If the reverse power is limited to 85% of the DOC current setting then the maximum allowed reverse power flow would be 510A (64.80% of firm capacity) at March Grid and 544A (51.8% of firm capacity) at Peterborough Central.

A viable alternative to DOC protection, in which the full thermal capacity of the network could be utilised, would therefore benefit both UK Power Networks and their customers.

THE TRIALLED SOLUTIONS

There are a number of alternative solutions to DOC protection, although at present there are questions around the viability of all of these systems. The following provides an overview of the solutions considered as part of the Flexible Plug and Play trials:

Duplication of intertripping

From the sequence of events after a 132kV fault. it can be seen that the DOC will only be called upon to operate in the event of intertrip failure. Therefore, if the intertripping system is securely duplicated, there will be no need for the DOC protection and hence full thermal capacity can be utilised.

For the two sites considered, the communication system for the existing intertrip system ceases to be available from 2018. As such, UK Power Networks are undertaking a project to replace this communication system with a private self-healing fibre ring. Unfortunately, the complete self-healing ring, required for the duplication of the intertripping, will not be available until 2017/18, which prevents its immediate use.

DOC automatic disabling scheme

As most of the 132kV to 33kV transformation sites are typically radial in topography, with two interconnected transformers at each site, it can be argued that in an N-1 scenario the intertrip is not required. If one transformer is out on maintenance or trips out on fault then a trip on the other circuit of the 132kV system will effectively disconnect the supply to the site whether an intertrip is there or not. As intertrip is effectively not needed in such a scenario then the DOC (which is back up to intertrip) is also not needed. To achieve this, the DOC scheme can be disabled when the opposite transformer’s incomer breaker is open.

The relays at both sites were configured to operate using a traditional DOC scheme but with additional logic to automatically disable the DOC scheme on the “healthy” circuit following a loss of a circuit. At March Grid, this includes a further auto-switching scheme which both disables the DOC and opens a 33kV interconnection in the event of a loss of either of the site transformers. This was necessary to prevent any potential for islanding that could occur as a result of this interconnection on the lower voltage side. Whilst this revised scheme enables the full firm capacity of the sites to be utilised, at March grid this comes at the expense of the reduction in the security of supply of the wider network, which occurs due to the loss of interconnection. Due to this limitation, the DOC automatic disabling scheme was only considered as a short term solution for March Grid.

Combined DNPS and DVDO scheme

The combined directional voltage dependant overcurrent (DVDO) and directional negative phase sequence protection (DNPS) scheme is expected to be suitable for both networks considered and can be explained individually as follows:

Directional voltage dependant overcurrent protection

As the system voltage is suppressed under fault conditions, this can be utilised to improve the reach of a current operated relay. Using voltage dependent (or voltage controlled) overcurrent protection, the pickup setting can be increased whilst maintaining the reach setting. The studies show that for remote earth faults the voltage might not be suppressed sufficiently to ensure the required sensitivity whilst maintaining stability. As such, this method is predominantly used to detect three phase faults.

Directional negative phase sequence protection

From sequence component theory, under any unbalance in load or fault there will be a resultant negative and zero sequence components. Therefore, for any faults other than three-phase faults, the fault might be detectable by calculating the resultant negative and zero currents.

Calculations have confirmed that a directional negative phase sequence (DNPS) protection scheme can be used to detect all unbalanced faults. However, what could not be confirmed is the stability of the system.

DOC with Load Blinder Functions

For a number of years, distance protection relays and schemes have had a load blinder (or load encroachment detection) functions available. This utilised the fact that the load and fault angles are significantly different which allows for the necessary discrimination. If the load blinder principle is combined with the basic DOC function, the DOC relay will be blind to reverse load but will still be operate as normal for normal faults, as illustrated in Figure 2.

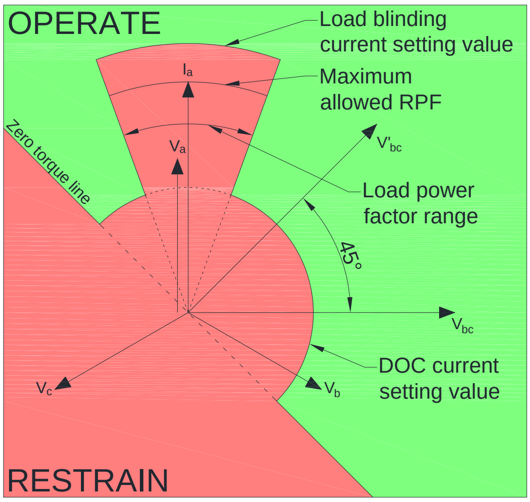

Figure 2: Vector diagram for response of a DOC relay with a load blinding function.

This scheme has the benefit of removing the protection-related constraints on reverse power flow whilst maintaining a relatively simple tried and tested philosophy for the protection settings.

The main issue with this scheme is high resistance faults. In such cases, there will be a potential that the fault current angle will be pushed into the blind zone making the relay restrained from operation. This issue is simply resolved by utilising voltage depression that occurs under such conditions and the negative phase sequence currents to disable the load blinding element.

TRIAL APPROACH

For the trial, Alstom MiCOM P142 feeder management relays were installed at March Grid and Peterborough Central. These relays were configured to provide alarm indications for a combined directional negative phase sequence (DNPS) and directional voltage dependent overcurrent (DVDO) protection scheme. With the presence of large levels of distributed generation both at the 33kV and the 132kV side of the networks, there is a concern over the level of normal and abnormal negative phase currents and voltage that the scheme might be subjected to for which it must be stable. By configuring the DNPS and DVDO systems to alarm only, the stability of the systems could be verified in a field environment without impacting on the security of the system. Data loggers were also installed on 33kV incomers at both sites in order to monitor the background negative phase sequence (NPS) levels, which were used to find a method for determining suitable DNPS protection settings which have a current setting that is both:

1. 20% higher than the maximum anticipated NPS currents which the DNPS scheme must be stable for;
2. 50% of the minimum NPS currents which the DNPS scheme must treat as a fault.

For the trial to be successful, the combined system should detect all fault types, whilst providing suitable discrimination for normal system operation and for faults outside of the fault zone.

The relays were also configured to provide alarm indications for two additional DOC schemes. The first of these was a very low DOC setting without load blinding function applied, for which it was expected that a number of events would be generated for non-fault scenarios. The second additional DOC setting was set at the same low value for the DOC but with the load blinding functionality enabled. The settings for this load blinder scheme were determined using the approach provided by Alstom [4]. For the trial to be deemed successful there should be a number of events for the unblended DOC but no recorded events for the blinded DOC, unless the load blinder is off for which there should be both events.

ANALYSIS OF RESULTS

The data used for the analysis of the trialled schemes has been generated from the following sources:

- Protection relay event and disturbance records;
- Power quality monitors;
- Fault studies;
- Network alarm schedules.

Combined DVDO and DNPS scheme

Over the trial period, September 2013 – September 2014, at March grid there were three DVDO events, all of which were pick-ups only, and four DNPS events, which included one tripping event. These events coincided with two network disturbances on the 132kV network outside of the protected zone. These were recorded on 08/10/2013 at approximately 09:30 and on 29/10/2013 at approximately 09:00.

For the three instances where the DVDO picked up, the operational DOC also picked up, which suggests that the relays operated as expected. There was, however, a trip event recorded on GT2 for the DNPS scheme but, it should be noted that the trial scheme had been configured with 250ms DT delay. This shorter time was chosen to ensure that appropriate trip signals would be generated for any fault conditions, which would otherwise be cleared by the primary protection system. This was deemed necessary to mitigate the reduced likelihood of a fault occurring on the network occurring simultaneously with a failure of the primary protection system against which the system would be graded, which would further reduce the chance of operation. Given that the scheme would be configured with a greater time delay, it is expected that the relay would have ridden through the fault. This is evident from the fact that the DOC only picked up but did not trip. There were a number of instances where the voltage dipped below the threshold for the scheme, which all occurred as a result faults on the 33kV network outside of the protection zone. Again, discrimination was achieved as there were no pickups on the DVDO scheme.

There was a DNPS event recorded at Peterborough Central which coincided with one of the network disturbances also seen by the March Grid relays on 29/10/2013 at approximately 09:00. This also occurred as a result of disturbances on the 132kV network outside the zone of protection. In this instance neither the DOC nor the DVDO schemes picked up for the disturbance, although the voltage did drop below the threshold for the scheme.

For March Grid, the minimum NPS current recorded from the fault studies was 372A, for a phase-phase-earth fault with a fault impedance of 100Ω. For Peterborough Central, the minimum NPS current recorded for a similar fault was 591A. To achieve the 50% target the DNPS setting would need to be less than 186A at March Grid and 295A at Peterborough Central.

Both of these settings are significantly higher than the all the standing negative phase sequence currents recorded over the trial period. It should be noted, however, that the standing NPS currents at Peterborough central were around 110A, which are generated from a transformer that supplies an unbalanced load (railway connection) on the 132kV network. For all other relays, the standing NS currents were under 15A.

DOC with load blinder functions

Over the trial period, July 2014 – September 2014, there were no operations for the blinded DOC where there were not similar (within 1ms) operations for the un-blinded trial DOC setting. Also, there were no operations of blinded DOC when the load blinder was on. These results would suggest that the load blinder functionality operates as expected. The results from the fault studies suggest that the positive sequence impedance, NPS and under voltage settings, which would disable the load blinding function, were also suitably sensitive to cover all fault scenarios, whilst maintaining a sufficient safety margin to provide suitable discrimination for no fault conditions.

There were, however, a number of instances where the load blinder was disabled and the trial DOC setting operated, which was not expected. This occurred when the levels of generation were not significantly higher than the load. In this condition, the generation, which operates at or near unity power factor, would support the real power on the network, whilst the 132kV network would support the reactive power. During these conditions the power factor is low and leading. This resulted in the load blinder function being disabled for low levels of reverse power flow, due to the positive sequence impedance threshold being exceeded. This is illustrated in Figure 3, which shows that the measured phase currents sit in the un-blinded region, and in Figure 4, which shows the positive sequence impedance, which would have removed the load blinder function.

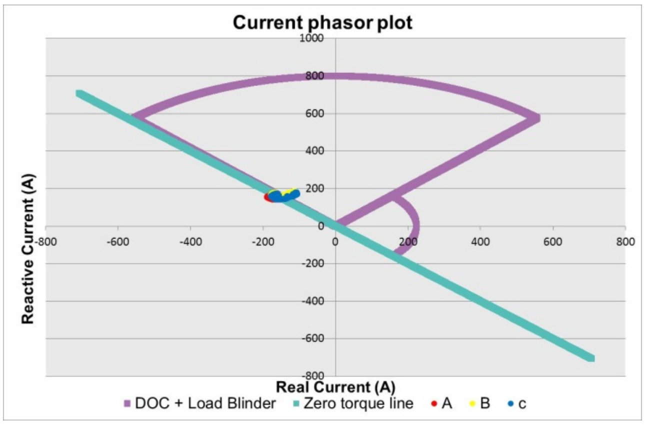

Figure 3: current-phasor plot for a recorded disturbance

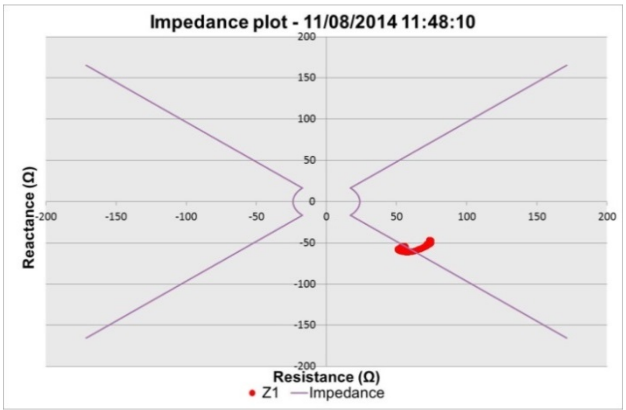

Figure 4: impedance plot for a recorded disturbance

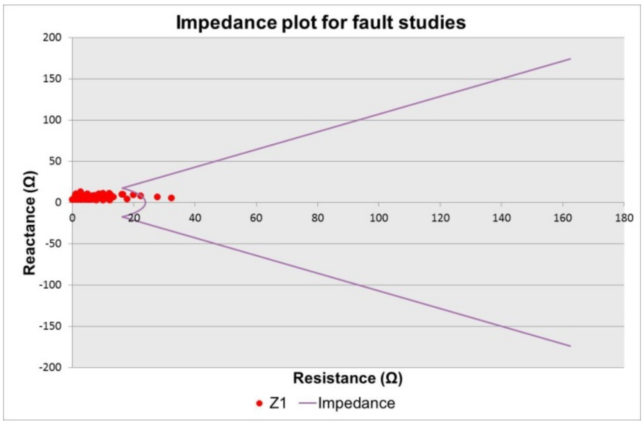

Figure 5: impedance plot for fault conditions

CONCLUSIONS

Based on the data collected from the trial, along with the fault studies undertaken, both protection schemes trialled would remain stable for all instances where the power flow into the 132kV network was caused as a result of load. The system would also respond to all fault types with fault impedances up to 100Ω.

For the DOC load blinding scheme, the following approach could be applied, if being utilised as backup protection for 132kV circuits:

- Standard DOC setting;
- The minimum load impedance (Z Impedance) can be determined using the following equation:

$$Z\ Impedance = \frac{Rated\ Primary\ Voltage\ (Ph - Ph)}{\sqrt{3} \times CT\ primary\ rating}$$

- A load blinder angle (Z angle) of 47° should be used for instances where the RCA is 45°;
- The under-voltage setting (Blinding V< Block) can be taken as 0.7 of the nominal phase-line voltage;
- The NPS setting (Blinding I2> Block) can be taken as 0.38 of the CT primary rating.

For the combined DNPS and DVDO scheme, the settings for the DNPS scheme would be taken as 50% of the minimum negative phase sequence and checked to ensure this is greater than 120% of the standing NPS eves. The setting for the DVDO scheme can be taken as 0.7 of the nominal phase-phase voltage.

However, for both schemes, there is concern that the standing levels of NPS could affect the stability of the system, which was illustrated by the high NPS currents measured at Peterborough Central. There is also very little data available on the actual levels of NPS that would be generated in various fault conditions. For the DOC with a load blinder scheme this is somewhat mitigated by the use of the positive sequence impedance and the under voltage settings.

Following the completion of the trial, the DOC load blinding scheme was implemented at March grid, as this most closely resembled the DOC scheme for which staff have confidence in the operation and testing. At Peterborough Central, the DOC automatic disabling scheme remains.

MISCELLANEOUS

Acknowledgments

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