DISTRIBUTED GENERATION CONNECTIONS UNDER A FAULT LEVEL ACTIVE NETWORK MANAGEMENT SCHEME

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ABSTRACT

This paper describes the process used for monitoring fault levels on the 11kV network and how the data gathered can be used to inform an Active Network Management (ANM) scheme. The paper will demonstrate the possible control strategies, system requirements and benefits of using real-time fault level data to actively control Distributed Generation (DG) on a primary distribution network.

INTRODUCTION

In line with the UK Government's plan to reduce carbon dioxide emissions, low-carbon generation technologies are increasingly being connected to the distribution network. This integration of DG increases network fault levels and can consequently trigger significant network reinforcement such as replacement of primary circuit breakers. Prior to connection, system studies are performed to estimate the impact of the proposed DG on fault levels. These studies are typically carried out on a desktop basis using static worst-case conditions without considering the dynamic operation of the network and the performance of other connected DG. This can often lead to a very conservative estimation of fault level despite capacity being available for a large percentage of time during normal operation.

FlexDGrid [1] is a Low Carbon Networks Fund innovation project which focused on enhancing fault level modelling processes and capturing real-time fault level data through the trial and installation of Fault Level Monitors (FLMs) on the 11kV network in Birmingham, UK.

The enhanced approach deployed by FlexDGrid to monitor the network fault levels on a real-time basis has provided a more detailed understanding of dynamic fault levels on the distribution system. Using the FLM technology it is possible to monitor the real-time fault level on the distribution system and provide a flexible connection scheme to customers. In this way, customers are likely to connect to the network more quickly, with network reinforcement being deferred or even discarded.

TECHNOLOGY FOR MEASURING FAULT LEVELS

Ten FLMs were installed on the 11kV network around the centre of Birmingham, UK, as part of FlexDGrid. The FLM is a hybrid device [2] combining an S&C Electric Company IntelliRupter medium-voltage switchgear with a resistor bank and PM7000 power quality monitors to measure and capture real-time fault level. The IntelliRupter operates as a fast-action recloser to create a very short, controlled, phase-phase disturbance on the 11kV network through the resistor. This Artificial Disturbance (AD) is recorded and analysed through the PM7000 units that estimate the peak make and RMS break fault currents at that particular moment in time. Figure 1 shows a simplified single-line diagram of the FLM.

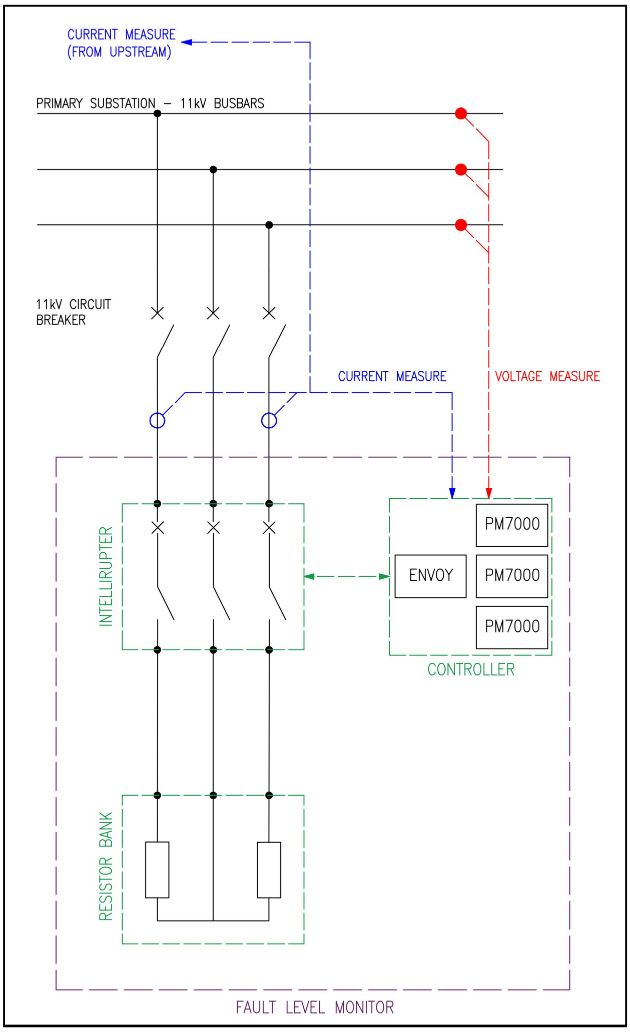

Figure 1: Single-line diagram of FLM

For FlexDGrid, the FLM was programmed to pulse at six-hour intervals and therefore data was collected for four ADs per day. The FLM would also record any other disturbances on the network such as faults or the connection/disconnection of large loads/generation. These are designated as Natural Disturbances (NDs).

FAULT LEVEL DATA

The data captured by an FLM is sent to an iHost system via GPRS for storing and further analysis. Figure 2 shows an example of the data that can be retrieved from each FLM. The four AD measurements can be seen as "spikes" in the graph as they represent high levels of confidence in the fault level data. This is due to the predictable ADs causing larger disturbances as compared with an ND.

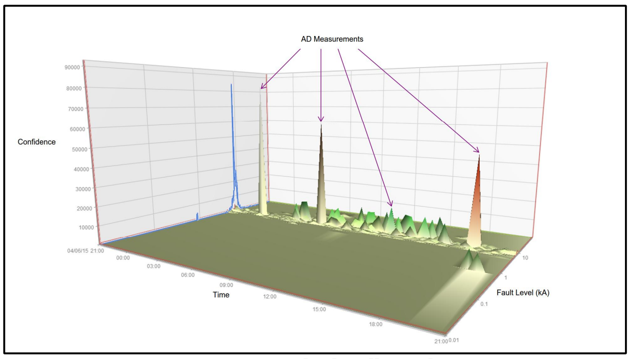

Figure 2: AD Measurements at Chad Valley 11kV

Fault level data measurements have been analysed over a period of 15 months for the 10 FLMs connected under FlexDGrid [3]. Analysis has shown that the FLM AD fault level data corresponds with changes on the 11kV distribution system. Figure 3 shows an example of Kitts Green substation whereby the peak fault level will reduce during times when the load at the substation decreases. In this example a large industrial load was switched off during a bank holiday.

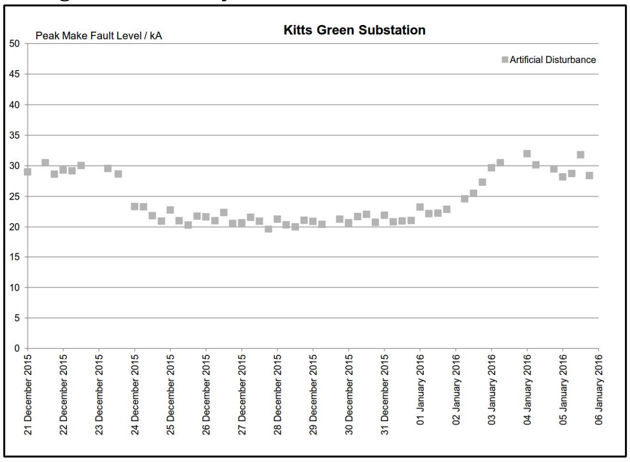

Figure 3: AD Measurements for Kitts Green Substation

FLM MEASUREMENTS FOR ANM SCHEME

The results from the initial analysis carried out for FlexDGrid indicated that it could be possible to use the measured fault level data to inform an ANM scheme. In this arrangement, an AD would be triggered to produce a real-time fault level measurement. The measured AD peak fault level and AD RMS break fault level can be used to determine the amount of fault level headroom available at that particular moment in time.

FlexDGrid has trialled a customer generation connection with a soft-intertrip driven by the results of an FLM [4]. The scheme involved an existing FLM installed at Nechells West 132/11kV substation. The control of the FLM was modified so that an AD could be triggered on demand to provide real-time fault level measurement. The measurement values are displayed in Western Power Distribution's (WPD) Network Management System (NMS) allowing Control Engineers to make a decision as to whether the generator needs to be constrained. The Control Engineer has the ability to trigger an AD operation and produce an AD measurement whenever the need arises (for example when the network configuration has changed).

ANM TECHNICAL REQUIREMENTS

Fault Level Measurement

The type of ANM constraint scheme for flexible customer connections could be dependent on a number of variables associated with thermal or voltage limitations. In most cases, monitoring of power flow and/or voltage can be achieved through the use of existing current and voltage transducers. Flexible connections under fault level constraints require the installation of an FLM before an offer can be made. The connection of the FLM prior to connection allows the Distribution Network Operator (DNO) to perform AD measurements to verify the fault levels under different operating conditions. Access to real-time data allows the DNO to have full visibility of the network fault levels and offer flexible connections.

Fault Ratings

Understanding the fault ratings of equipment is important so that the limits of the ANM constraint scheme can be determined. The DNO will need to make an assessment of both the peak make and RMS break ratings for each component of the network. Using this information, the DNO can determine the most appropriate rating to use in the ANM constraint scheme (often limited by the lowest rated item of equipment connected in proximity to the busbar being monitored for fault level). Figure 4 shows an example of a 132/11kV substation with short-time withstand ratings for each item of equipment. It can be seen that the primary 11kV busbar has equipment rated at 25kA (RMS break), however, a distribution substation on the first leg of an 11kV feeder has a Ring Main Unit (RMU) with a rating of 13.1kA. Therefore, fault level any greater than 13.1kA on the primary busbar could result in the distribution substation having a fault level above the short-time rating due to the close proximity to the primary busbar.

DNOs may already have a policy which determines the maximum fault level at particular voltage levels on the distribution system. This is normally instigated from a safety aspect whereby the ratings of customers' equipment installed beyond the Point of Connection (PoC) may not be known. In this instance, the policy values can be used as a limit for the ANM scheme.

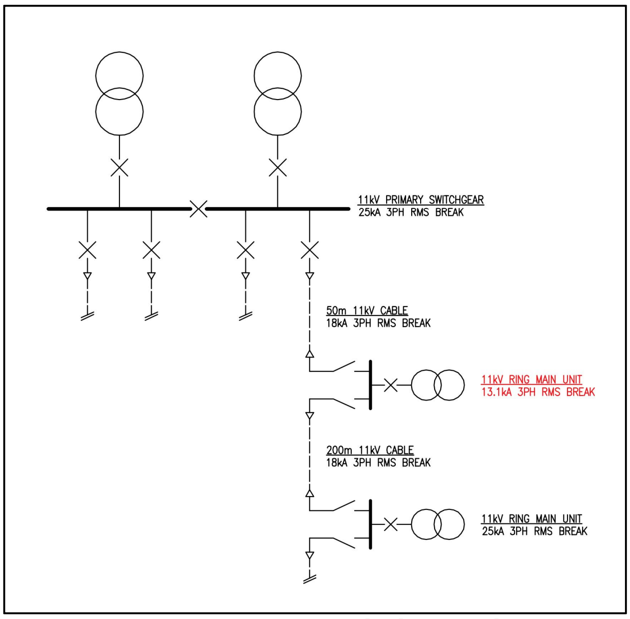

Figure 4: Equipment ratings on a typical 11kV network

Constraint Panel

The constraint panel acts as the ANM interface between the DNO and the customer allowing control of the circuit breakers supplying the generator(s). The panel installation forms part of the customer's flexible connection and in the simplest form would act to disconnect the generator(s) when the Control Engineer is informed by FLM data that fault levels have, or will, exceed the fault rating. The constraint panel could also be modified to allow for different control strategies such as those discussed later in this paper.

Communications

There are two different elements of the ANM scheme that require a communication system: the FLM and the constraint panel.

The communication system implemented for the FLMs connected under FlexDGrid utilised a third-party iHost system for collection and storage of fault level data. For an ANM application, a direct communication link to the NMS is required so that the real-time fault level can be instantaneously displayed for the Control Engineer. In addition, it is important to monitor the health status of the FLM to ensure that, if required, an AD operation can be instigated and a real-time fault level measurement taken.

The standard DNO Remote Telemetry Unit (RTU) can be used as the communication system for the Constraint Panel. The RTU shall be equipped with a number of hardwired input and output contacts to allow the system to monitor and control circuit breakers and/or power factor. The reason for the more robust communication system for the constraint panel is due to the higher sensitivity compared with the system for collecting FLM data. If the FLM data communication system fails or the information from it is delayed, then the Control Engineer can make a decision based on this. However, for the control of the generator, it is important that the system responds immediately and predictably so that fault levels can be kept within ratings. Both systems should, however, have a high degree of accuracy so that the Control Engineer has confidence in the data and feedback received.

An overview of the ANM technical design can be seen in Figure 5.

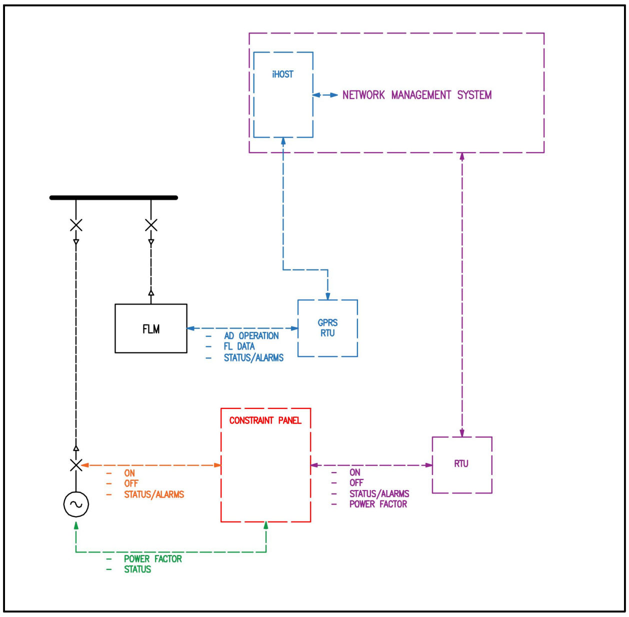

Figure 5: Example overview of ANM design for generator control

CONTROL STRATEGY

As part of FlexDGrid, studies were carried out to understand the sensitivity of fault level assessments on HV networks [5]. The results of this showed that the power factor of a generator and the tap position at the primary substation could have a tangible impact on fault levels on the network. Hence, the ANM scheme for flexible generator connections could include these options in addition to generator disconnection and network reconfiguration. The following paragraphs describe the main points to consider when deciding which control strategy to adopt.

Generator Disconnection

The simplest option available for actively controlling fault level is to disconnect generation therefore reducing fault level infeed. One of the main points is to consider which generator needs to be disconnected and when.

In a distribution system there may be more than one DG connected to the same primary substation. The easiest, and perhaps fairest option would be to disconnect the generator that was the last to connect to the system and therefore most likely to have initiated fault levels exceeding ratings. Despite this being the fairest option, it is worth noting that this may not be the most efficient in terms of overall system operation. For example, the disconnection of a smaller generator may reduce fault levels to an acceptable level whilst keeping larger generators connected and providing vital MVA/MVAr support to the system.

It is recommended that the DNO prepares a constraint table for each substation which details the generation and actions that need to be taken to safely maintain fault levels within ratings. WPD has successfully trialled this option by use of a "soft-intertrip" to disconnect a generator when fault levels exceed pre-defined limits [4].

Network Configuration

One option for controlling fault levels without interfering with generators would be to reconfigure the network. Using FLM data, the Control Engineer could manually reconfigure or enable an auto-switching scheme to reduce fault level infeed.

There are two main methods that can be used to instigate reconfiguring the network, one pre-fault and the other post-fault. In the first method, the FLM AD operation would be used to determine if the fault level needs to be reduced. Depending on the results of the fault level data against the predefined ratings, the network would be reconfigured by opening either a bus-section, incoming transformer circuit breaker or other source of network infeed (such as an interconnector). Following reconfiguration, another FLM AD measurement can be taken to verify the impact of the changes.

The alternative method is to reconfigure the network following a fault. In a trial by Electricity North West (ENW) in the UK, an adaptive protection scheme is being used to reduce fault levels before the fault is cleared [6]. The scheme operation can be summarised as follows:

1. A fault occurs on an out-going feeder, and the fault is detected at the primary substation;
2. The protection at the primary substation first opens either the bus section or the incoming transformer circuit breaker. The fault level on the affected busbar is immediately reduced as it now has one less source infeed; and finally,
3. The feeder circuit breaker feeding the fault then opens.

Each method has its own individual merits and drawbacks. For example, the pre-fault scheme has the ability to control fault levels before any faults occur on the system but consequently may reduce system security for long periods of time. The post-fault scheme ensures that system security is only reduced when faults occur, however, faults can be held on the system for longer to allow for the scheme to operate.

Tap Position

Studies previously undertaken for FlexDGrid have shown that adjustment of the primary busbar voltage can result in a reduction of three-phase fault levels by up to 6% [5]. Therefore, it is possible to have an ANM scheme which can actively control voltage to ensure that fault levels do not exceed equipment ratings. To ensure that modelled values are consistent with real-time fault levels, an FLM could be connected to the appropriate busbar to measure these values.

Adjusting primary system voltages could however have a detrimental impact on the downstream network. The ANM scheme would therefore have to ensure that any adjustment at primary level would not result in customers' voltages falling outside the prescribed limits.

Power Factor

Sensitivity analysis has shown that controlling the power factor can have a large effect on fault level [5]. Adjusting the power factor of a generator from unity to 0.95 lead can result in a reduction in fault level of up to 7%.

Providing a flexible connection on this basis would first of all require a customer that has a generator capable of controlling the power factor. A closed feedback loop would need to be established to allow the generator's power factor to be adjusted with respect to the fault level requirement. System studies would be required to determine the modelled effect of adjusting the power factor under varying system conditions. An FLM would provide a means of ensuring that the new power factor set points result in the expected fault levels at the primary substation.

One of the main drawbacks of this system would be the need to persuade a DG customer to implement a system that allows the DNO to intermittently control their generator's power factor. However, this could be a more attractive option compared with being disconnected when fault levels dictate. The system requirements would need to include the ability to constantly monitor the power factor and allow new set points to be established in short timescales without necessarily notifying the customer prior to implementation. In addition, it would be necessary to ensure that the alteration of the power factor would not result in power flows and/or voltages which could cause a detrimental impact on other parts of the network.

SYSTEM OPPORTUNITIES

Commercial

Implementing a DG connection using an ANM scheme requires the customer to be assured that the arrangement will offer a quicker, more efficient connection compared with a scheme that requires system reinforcement. The Electricity Networks Association (ENA) in the UK has established a Working Group (WG) primarily studying how to offer this type of connection. The ANM WG has identified that a curtailment study should be produced for each connection to understand the frequency and level of constraints that could be applied [7]. This approach is in alignment with current market trends with respect to the active management of DG [8].

Although additional infrastructure will be required for installation of the ANM scheme (including the communications and interface panels), the cost of this infrastructure is likely to be much less compared with the required contribution towards network reinforcement. The difference in cost of network reinforcement versus possible curtailment costs (in MWh) can be analysed over the period of the generator life cycle to allow the customer to determine the expected cost benefit.

Operation

To date, only a limited number of connections have been offered using a flexible ANM scheme for fault level. The scheme offered under FlexDGrid has proven to be reliable although has not had to operate to constrain generation since being energised.

Further learning through the connection of additional DG under an ANM scheme would allow future systems to be improved through:

- Understanding FLM data in more detail and increasing the accuracy of AD measurements;
- Capturing and recording actual curtailment instances and durations;
- Development of more sophisticated control strategies such as power factor generator control; and
- Implementing systems which rely more on automatic actions rather than manual operation through a Control Engineer.

The installation of further ANM schemes for fault level could also help to improve customers' confidence in the system.

CONCLUSION

The development, installation and trialling of FLMs has significantly increased the understanding of real-time fault levels. The results from the fault level data analysis have created a basis on which fault level constraint schemes can be offered to customers.

This paper has described a number of steps that need to be considered before offering a customer a fault level dependent ANM connection. The most important aspects surround the verification of fault level data by using an FLM and ensuring a robust interface is installed between the customer and the DNO.

Although ANM using fault level data is in its infancy, there are clear benefits for potential DG customers. As additional schemes are connected using this method, further learning is likely to increase customer confidence and encourage more connections of this type.

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