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GUIDELINES FOR ACTIVELY MANAGING POWER FLOWS ASSOCIATED WITH THE CONNECTION OF A SINGLE DISTRIBUTED GENERATION PLANT

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CONTENTS PAGE

GUIDELINES FOR ACTIVELY MANAGING POWER FLOWS ON DISTRIBUTION NETWORKS

1 PURPOSE

The purpose of this Engineering Technical Report is to provide Distribution Network Operators (DNOs) with guidance on how to employ Active Management solutions to overcome power flow limitations associated with the connection of a single Distributed Generation (DG) plant. The solutions presented in this report should not be seen as prescriptive or exhaustive in that there could be circumstances where a DNO is unable to accept the solutions proposed here; or the DNO may wish to employ an alternative solution that will allow higher levels of power flow export than that which would be allowed under the solutions described in this report.

Note: Active Management solutions are designed to optimise the utilisation of distribution networks in terms of their capability to accept the connection of Distributed Generation. In this respect Active Management solutions are one of the methods available to help facilitate the connection of more distributed generation in support of Government targets for renewable generation and CHP.

2 SCOPE

The solutions described in this Engineering Technical Report are based on a project carried out for Future Energy Solutions (FES) on behalf of the DTI, by EATL [Ref 1]. The FES project considered three areas where basic active network management techniques could facilitate the connection of more Distributed Generation: Fault level management, Voltage control management and Power flow management. This report only considers solutions to overcome power flow Constraints associated with the connection of a single generation plant. However, when a network designer is assessing the connection requirements for Distributed Generation it will also be necessary to consider Constraints associated with voltage control and fault levels, solutions to these two issues are out of scope for this report.

The principles described in this report though written for single Distributed Generation (DG) installations can be extrapolated to cater for networks with multiple DG installations, however the possible need for scheduling and other commercial arrangements are outside of the scope of this report.

This report describes conceptually four solutions for increasing the utilisation of the power flow capability of the distribution network, treating each solution as a stand-alone option as an alternative to overcoming power flow constraints by traditional reinforcement.

The solutions and guidance provided in this report should not be seen as being prescriptive; it will be for the DNO to determine if the solutions as described here can be implemented for any particular situation on the network. In making this determination the DNO will be expected to consider the ratings of plant both in the forward and reverse direction. It is also the responsibility of the DNO to ensure that the network remains compliant with the requirements of the Distribution Code [Ref 2] and the ESQC Regulations [Ref 3]. This report also provides guidance on situations where a particular solution is most likely to be suitable.

The solutions described in this report are generally applicable to Distributed Generation plants connected to high voltage networks supplied by two or more circuits operating in parallel at 132kV or below. Although not described in this report it is possible to apply some of the principles of the solutions described here to single circuit connections.

3 DEFINITIONS

For the purposes of this Engineering Technical Report the following definitions apply.

Note: Defined terms are capitalised where they are used in the main text of this report.

Active Management
The methodology by which the DNO and the Generator monitor their respective plant with the intention of reacting to network or generation changes in order to ensure that the network and generation continue to operate within safe and prescribed limits, where monitoring means manual, electronic or any other form of monitoring that is suitable for the particular installation.

Arm
To activate a mechanism for implementing a network Constraint when the value of the monitored parameter exceeds the set operating point.

Constraint
A condition where the Generator has agreed to reduce the export from his Distributed Generation plant in some way in accordance with the requirements of another party, for the solutions described in this report the other party will normally be the DNO.

Demand – agreed (D)
Where D is the agreed value of demand, of the substation or network node, which is used as part of the calculation for determining the acceptable level of export from a Distributed Generation plant under the relevant Active Management solution.

Demand – actual (d)
Where d is the instantaneous value of demand, of the substation or network node, which is used as part of the calculation for determining the acceptable level of export from a Distributed Generation plant under the relevant Active Management solution.

Distribution Network Operator (DNO)
The organisation that owns and/or operates a distribution network and is responsible for agreeing the connection of Distributed Generation to that network. A DNO might also be referred to as a Distributor.

Note: For the purposes of this report the term DNO also includes the owners of the Scottish 132kV and lower voltage networks.

Distributed Generation (DG)
A generating plant connected to the distribution network. Where a generating plant is an installation comprising one or more generating units.

Firm Capacity

The capacity of the section of network under consideration following a first circuit outage (FCO).

Note: The firm rating may be other than the continuous rating of an item of plant / equipment, it may be a cyclic rating or a short duration emergency rating, i.e. it depends on the specification of the transformers and the circuit. Cable circuits are normally rated for cyclic loading therefore they may not be comparable with the continuous rating of a transformer.

Generator

A person who generates electricity under licence or exemption from Section 4.1(a) of the Electricity Act 1989 or the Electricity (Northern Ireland) Order 1992.

Intertripping

The communication of a trip signal between two or more nodes on a network designed to ensure that sections of network and / or Distributed Generation are correctly disconnected in response to commands, where these commands may for example be issued in response to a protection operation.

4 BACKGROUND

4.1 Introduction

One of the roles of a DNO is to manage the risks associated with network power flows. For example, power flow becomes a risk management issue when the Distributed Generation capacity connected to the network exceeds the Firm Capacity of the network to which it is connected. Under these circumstances, network assets are at risk of being operated above their rating (and therefore at risk of failing) following a circuit outage.

When assessing the rating of plant and circuits it is necessary to look at all possible conditions of operation, for example the ambient temperature and the short term rating of equipment. Additionally for plant, particularly transformers, it will be necessary to consider if there is any limitation on rating for reverse power flows. When determining an appropriate transformer rating, consideration should be given to the rating without cooling fans and pumps operating (as these auxiliary items are not designed for long term continuous operation) and whether there are any ambient temperature limitations (as in the case of continuous emergency rated (CER) transformers). When operating any CER transformer at its oil natural air natural (ONAN) rating (e.g. 24MVA on a 12/24MVA unit) it is necessary to have the fans and pumps running all the time.

Power flow management takes into account the capacity and security of the network for both an intact system and following circuit outages. A first circuit outage (FCO) event can be either a planned event (e.g. due to network maintenance or network development) or unplanned (due to faults). A second circuit outage (SCO) event almost always refers to a fault occurring on a network that has suffered a FCO.

4.2 Pre-Outage (pre-fault) Constraints

4.2.1 Application

The traditional method of assessing the level of Distributed Generation allowed to connect to the system is to limit the power flow in to the network to the capacity of the network that would be available under first circuit outage (FCO) conditions, i.e. the Firm Capacity of the network. This is described as a “pre-outage Constraint” (sometimes referred to as “pre-fault Constraint”) because it requires the generation output to be limited to the “post outage network capacity” prior to the network outage actually occurring i.e. pre outage. Considering a network comprised of two parallel circuits of equal rating (i.e. N = 2) this approach allows the DG plant to continue generating at full output for both an intact system and following a FCO.

It is likely that under conditions of FCO, whether it is planned or unplanned, the Generator will be required to reduce the output from the DG plant to a level at or below the second circuit outage (SCO) capacity of the network or shut down completely for the duration of the FCO. In this way, the network is not placed at any risk should a SCO occur.

This approach can be seen as a passive solution to power flow management; the "pre-fault Constraint" method provides the signal for network reinforcement in order to allow the Distributed Generation to operate at the desired level of output largely irrespective of FCO outages.

Considering the example network shown in Figure 4.1 below, the maximum allowed Distributed Generation (DG) capacity that could be accommodated on the network, in terms of power flow, would be restricted by conventional network design methodology to the Firm Capacity of the 11kV busbar, which in this case is 12MVA. Upon a FCO, the DG could continue to generate 12MVA.

Following a FCO, (planned or unplanned), there would generally be no need to apply a pre-fault Constraint to disconnect the Distributed Generation because a SCO would usually result in the DG being tripped off by action of the loss of mains protection.

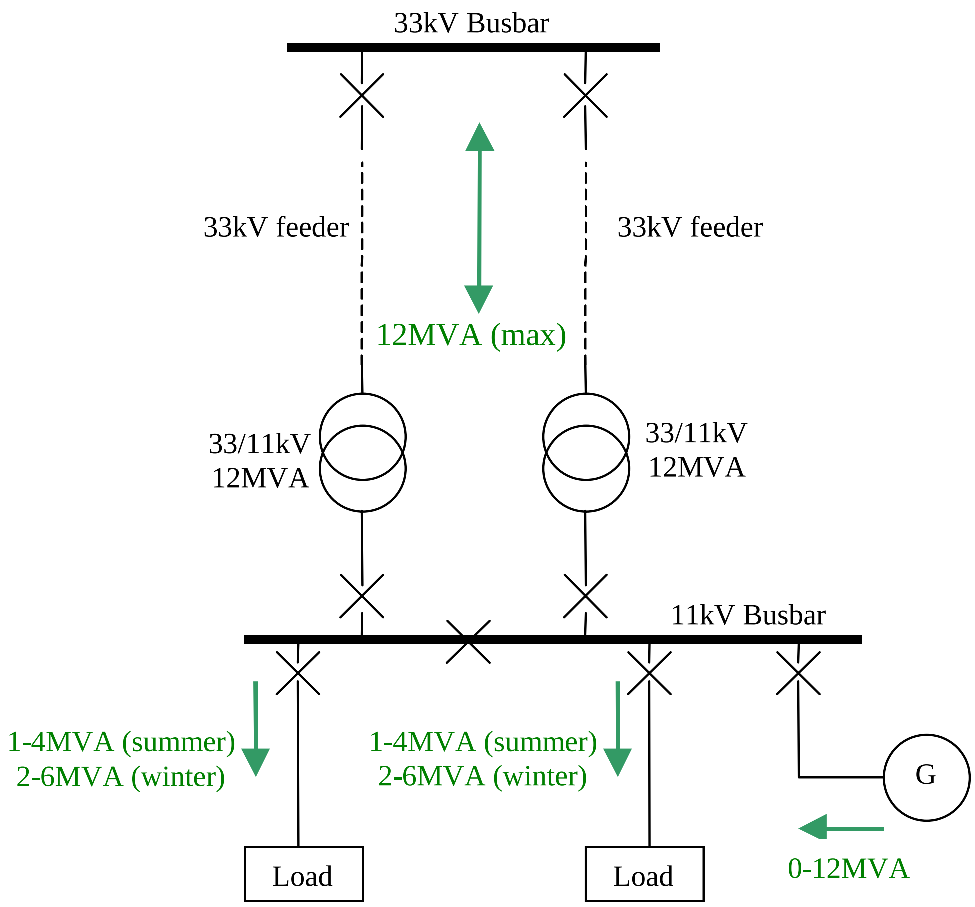

Figure 4.1: Network power flows

Note: All circuit breakers are assumed closed unless otherwise indicated.

The connection of a Distributed Generation plant with a capacity requirement larger than 12MVA would normally be achieved either by connecting the generator at a higher voltage level or by reinforcing the network in order to increase the network Firm Capacity. For this example, the reinforcement would involve uprating the two circuits and / or the transformers or by installing an additional circuit / transformer.

4.2.2 Use of Demand Levels

It is possible to gain an increase in Distributed Generation (DG) connection capacity by taking into account the local demand on the primary substation. If the substation minimum demand is taken into account, allowed DG capacity can be increased to 14MVA (i.e. 12 + 1 + 1). In this example it is assumed that the substation plant can accept 100% reverse power flow, noting that in reality this will need to be checked both in terms of protection settings and plant reverse power capability.

This opportunity for increasing the level of capacity could be further refined by the use of summer and winter minimum demands, where a winter minimum demand of 2MVA per circuit would increase the maximum Distributed Generation (DG) capacity still further to 16MVA (i.e. 12 + 2 + 2). Noting that the DNO is unable to guarantee that demand will always remain at or above a particular level, i.e. it is feasible that this demand could reduce or increase over time and so reduce or increase the acceptable level of export. With this example, it would be necessary during the summer months or other periods of low demand, to maintain the output Constraint of 14MVA. These Constraints would need to be actively managed to ensure that the DG output never exceeded the Firm Capacity of the substation plus the substation demand.

4.3 Post Outage (post fault) Constraints

An alternative approach to the pre-outage Constraint approach described in 4.2 is to apply a "post outage Constraint" that limits Distributed Generation output to the "post outage network capacity" after the first network outage has occurred. This would require the application of an Active Management solution. As its name implies, a post-outage Constraint is applied after a circuit outage has occurred rather than being applied in anticipation of an outage. In this way, greater generation capacity can be connected, and the frequency of application of the Constraint is much reduced. However, given the risk to the network it would be necessary to ensure that means for implementing the Constraint are reliable and will operate within the design time under all credible conditions.

The generation capacity allowed at a particular point on the network could be based on an '(N-1) plus winter demand' condition or an intact system (N) with summer minimum demand. Of these two options the '(N-1) plus winter demand' is normally the more conservative, providing a capacity margin, and leaves the local demand secured by the remaining circuit(s). Considering the example of Fig 4.1, and applying a capacity limit equalling '(N-1) plus winter demand', the allowed generation capacity could be increased to 24MVA (i.e. 6 + 6 + 12 MVA).

Recognising the potential risk posed by allowing DG capacity in excess of the traditional limit of the Firm Capacity of the substation, this report considers four scenarios and proposes four solutions: one passive solution (A) and three Active Management solutions (B, C and D) - see Table 1 below.

The passive solution has been described in Section 4.2, whilst the three active management solutions are more fully described in Sections 5, 6 & 7.

The solutions outlined in Table 1 have assumed that the substation plant can accept reverse power flow at 100% of the forward rating, for practical situations this will not always be the case and will need to be verified by the network designer.

The solutions outlined in Table 1 are based on the connection of a single Distributed Generation plant, i.e. the network in question is considered to be free of other DG plant(s). In the event that there are other DG plant(s) already on the network it will be necessary for the designer to subtract any capacity allocated to this other plant(s) from the capacity, as derived under the solutions proposed in this report, for the new DG plant.

Table 1. Increased Generator Capacity Solutions and Commentary

Solution	Scheme	Implications for Generators	Commentary on Active Management requirements
A Section 4.2	Pre-Outage Constraint	Allowed generation capacity is (N-1) plus minimum demand. There should be no Constraint on output up to the limit for both intact system and FCO. However, upon a FCO the DG must be tripped if the level of output exceeds the transformer or circuit overload capability, although in theory, this should not be the case. Applying this solution to the example in Fig 4.1, 14MVA of DG could be connected.	This solution is simply an extension of the pre-outage condition, taking account of minimum demand. The output current through the transformers / circuits should be monitored with an alarm to the DNO's control room in the event of safe limits being exceeded. Note: This solution is simply an extension of traditional planning guidelines as such it is not seen as an Active Management solution.
B Section 5	Post-Outage, Direct Intertrip	Allowed generation capacity is (N-1) plus maximum demand. With this solution a higher level of DG can be connected compared with Solution A. There is no output restriction under an intact system. Upon a FCO the DG is tripped. The DG may be reconnected, with the agreement of the DNO, with a restricted output, e.g. (N-1) plus minimum demand for the duration of the FCO. Applying this solution to the example in Fig 4.1, 24MVA could be connected.	DG Intertrip based on network availability – see section 5
C Section 6	Post-Outage, Measured Power Flow	Maximum DG capacity is (N-1) plus maximum demand. With this solution the DG has an operating range between that permitted under solutions A and B under system normal conditions. Unlike B, the DG does not need to be tripped under FCO conditions providing that the level does not exceed certain limits. Applying this solution to the example in Fig 4.1, 24MVA could be connected, but would be tripped if the level of export off the system exceeded the transformer / circuit(s) overload capability.	DG Intertrip based on power flow measurements – see section 6. The Intertripping is only armed at times when the export off the system exceeds certain limits.

Solution	Scheme	Implications for Generators	Commentary on Active Management requirements
D Section 7	Post-outage, demand following	Allowed generation capacity is '(N-1) + max demand'. As per solution C the DG has an operating range between that permitted in solutions A and B under system normal conditions, but unlike the other solutions the DG will not be tripped following a FCO because the generated output is dynamically controlled to ensure that it never exceeds the dynamic capacity of the network i.e. '(N-1) + actual demand'. Applying this solution to the example in Fig 4.1, 24MVA could be connected, and would not be tripped for a FCO, provided the generated output can reduce to within system capacity limits and within acceptable timescales.	DG output control based on power flow measurements – see Section 7

Note: (N-1) = the Firm Capacity of the substation / network in question

4.4 Issues to be considered when designing an Active Management solution

a. For all of the solutions identified in Table 1 it will be necessary for the DNO to ensure that the application of the solution does not result in the DNO's network being put at risk either in terms of safety (e.g. by operating plant or lines beyond their rating); or in terms of reliability – e.g. plant / circuits being disconnected by the operation of overload protection.

b. The decision on which solution, if any, from Table 1 should be used in any particular circumstance is for the DNO to agree with the Generator, recognising that the aim of this document is to provide guidance that will help inform the decision making process without constraining either party.

c. As an alternative to Intertripping or disconnecting all Distribution Generation plant, it might be possible for the output from the Distributed Generation (DG) to be constrained such that following a FCO the output is reduced to a level that is still acceptable to the DNO hence there would be no need for the DG to be disconnected. Before accepting constraining as an alternative to Intertripping the DNO would need to verify that the time delay associated with the DG plant implementing a constraining action would not lead to any network components operating beyond their rating or the unnecessary operation of protection schemes. Intertrips would then be applied as a backup.

d. For situations where solutions A – C have been employed it may be possible, following a FCO, to bring the DG plant back on line but operating at a reduced level for the time that the FCO remains in place. Any such arrangement would need to be agreed between the DNO and the Generator, ideally at the time of agreeing the Connection Agreement.

e. The DNO and the Generator will need to agree on the level of backup required to cater for failure of the main Intertripping arrangements or failure of the Distributed Generation's control system.

f. It is suggested that any Active Management arrangements / agreements are recorded as an appendix schedule to the Generator's Connection Agreement.

g. Loss of generation export will occur during periods of Constraints - see 4.5.2 c).

h. Some DNO's, through local network conditions, may be able to consider a connection based on N for generation, rather than (N-1), whilst still maintaining (N-1) security for demand customers. This report does not preclude such considerations. Consideration of the addition of local demand to the export capability would be inherently limited to d in this case, and would have to be carefully assessed.

4.5 Possible Implications

Power flow management in the form of generation power reduction or Intertripping is a technically viable alternative to network reinforcement in many circumstances. However, there are implications at both the "planning" and "operational" level. The main issues can be summarised as:

4.5.1 Implications for Customers

These power flow management solutions increase the frequency at which Generators would be required to vary their output to the network. This could lead to a small increase in the number of voltage step changes. The frequency of such events would be higher for networks with higher fault rates. For normal operation of the network the resulting voltage changes should not exceed the limits specified in Engineering Recommendation P28 [Ref 5].

4.5.2 Implications for Distributed Generators

a. Whilst it may be desirable to actively manage the electrical output of Distributed Generation this may not always be feasible for types of generation, e.g. CHP generation which are very often heat led installations.

b. The solutions proposed in this Engineering Technical Report may result in a reduced overall connection cost since system reinforcement may not be necessary. There is always a balance to be struck between the cost of the connection and the Distributed Generation capacity that can be installed. In order to optimize this trade off it is important that the Generator and DNO discuss the connection and the Generator's scheme at an early stage in the application process.

c. Loss of generation export will occur during periods of Constraints. This may be for a limited period in response to a maintenance outage or for a more extensive period where the network is being developed or to repair a network fault. In addition there may be times where the Distributed Generation has to be constrained off due to outages on the Active Management system itself.

d. The solutions proposed in this report could have implications for the potential for a Generator to provide a contribution to network security or to participate in ancillary service markets.

e. Distributed Generation (DG) that could otherwise be able to remain connected and generating following a FCO might become disconnected because loss of mains protection or under voltage protection may be over sensitive in that it operates unnecessarily for a distant network fault. This condition is not peculiar to actively managed DG.

4.5.3 Implications for Distribution Network Operators

a. The DNO will need to consider the consequences in terms of safety and network integrity if the Active Management solution fails to operate. This may result in the DNO specifying a resilient form of backup to the Intertripping scheme or real time monitoring designed to immediately constrain or disconnect the Distributed Generation plant if the Intertripping scheme failed.

b. The introduction of an Active Management solution could mean that it is necessary to review the clearance times for circuit / transformer protection in order to ensure that there is a sufficient margin between this protection and the Intertripping scheme for disconnecting the Distributed Generation.

c. The technical and commercial complexity of an Intertripping scheme increases rapidly as the number of Distributed Generation plant and the number of network ‘ends’ increases. The number of network ‘ends’ is influenced by network design philosophies.

d. At the project design stage it will be necessary to take in to account the consequences surrounding planned and unplanned outages of the Intertripping scheme, particularly unplanned maintenance related to communication link service-provider issues. Under these circumstances it is expected that the Generator will be requested to disconnect or cease generating or be constrained to a lower output level for the duration of the maintenance.

e. It may be necessary to introduce new real-time monitoring, control and communication systems, as well as software and hardware in the DNO’s control room. This will become more important as the number of Distributed Generation plants, connected within individual network groups, increases.

f. For unplanned events the connection / disconnection of a Distributed Generation plant should not result in a voltage step change beyond the limits specified in clause 6.1 of ER G75/1 [7], i.e. *Step Voltage Changes caused by the connection and disconnection of Generating Plants from the Distribution System, should be ±3% for infrequent planned* *switching events or outages (in accordance with Engineering Recommendation P28) and ±6% for unplanned outages such as faults.*

4.6 Power Flow Management in Interconnected Networks

The design approach used in interconnected networks is different to radial network design and therefore the implementation of power flow management solutions will need to be slightly different.

In traditional radial networks it is often the case that primary transformers are located in pairs in order to ensure compliance with Engineering Recommendation P2/5 [Ref 6]. In some interconnected networks, single transformer substations are connected together in groups of three, four or five. If more capacity is required to service demand, additional transformers are inserted into a new node in the network. If this insertion creates a group with six transformers, this group is then split to create two groups of three. In this way, interconnected networks are designed to cope well with a certain level of “organic” growth and in this way manage fault levels and power flow “automatically”. However, some interconnected networks work with smaller unit sizes (e.g. single 33/11kV, 7MVA transformers as opposed to 12 + 12MVA transformer pairs) therefore the scope for increasing connection capacity for Distributed Generation at single nodes is more limited.

When specifying Intertripping and the necessary back-up / monitoring schemes for an interconnected network, the DNO will need to give due consideration to the risk of a cascade failure should the Intertripping scheme fail to work as expected.

5 GENERATION INTERTRIP BASED ON NETWORK AVAILABILITY

5.1 Outline Description of the Solution

This solution employs direct Intertripping to actively manage the power flow from a single Distributed Generation (DG) plant. The maximum connection capacity of the DG is specified by the DNO at the design stage e.g. the Firm Capacity of the substation plus an allowance for the substation demand, i.e. ((N-1) + D). Where the maximum value that D can be set to is the maximum demand of the substation. If this solution were to be applied to the network example shown in Figure 4.1, the maximum allowable capacity of the DG would be 24MVA i.e. (12 + 6 + 6) MVA.

The benefit for the Generator is that this solution offers a higher level of connected capacity than would be allowed under the traditional planning arrangements, as described in Section 4.2. For the DNO this solution ensures that the Distributed Generation will not put the network at risk of a trip on overload following a FCO.

For an intact system, the direct Intertripping solution allows the Distributed Generation (DG) plant to connect at (N-1) + D. This is usually below the capacity of the intact system, and provides a capacity margin. In the event of a FCO, the DG (or part of the DG plant) will be tripped automatically by the direct Intertripping.

Following a FCO, either planned or unplanned, the Distributed Generation (DG) plant could be brought back onto the system to operate at ((N-1) + summer minimum demand), i.e. 14MVA for the example network shown in Figure 4.1; the procedure for reconnecting the DG plant will need to be agreed in advance between the DNO and the Generator.

In the event of a SCO, the DG plant would again be tripped off, either by operation of the loss of mains protection for a dual circuit network as shown in Figure 4.1 or by means of direct Intertripping.

Figure 5.1 shows an example of how to implement a post-fault Constraint using direct Intertripping. The Distributed Generation plant is disconnected (tripped) by Intertripping from the DNO’s substation following a FCO e.g. the loss of a 33/11kV transformer or a fault on either 33kV feeder.

It may be possible to simplify the Intertripping scheme for sections of network where there are no 33kV circuit breakers at the Primary substation or if there is some Intertripping provided as part of the existing protection system.

During periods when the Intertripping scheme is out of service (e.g. due to scheme maintenance or communications failure), the Distributed Generation will need to be operated according to the pre-fault Constraint approach (e.g. output limited to N-1 plus minimum demand) in order to protect the network from potential operation beyond its thermal rating. Also, experience has shown that in practice some false tripping of the Intertripping scheme can occur.

Examples of where this solution could be used include the situation where a Distributed Generation (DG) plant normally operates at 100% load factor and is not very controllable; or a DG plant with variable output which does not have measurement and control capabilities.

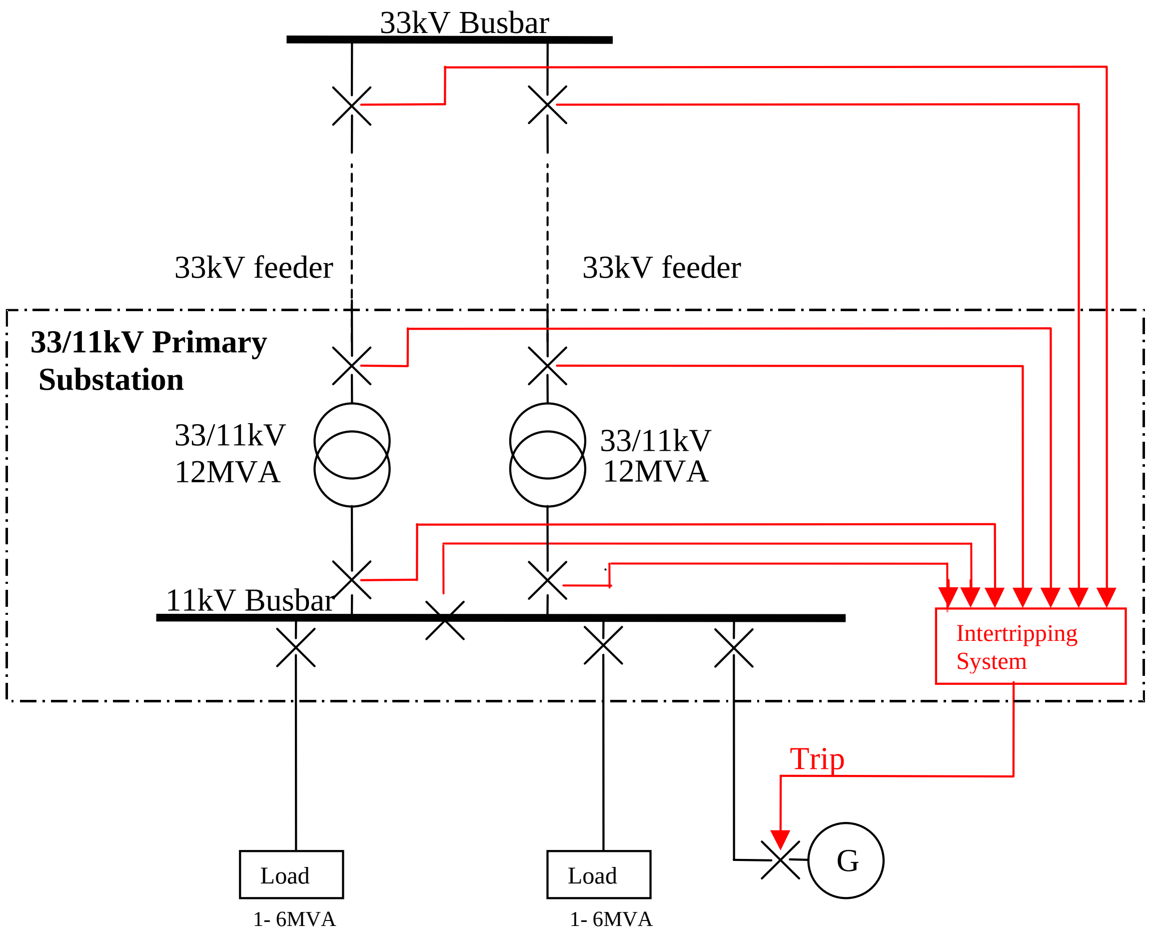

Figure 5.1: Generation power flow control based on Intertripping

Note: All circuit breakers are assumed closed unless otherwise indicated.

5.2 Communication Reliability

The use of Intertripping has the potential for fast response but its overall reliability is dependent on the reliability of the communication links between the remote circuit breakers (DNO's substation) and the Distributed Generation plant's circuit breaker. The reliability is likely to be highest when the Generator's circuit breaker and the DNO's circuit breakers share the same substation. For more remote communication, dedicated hard-wired pilot wires offer the most reliable communications solution, but this is often not practical due to cost. The most commonly used communication links are public telephone lines. These can prove to be unreliable, especially in remote, rural areas, and their cost can be high. Satellite-based communication has been used in some remote rural locations in the UK.

5.3 Intertripping Equipment

For short distances and where induction and other interference modes are known not to be a problem, a modern form of DC surgeproof Intertripping can be used. Modern types can operate (i.e. send and receive) to four ends (in total). Such equipment require metallic conductors end to end, with appropriate electrical characteristics (as specified by the Intertripping equipment manufacturer), and most systems will be capable of continuously monitoring the continuity of the metallic circuit, and generating a SCADA alarm if the equipment becomes unserviceable.

Where metallic circuits are not available (historically this has been at 132kV and above) voice frequency (VF) equipment can be used to provide the medium for communicating Intertripping signals. Such equipment will work over standard rented pilot cables from BT or other provider, and also directly over fibre optic channels where the appropriate interface equipment is used. As the communication medium is frequency keyed tones, the use of non-metallic media and multiplexing provides no impediment to this kind of Intertripping device. Again, the equipment continuously monitors the communication link and will generate a SCADA alarm if the service or equipment becomes unavailable. Traditionally VF equipment has had more than one communication (i.e. tripping) channel available, and it has been common practice to deploy two such equipments to protect a pair of transformer feeders, with a tripping signal from each transformer transmitted in each equipment – see Figure 5.2. In this way the complete loss of one set of Intertripping equipment still allows the transmission of a trip signal from either circuit.

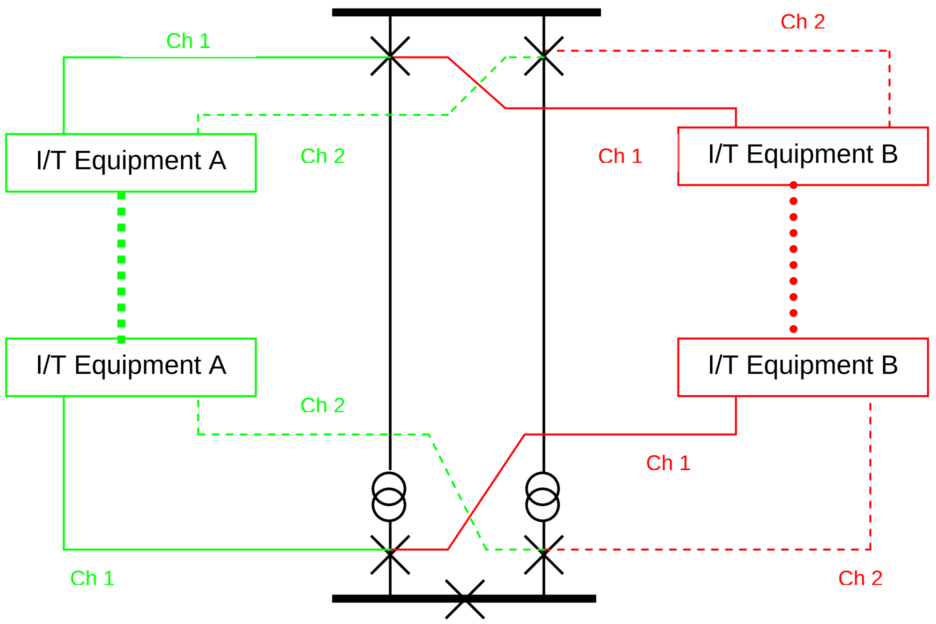

Figure 5.2: Example of duplicate Intertripping lines

Note: All circuit breakers are assumed closed unless otherwise indicated.

6 GENERATION TRIP BASED ON POWER FLOW MEASUREMENTS

6.1 Outline Description of the Solution

The principle of this post-outage approach is to measure the net export of power, through the key parts of the network, taking local demand into account, and disconnect the Distributed Generation (or part of the DG plant) if the export causes the capability of the network to be exceeded. If the net export is less than the post-fault network capacity, no trip is necessary for a FCO, therefore the Intertripping need only be Armed when the net export is greater than the post-fault network capacity. Real and reactive power flows should be considered.

The implementation of this solution is shown conceptually in Figure 6.1. As for the direct Intertrip solution described in Section 5, the maximum connected capacity of the Distributed Generation is specified by the DNO at the design stage based on the Firm Capacity of the substation plus an allowance for the substation demand i.e. (N-1) + D, where the maximum value that can be ascribed to D is the maximum demand of the substation.

If this solution were to be applied to the network example shown in Figure 4.1, the maximum allowable DG connected capacity would be 24MVA i.e. (12 + 6 + 6) MVA.

This solution calls for continuous monitoring of the substation demand or net export and only Arms the Intertrip if the export from the Distributed Generation on to the DNO's network exceeds the threshold level of ((N-1) + d), i.e. firm capacity plus the actual instantaneous demand on the substation. Noting that the threshold level will vary over time as the demand on the substation varies over time.

The Generator will be advised of the FCO condition, and will continue to generate (or not if considered inappropriate) to the level agreed with the DNO. This may be to full output with high risk of tripping, or may be at reduced output, depending on the Generator's arrangement and capabilities, e.g. for a wind farm output power can be computer controlled to remain within ((N-1) + minimum demand), or an appropriate number of turbines switched out.

For an intact system, the Power Flow Measurement solution allows the Distributed Generation (DG) plant to generate up to (N-1) + D. Considering the example in Figure 4.1, if 24MVA of DG was connected, but was only generating at 20MVA, the Intertripping would only be Armed if the demand on the substation fell below 8MVA. Therefore in the event of a FCO the DG will only be tripped if the Intertripping was Armed at the time of the FCO. If the DG remained connected following a FCO the Intertripping would be Armed in readiness either for a reduction in demand or for a SCO, noting that in the event of a SCO the DG would be tripped off, either by operation of the loss of mains protection for a dual circuit network as shown in Figure 4.1 or by means of the Intertripping.

The benefit for the Generator is that this solution offers a higher level of connection capacity than would be allowed under conventional ‘pre-outage’ planning arrangements; and it also offers an improvement over the direct Intertripping solution in Section 5 because it will not always be necessary to trip the Distributed Generation (DG) following a FCO. However this solution could be more complex to implement than the direct Intertripping solution. For the DNO the solution ensures that the DG will not put the network at risk of a trip on overload following a FCO.

Examples of where this solution may be used include a Distributed Generation plant with a variable output which may not be exporting to its full rated capacity (i.e. operates at low load factor) and which might not have measurement and control capabilities. The Generator might also choose to use this solution combined with an agreement for rapid re-start after a FCO with a constrained level of export.

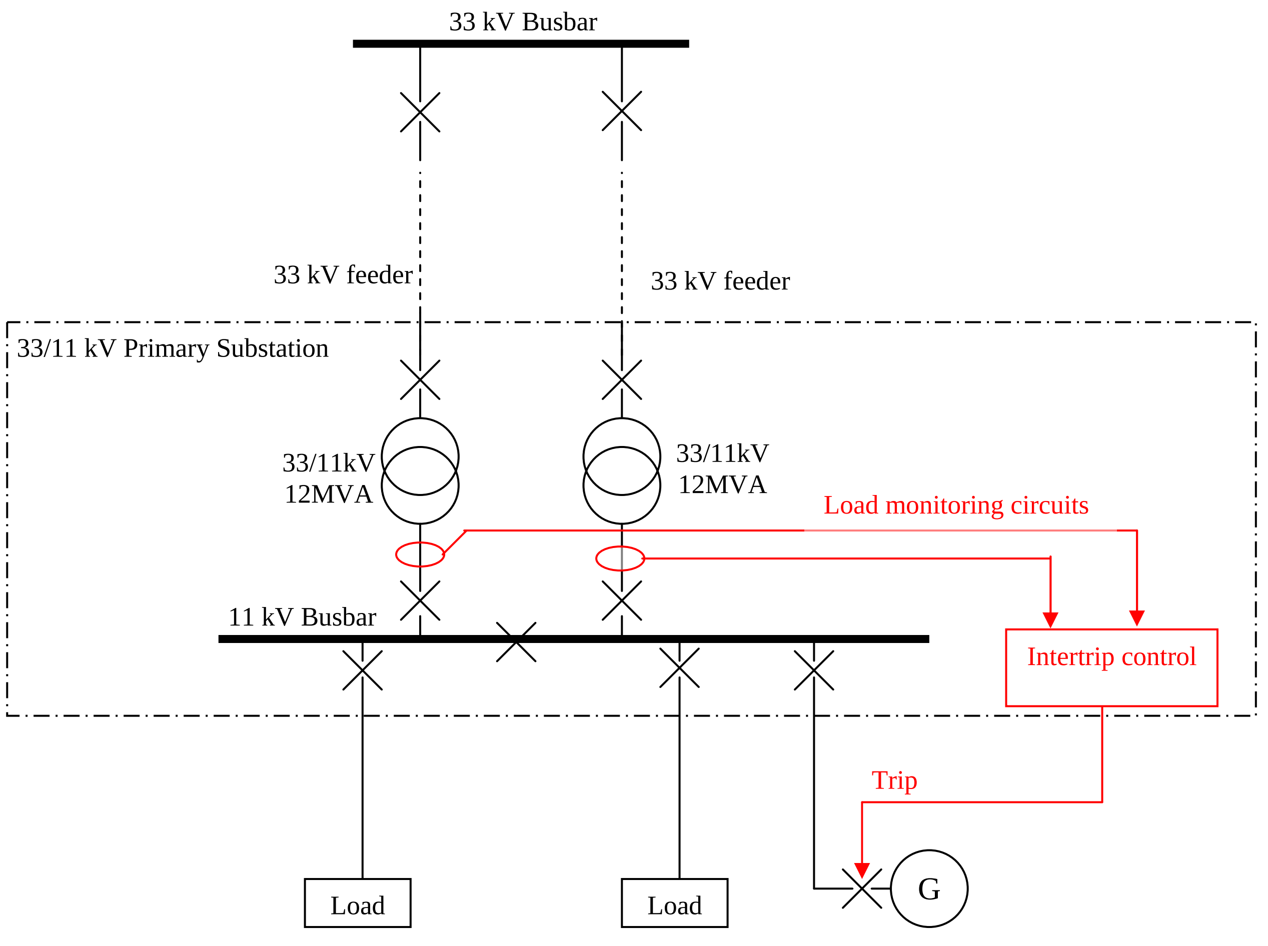

Figure 6.1 Generation power flow control based on power flow measurements

Note: All circuit breakers are assumed closed unless otherwise indicated.

7 GENERATION POWER OUTPUT CONTROL BASED ON POWER FLOW MEASUREMENTS

7.1 Outline Description of the Solution

This solution employs a more dynamic form of power flow control that requires the Distributed Generation (DG) to make a controlled reduction of its output, without exceeding the short-term power ratings of network plant taking into account the actual levels of demand. This minimises any operational Constraint on the DG and maximises the generated energy.

This solution is similar to the two solutions described in sections 5 and 6 above, in that the maximum connected capacity of the Distributed Generation (DG) plant is set at the Firm Capacity of the substation plus an allowance for demand. However with this solution the demand (d) is the actual demand on the substation / network node at any point in time. Therefore this solution calls for measurement of the demand and then the use of this measured value to ensure that the DG output onto the DNO's network does not exceed the Firm Capacity of the substation plus the instantaneous demand i.e. (N-1) + d.

With this solution it will not be necessary to disconnect the Distributed Generation (DG) plant in the event of a FCO. Controlling the output of the DG plant in this way should ensure that the generated output present at the time of the FCO will not cause any plant or circuit to become overstressed. The Generator will be advised when a FCO condition is present, this could be by automatic signal.

The implementation of a power reduction scheme for a Distributed Generation (DG) plant is shown in Figure 7.1. In this arrangement the DG output is dynamically controlled to ensure that it never causes the power flow through the 33/11kV transformers and 33kV feeders to exceed their ratings. The short-term plant ratings can also be taken into account to allow the DG plant time to reduce its output power in a controlled manner should a sudden unpredictable change in network capacity occur (e.g. as a result of a network fault).

The benefit for the Generator is that this solution allows output to continuously match network capacity without risk of trip following a FCO. However this solution would require all of the complexity of the monitoring solution plus the need for fast responding control of generation output. For the DNO the solution ensures that the Distributed Generation will not put the network at risk of a trip on overload following a FCO.

This solution would be suitable for Distributed Generation plants with a variable load factor and a high level of monitoring and control.

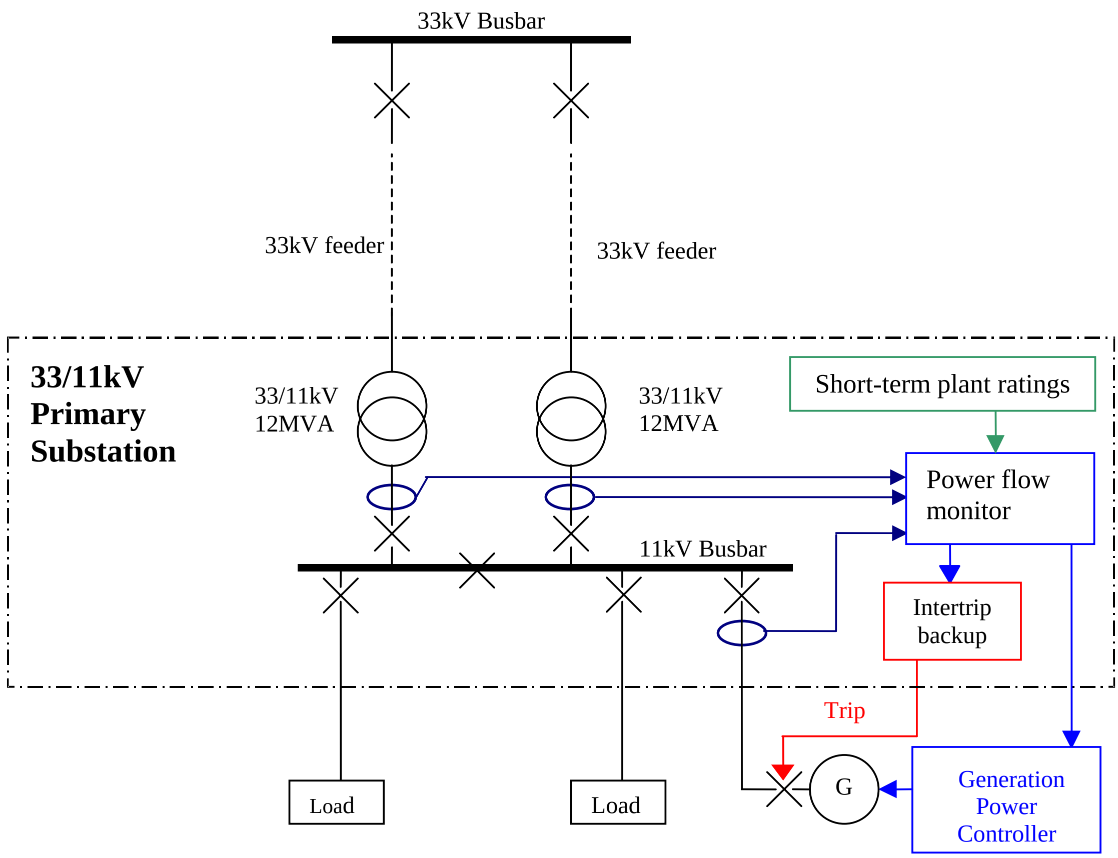

Figure 7.1: Generation power reduction scheme with Intertrip backup

Note: All circuit breakers are assumed closed unless otherwise indicated.

8 BACK-UP FOR CONTROL SYSTEM FAILURE

When designing the control system for implementing an Active Management solution, be it Intertripping, constraining or dynamic control of the generation, consideration should be given to the implications for the safety and integrity of the distribution network in the event that the main control system were to fail. A failure of the control system might give rise to a potentially dangerous situation such that corrective action will need to be taken in a short space of time by some form of additional backup control system. Therefore the design of a backup control system will depend on the immediacy of the dangers that would be created by the failure of the main control system. If the power flows would exceed the short-term rating of the network equipment, immediate Intertripping would be required; if the increased power flow could be accommodated for a period of several hours before damage occurs, a simpler back-up scheme (e.g. manual intervention) may be more appropriate.

Whilst not essential, monitoring of the power flow on the circuit connecting the Distributed Generation (DG) would give additional flexibility in the power flow control strategy. For example, it would give a direct indication of the response of the DG plant to any change in Constraint conditions.

The practical implementation of any scheme to reduce the power output from a Distributed Generation plant is likely to be more complex than the simple examples previously described, due to any specific local factors. Therefore, the viability of any scheme will need to be judged on its own merits. In practice, the nature of the local historical development will have a strong influence on the design of any power reduction scheme. For example, Intertripping schemes become very complex very quickly within meshed or interconnected networks.

REFERENCES

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