

Loss of Mains Protection



Summary

All generators that are connected to or are capable of being connected to the Distribution Network are required to implement Loss of Mains protection. This applies to all generating plant irrespective of the type of electrical machine and electrical equipment used to convert any primary energy source into electrical energy. Loss of Mains protections helps to maintain the integrity and safe operation of the Distribution Network by disconnecting generating plant from the Distribution Network in the event the main utility electricity supply is lost.

With the continued growth of Distributed Generation connecting to WPD's network, increased consideration must be given to the type Loss of Mains protection that is being implemented at the generator's point of connection. Incorrect operation of the Loss of Mains protection can have a large impact on the operation of the Distribution Network and even the Transmission Network.

Background

Loss of Mains (LoM) protection (including under voltage, over voltage and frequency protection) is used to detect a loss of the main utility electricity supply and prevent power islanding. Power islanding can occur when the main utility electricity supply is lost to part of the distribution network and distributed generation (DG) continues to export power to support the load in the affected area. This creates a power island that operates in isolation and independently to the main utility electricity supply. Power islanding can present a number of operational and safety related problems:

- Voltage and frequency within the islanded network cannot be reliably controlled by the Distribution Network Operator (DNO) or the UK System Operator (GBSO).
- Enclosure following loss of synchronism between the islanded network and the distribution network.
- The power supply to the islanded network cannot be easily be isolated as many generators connected at different voltage levels could be exporting power and keeping the network energised.
- Protection sensitivity, operating times and grading within the power island may adversely be affected.
- The islanded network may become unearthed.
- Damaged can be caused to customer plant equipment when operating outside design voltage and frequency limits.

The DNO is responsible under the Distribution Code [1] for ensuring, by design, that the voltage and frequency at the customer's connection point remains within statutory limits. The purpose of the Loss of Mains protection, and other generation interface protection, is to ensure that distributed generation does not impair the integrity or degrade the safety of the distribution network by preventing power islanding.

Types of Loss of Mains Protection

Loss of Mains protection is implemented to help prevent the formation of power islands. For generators that operate in long-term parallel with the distribution network and do not implement intertripping, Loss of Mains protection is mandatory. Loss of main utility electricity supply may be detected by one of the following methods:

Rate of Change of Frequency

Rate of Change of Frequency (RoCoF) protection detects how quickly the system frequency is changing by continuously sampling the frequency of mains voltage. Changes in frequency occur when there is a difference between the power being produced by generation to support an electrical system and the power being consumed by the load connected to the same electrical system. Frequency variations are an inherent feature of any AC electricity network. During normal operation of the UK electricity system NGET maintains the frequency within statutory limits of 49.5Hz to 50.5Hz. However the loss of a large power station or block of load may disturb the system such that it goes outside of statutory limits for a short time period. It is important that unnecessary Loss of Mains protection operation does not occur during these events.

Vector Shift

Vector Shift (VS) protection detects sudden changes in the mains voltage angle caused by a change in output from the generating plant or changes to demand connected to the network. Vector shift protection may respond quickly to changes in network impedance which often occur during islanding.

Vector Shift protection has been found to be sensitive to short circuit faults on the transmission, distribution and on customer networks.

Intertripping

Intertripping may be used as an alternative to Loss of Mains protection. Intertripping works by monitoring circuit breakers that would normally disconnect a section of network if opened. If these circuit breakers open, or their protection operates, the generator's circuit breaker will be opened, thus disconnecting it from the distribution network. Intertripping is sometimes implemented on radial or simple networks where it can easily be determined which circuit breakers, if opened, could lead to the islanding of a particular part of the distribution network. Communication systems, such as pilot wires, fibre optic or microwave communications, are required to deliver Intertripping functionality.

Implementation of Loss of Mains Protection

The requirements for the implementation of Loss of Mains protection for generators connected to the Distribution Network are detailed in the ENA Engineering Recommendations G59 Issue 3 Amendment 3 (G59/3-3) and G83 Issue 2 (G83/2) [2] [3].

ENA Engineering Recommendation G83 Issue 2

Engineering Recommendation G83 applies to type tested small-scale embedded generators (up to 16 Amps per phase) connected in parallel to the low voltage distribution network. The Loss of Mains settings that may be implemented for generators in this class are listed in Table 1.

Table 1: G83/2 Loss of Mains Protection Settings

Protection Function	Trip Setting	Trip Delay Setting (time)
Vector Shift (VS)	12 degrees	0.0s
Rate of Change of Frequency (RoCoF)	0.2 Hz per second	0.0s

G83/2 allows for other types of loss of mains protection (such as frequency drift) to be implemented, and the generator should be type tested in accordance with the procedures define within the G83/2 document. G83/2 requires the implementation of other types of protection to form what it referred to as the generator interface protection. In addition to the Loss of Mains protection, which is to prevent islanding, the interface protection should also have under and over voltage protection, and under and over frequency protection to prevent operation outside of statutory limits.

ENA Engineering Recommendation G59 Issue 3 Amendment 3

Engineering Recommendation G59/3-3 applies to the following generators:

- Generating unit's type tested in accordance with G59/3-3 that are greater than 16 Amps per phase but are less than 17kW per phase or 50kW three phase.
- Non-type tested generating units less than or equal to 16 Amps per phase.
- Generating units that are less than or equal to 16 Amps per phase but do not meet the requirements of G83/2.
- Small Power Stations, smaller that 50MW as defined by the Distribution Code.

G59/3-3 also describes the modes of operation generation plant may be designed for:

- **Long-Term Parallel** – This refers to the frequent or long-term operation of generating plant in parallel with the distribution network.
- **Infrequent Short Term Parallel** – This mode of operation typically enables generation plant to operate as a standby to the DNO’s supply. A short term parallel is required to maintain continuity of supply during changeover and to facilitate testing of the generation plant. Operation in this mode is infrequent and brief and under such conditions it is acceptable to relax certain design requirements, including Loss of Mains protection.
- **Switched Alternative Only** – Under this mode of operation it is not permissible to operate generation plant in parallel with the distribution network and Loss of Mains protection is not required.

As long-term parallel operation of generation plant has the largest impact on the distribution network, this will be the main mode of operation considered when discussing the G59/3-3 Loss of Mains requirements for distributed generation. Generators that are less than 5MW and implement RoCoF protection are required to implement the protection settings listed in **Error! Reference source not found.**

Table 2: G59/3-3 RoCoF settings for Power Stations <5MW

RoCoF settings for Power Stations <5MW		
Date of Commissioning	Asynchronous	Synchronous
Generating Plant commissioned before 01/02/2018	Not to be less than $K2 \times 0.125 \text{ Hz/s}$ and not to be greater than 1.0 Hz/s , time delay 0.5s	Not to be less than $K2 \times 0.125 \text{ Hz/s}$ and not to be greater than 1.0 Hz/s , time delay 0.5s
Generating Plant commissioned on or after 01/02/2018	1.0 Hz/s , time delay 0.5s	1.0 Hz/s , time delay 0.5s

Generators that fall into the G59/3-3 category and are greater than or equal to 5MW and implement RoCoF as the form of Loss of Mains Protection are required to implement the protection setting listed in **Error! Reference source not found.** It can be seen from Table 3 that all generators that implemented RoCoF as the form of Loss of Mains protection and were installed before 01/08/2016 were required to make changes to the protections settings and all generators installed after 01/08/2016 are required to implement the new RoCoF settings. This change is required because the UK generation mix is changing and system inertia is in decline. Disturbances to the system, such as the loss of a large generator or block of load, are having a larger impact on the system Rate of Change of Frequency. In order for distributed generation to help support the system and provide ride through capability to frequency excursions the RoCoF settings have been raised. The RoCoF settings for power stations greater than or equal to 5MW are intended to strike the appropriate balance between the need to protect against genuine island conditions and the risk of unnecessarily disturbing the system stability.

Table 3: G59/3-3 RoCoF Protection Settings for Generators Greater Than or Equal to 5MW

RoCoF Settings for Power Stations \geq 5MW				
Date of Commissioning		Small Power Stations		Medium Power Stations
		Asynchronous	Synchronous	
Generating Plant Commissioned Before 01/08/14	Settings permitted until 01/08/2016	Not to be less than $K2 \times 0.125$ Hz/s and not to be greater than 1Hz/s , time delay 0.5s	Not to be less than $K2 \times 0.125$ Hz/s and not to be greater than 0.5Hz/s , time delay 0.5s	Intertripping Expected
	Settings Permitted on or after 01/08/2016	1Hz/s , time delay 0.5s	0.5Hz/s , time delay 0.5s	Intertripping Expected
Generating Plant commissioned between 01/08/14 and 31/07/2016		1Hz/s , time delay 0.5s	.5Hz/s , time delay 0.5s	- Intertripping Expected
Generating Plant commissioned on or after 01/08/2016		1Hz/s , time delay 0.5s	1Hz/s , time delay 0.5s	Intertripping Expected

Generators that fall into the G59/3-3 category and implement Vector Shift as the form of Loss of Mains protection and were commissioned before 01/02/2018 are required to implement the settings listed in Table 4. Generation plant commissioned on or after 01/02/2018 will not be permitted to implement Vector Shift as the form of Loss of Mains protection. This change is to help improve system stability by reducing the amount of distributed generation that is disconnected due to the inadvertent operation of Vector Shift protection.

Table 4: G59/3-3 Vector Shift settings

Historic Vector Shift Settings			
Date of Commissioning	Small Power Stations		Medium Power Stations
	Asynchronous	Synchronous	
Generating Plant commissioned before 01/02/2018	K1 x 6 degrees	. K1 x 6 degrees	- Intertripping Expected
Generating Plant commissioned on or after 01/08/2016	Vector Shift Not allowed as LoM in these Power Stations		Intertripping Expected

Network Impact

Loss of Mains protection is a requirement for all generators that operate in parallel with the distribution network and is primarily to prevent the formation of power islands during post fault conditions or post switching operations. Loss of Mains protection can affect the distribution network, and in fact the wider UK power system, in a number of different ways and can be categorised into two distinct categories; failure of Loss of Mains protection and Loss of Mains mal-operation. Both of these scenarios will be discussed along with the potential impact to the distribution network.

Failure or Loss of Mains Protection

Loss of Mains protection and other generator interface protection is to detect the loss of the main utility electricity supply and prevent the formation of power islands. Power islands present a number of operational and safety related problems to the DNO and are ordinarily avoided at all costs.

Operation Related Problems

The formation of a power island could lead to the following problems and would most likely require the intervention of a control engineer or deployment of an engineer to rectify it:

- Deviation of voltage and frequency from statutory limits as defined in the ESQC Regulations 2002 [4]. It is the responsibility of the DNO to ensure voltage and frequency limits defined in the ESQC Regulations are not exceeded at any point on the network or at a customer's point of connection to the distribution network. The formation of a power island may impair or completely remove the ability of the DNO to control and monitor the voltage and frequency with in the affected area. In addition to this it may not be possible to shut down the power island from a remote location such as the DNO's control room.
- Unexpected power flows could arise when a section of network enters into islanded operation. This can be due to a change in the network impedance but is also heavily influenced by where distributed generation and demand is geographically located. Depending on the size of the power island that has been created, back feeding through transformers to different voltage levels could occur. Back feeding from the 11kV to 33kV network, for example, means that the 33kV network will become unearthed and the 33kV voltage would not be controlled. In addition to this unexpected power flows could lead to equipment being operated outside of its thermal

rating and could cause protection to operate in unexpected ways. Again, the ability to remotely control and monitor the network could be completely removed.

- Loss of synchronisation. When a power island forms it becomes decoupled from the main utility electricity supply and loss of synchronism between the power systems is highly likely to occur, as are changes in voltage, frequency and phase angle. Whilst this may not be a problem during the operation of the two decoupled networks, it could cause damage when the two power systems are recoupled. Where auto-reclose schemes are used, distributed generation must be disconnected before a circuit breaker automatically recloses. Generation must be disconnected in order to avoid connecting two networks that are not synchronised. During islanded operation of a section of network, the GBSO and the DNO lose all control of the voltage and frequency in the affected network. This means the power island must be destroyed before the affected network can be recoupled to the main utility electricity supply. Again, the ability to remotely control and monitor the network could be completely removed. In addition to this, the risk of causing significant damage to plant equipment or risk of injury to operational personal is increased dramatically when switching operations are carried out between to decoupled (non-synchronised) networks.

Safety Related Problems

The formation of power islands can impact on maintaining the safe operation of the distribution network and could lead to the following problems:

- Difficult Isolation. If there are many distributed generators supporting an islanded network it can be a lengthy and difficult process to isolate or shut down the islanded network, especially if it is not possible to carry out remote switching.
- Loss of Mains protection doesn't just prevent the formation of power islands it may also prevent generators connecting or re-connecting to de-energised sections of network. This is an important feature as it protects operational personnel whom may be working on the isolated network.
- Removal of network earthing. Under Long-Term Parallel operation, distributed generators are not permitted to form an earth point that is parallel to the DNO's earthing system. This means that when an islanded network is initially formed it may be unearthed which is not a permitted mode of operation for distribution networks as described by ESQCR. The removal of network earthing means certain fault cannot be detected, such as phase-to-earth.
- Damage could be caused to customer's equipment if parameters such as voltage and frequency cannot be controlled by the DNO or ESO if a power island is formed.

Inadvertent Operation of Loss of Mains Protection

Inadvertent operation of protection is a when protection scheme cannot distinguish between the event for which it is designed to detect, and some other event with similar characteristics. In the case of Loss of Mains protection inadvertent operation, this is when the protection operates due to a system disturbance or fault that is not a genuine loss of mains event on the network. Inadvertent operation of Loss of Mains protection can have an impact on both the distribution network and the wider UK power system, and can be caused by a range of system disturbance, both will be discussed in this section.

Causes for Inadvertent Operation of Loss of Mains Protection

Different types of Loss of Mains protection schemes are susceptible to different types of system disturbances which can lead to inadvertent operation of protection. The two types of Loss of Mains protection that will be considered are RoCoF and Vector Shift. The reason for considering these types of protection is because they use a measurement of the voltage, at the point of connection, to detect a local or remote disturbance.

- Rate of Change of Frequency protection detects how quickly the system frequency is changing by measuring the frequency of mains voltage. Changes in frequency occur when there is a difference between the power being produced by generation to support an electrical system and the power being consumed by the demand connected to the same electrical system. While RoCoF protection is sensitive to the balancing of the system frequency which is affected by changes of load and generation in remote locations, it is less sensitive to other system disturbances and faults. The inadvertent operation of RoCoF protection is less common compared to Vector Shift which makes it a good choice for Loss of Mains protection. This however, may not be the case in the future as system inertia decrease and as the distributed generation output in a particular area of network becomes closer to the load demand in the same area of network.
- Vector Shift has long been considered to be a fast and reliable way to detect and protect against a Loss of Mains event. Vector Shift protection responds extremely quickly to transient disturbances which may occur during the formation of a power island. Vector Shift is susceptible to inadvertent operation during transmission, distribution and customer fault. This makes it less effective at accurately detecting genuine islanding conditions.

Impact of Inadvertent Operation of Loss of Mains Protection

Inadvertent operation of Loss of Mains protection causes distributed generation to be disconnected from the distribution network. As more and more distributed generation is being connected to the distribution network there is more reliance on the distributed generation to support the system frequency and system stability. Unnecessarily disconnecting large amounts of distributed generation can have a large effect on the wider electricity system as well as negatively impacting on the customer's generation activities. Losing large amounts of distributed generation caused by inadvertent operation of protection, in severe cases, can lead to the following:

- Wide spread operation of RoCoF protection. Losing large amounts of DG due to an inadvertent operation of Loss of Mains protection can affect the system RoCoF and in turn cause RoCoF protection to operate. This can lead to a cascading loss of distributed generation which can impact on the ability of the GBSO to control system frequency.
- Operation of LFDD protection. If a large amount of distributed generation is disconnected and it affects the system frequency, LFDD protection should operate to remove load in order to bring the frequency back within statutory limits and restore system stability. Operation of this protection is a response to control system frequency and is undesirable as it can involve disconnected large amounts of customers from the distribution network.
- On a smaller scale, inadvertent operation of protection due to no genuine Loss of Mains event could interrupt the operations of generation customers.

Detailed Assessment

In May 2016 WPD suffered a wide spread loss of distributed generation as a result of Vector Shift Loss of Mains protection operation in the South West licence area. Following a fault on the 400kV transmission network, there was a significant increase in demand observed across the distribution network. Lightning activity in the area was thought to be the cause of the fault and NGET's protection operated as expected.

A joint investigation by WPD and NGET established that around 400MW of distributed generation connected to the WPD and SSE distribution networks was lost from the system. The majority of this automatically reconnected after ten minutes. If this event had occurred at a time of peak DG output it

could have resulted in an 800MW loss. The evidence pointed to a wide spread operation of Vector Shift protection while RoCoF protection remained unaffected as the event did not cause a frequency change outside of the G59 settings.

The industry has recently undertaken work to review the use and effectiveness of Loss of Mains protection policy. Due to the risk that a similar event could lead to a wide spread loss of generation in the South West and an associated risk to the transmission network, it was decided in March 2017 to prohibit the use of Vector Shift Loss of Mains protection in the WPD South West licence area.

Further Loss of Mains policy will be included in G98 and G99 to enact the requirements of the RfG which comes into force 27th April 2019.

As distributed generation is now playing a larger role in supporting the frequency and the stability of the wider power system, it is essential that the risk of inadvertent operation of protection is minimised.

Short Term Solutions

Loss of Mains protection provides many critical features and will continue to be a requirement for generators connected to the distribution network. Loss of Mains protection is required to protect against a number of undesirable effects that arise if a network enters into islanded operation. However the inadvertent operation of Loss of Mains protection can impact the integrity and stability of the distribution network and wider electricity system. Listed below are some potential short term solutions to the inadvertent operation of Loss of Mains protection and the prevention of islanded networks forming:

- Understanding how much of a particular type of Loss of Mains protection (RoCoF or VS) there is in an area is important as it provides a good indication of the susceptibility to the mal-operation of Loss of Mains protection and the impact it can have. While WPD does keep records of distributed generators installed capacities and the type of protection implemented, it would be useful to analyse the impact of losing blocks of distributed generation in all areas and understand the impact it can have.
- Identify areas of the distribution network that are more likely to be susceptible to the formation of power islands. As the amount of power exported by distributed generation in a particular area starts to become close to the demand in that same area, the risk of power islands forming without the Loss of Mains protection operating increases. Identifying these areas means that measures can be put in place to enhance or assist the Loss of Mains protection in that area; e.g. intertripping may be considered.
- Define an operational plan to deal with power islands if they form. Having a plan that can be executed when a power island has formed can enable a DNO to safely manage and monitor the network, and help shut down the power island in a timely manner.
- Understand the critical level of distributed generation export, in each area, that could have an impact on the system stability if inadvertent operation Loss of Mains protection occurred. This would require input from NGET and may require WPD to undertake system stability studies.
- Identify the maximum limits of distributed generation that should be protected by particular type of Loss of Mains protection to maintain system stability. Where these limits are being reached in certain areas then restrictions on the types of Loss of Mains protection should be imposed. Where these limits have been exceeded, then retrospective action may be required to alter the protection implemented on the distributed generation contributing the most to the instability.
- Mitigation of some of the issues identified in this report will be enacted through additional requirements within RfG, G98 and G99 as they come into force.

Long Term Solutions

Both RoCoF and VS Loss of Mains protection types have their disadvantages and are susceptible to disturbances on the wider electricity system that can lead to inadvertent operation of protection. As the UK electricity system continues to change and the dependence on DG to support the system increases, inadvertent operation of Loss of Mains protection must be minimised. Listed below are some potential long term solutions:

- Faults on the transmission network can lead to the mal-operation of Loss of Mains protection as described in the 2016 case study. It may be necessary to undertake a joint study with NGET to understand how different faults on the transmission network can propagate through to the distribution network and lead to the inadvertent operation of Loss of Mains protection.
- In certain areas it may become difficult to prevent power islanding using the currently available types of Loss of Mains protection. In these cases it may be more beneficial in terms of safety and economic operability to allow power islands to form. Allowing power islands to form would require a complete design review of the area of network in question to understand the earthing requirements, protection schemes, power flows, system monitoring, and system controls.
- Monitoring of Distributed Generation export, in real-time, in areas identified to be susceptible to the power islands forming.

Bibliography

- [1] The GB Distribution Code Review Panel, "The Distribution Code of Licenced Distribution Network Operators of Great Britain," Issue 28, 1st May 2017.
- [2] The Energy Networks Association, "Engineering Recommendation G59/3-3: Recommendations for the Connection of Generating Plant to the Distribution Systems of Licenced Distribution Network Operators," February 2018.
- [3] The Energy Networks Association, "Engineering Recommendation G5/4-1: Recommendations for the Connection of Type Tested Small-scale Embedded Generators (Up to 16A per Phase) in Parallel with Low-Voltage Distribution Systems," August 2012.
- [4] *The Electricity Safety, Quality and Continuity Regulations*, 2002.