GUIDELINES FOR GRID INTERCONNECTION OF SMALL POWER PROJECTS IN TANZANIA

PART B:

TECHNICAL GUIDELINES

DRAFT

MARCH 2011

ENERGY AND WATER UTILITIES REGULATORY AGENCY

CONTENTS OF PART B

LIST OF FIGURES IN PART B

LIST OF TABLES IN PART B

GLOSSARY, DEFINITIONS AND ABBREVIATIONS

AVC	Automatic Voltage Controller
AVR	Automatic Voltage Regulator
Captive Generation	Generating plant available at customer facilities, but not connected in parallel with the distribution network.
Captive Line Load	Load, up to the 1st point of automatic isolation, which is (or may be) supplied by an Embedded Generator, excluding Captive Local Load.
Captive Local Load	Load within the Embedded Generator premises including generator auxiliaries.
Captive Load	The sum of Captive Line Load and Captive Local Load
Combined Heat and Power (CHP)	A plant that generates electricity and supplies thermal energy, typically steam, to an industrial or other heating or cooling requirement.
Distribution Network	A public electricity supply network operating at or below 33 kV, connected to Tanzania's main grid or operating as an isolated mini-grid.
DNO:Distribution Network Operator	Licensee responsible for the operation of a distribution network in Tanzania.
EF	Earth Fault (protection)
EG	Embedded Generator
Embedded Generator	A single generator, or a group of generators, connected to the DNO's distribution network, of capacity range and interconnection voltages stated in Section A2 of the guidelines.
Export of Electrical Energy	Supply of Electrical Energy by a Generator to a Distribution Network.
Generating Company	A company, a group or an individual who plans to connect or has already connected an Embedded Generator to a Distribution Network.

Grid Interconnection	A link between a Distribution Network and the Embedded Generator's electricity system, made for the purpose of Exporting or Importing Electrical Energy.
Grid Substation	A substation in the main grid where electrical energy at 220 kV, 132 kV or 66kV is transformed into 33 kV or 11 kV.
Highest (Lowest) Voltage of a System)	The highest (lowest) value of operating voltage which occurs under normal operating conditions at any time and at any point in the system.
HV	High voltage, exceeding 1000 V between conductors and 600 V between conductors and earth.
Import of Electrical Energy	Receipt of Electrical Energy by the Embedded Generator from a Distribution Network.
Interconnection Certificate	A Certificate issued by a Distribution Network Operator to an Embedded Generator, after testing the Grid Interconnection.
Interconnection Voltage	The nominal voltage at which the grid interconnection is made.
Islanding	The process whereby a power system is separated into two or more parts, with generators supplying loads connected to some of the separated systems.
Islanded Operation	The situation that arises when a part of the Distribution Network is disconnected from the grid and is energised by one or more generators connected to it.
LOI: Letter of Intent	Issued by a Distribution Network Operator to a Generating Company to signify the intent to purchase power from a Generating Company at a particular location.
LOM	Loss of Mains (protection)
LV	Low voltage, not exceeding 1000 V between conductors and 600 V between conductors and earth.

Mini-grid	An isolated power system not connected to the Tanzania national grid, and operated under the regulatory supervision of Energy and Water Utilities Regulatory Authority.
Neutral Point Displacement Voltage	The voltage between the real or virtual neutral point and the earth.
NVD:Neutral Voltage Displacement	A technique to measure the displacement of the neutral voltage with respect to earth.
Nominal Voltage	A suitable approximate value of voltage used to designate or identify a System.
OC	Over-current (protection)
OF	Over-frequency (protection)
Operating Voltage	The value of the voltage under normal conditions at a given instant and at a given point in the system.
OV	Over-voltage (protection)
Point of Common Coupling (PCC)	The location of the connection between a Distribution Network and the Embedded Generator, beyond which other customer loads.
Point of Supply (POS)	The location of the connection between a Distribution Network and an Embedded Generator.
Power Purchase Agreement(SPPA)	An agreement between the Distribution Network Operator and the Generating Company for the purchase of electricity.
ROCOF	Rate-of-change of Frequency (protection)
RP	Reverse Power (protection)
SBEF	Standby Earth Fault (protection)
Spinning Reserve	The difference between the total available capacity of all generating sets already coupled to a power system and their total actual loading.

Step Voltage The difference in surface potential experienced by a person bridging a distance of 1 m with his feet without contacting any other grounded structure.

Touch Voltage The potential difference between the ground potential rise (GPR) and the surface potential at the point where a person is standing, where at the same time having his hands in contact with a grounded structure. GPR is defined as the maximum voltage that a station grounding grid may attain relative to a distant grounding point assumed to be at the potential of remote earth. The touch voltage could be from hand to hand as well.

Transferred Voltage This is a special case of the touch voltage where the voltage is transferred into or out of the station by a conductor grounded at a remote point or at the station ground, respectively.

TNS:Terra Neutral Separate (system of earthing) In this earthing (grounding) system, the DNO provides separate neutral and protective conductors throughout the system. The protective conductor is connected to the neutral of the source. All exposed conductive parts of a consumer's installation are connected to the protective conductor provided by the DNO via the main earthing terminal of the consumer's installation.

TNO:Transmission Network Operator Licensee responsible for the operation of transmission network in Tanzania.

TT:Tera Tera(system of earthing) An earthing (grounding) system where all exposed conductive parts of an installation are connected to an earth electrode provided by the consumer which is electrically independent of the source earth.

UV Under-voltage (protection)

UF Under-frequency (protection)

Voltage Level One of the Nominal Voltage values used in a given system.

VS Vector Shift (protection)

B1 STUDIES AND INFORMATION TO BE EXCHANGED

DNO may conduct the following studies before authorising the interconnection of an Embedded Generator (EG) and the Generating Company shall provide the information shown in Annex A1 of Part A of these Guidelines. These studies will be conducted within the period of validity of the LOI and when the DNO is satisfied that the detailed designs for the Embedded Generator are in progress.

B1.1 Stability

DNO may analyse the effect of implementing the additional generation on the stability of its distribution system as well as the source systems.

Information on the embedded generator required for a stability study should be submitted by the Generating Company, irrespective of the generator capacity. Information required may vary according to the generator capacity.

B1.2 Load Flow

DNO may carry out load flow studies to ascertain distribution system performance and also the remedial measures required to ensure satisfactory system performance, when the proposed embedded generator is added to its network.

B1.3 Fault Levels

DNO will carry out a fault study with the proposed generator included in the network model. The Generating Company shall provide to the DNO, information related to fault levels as shown in Annex 1 of Part A of these Guidelines and, if requested, even more information for a detailed analysis.

In the case of generators proposed to be connected to the 66 kV systems, the Generating Company will be required to provide information to the DNO to enable the TNO to assess the asymmetrical fault currents as well.

B1.4 Protection

DNO will be required to carryout a protection study to ascertain that the protection system agreed upon will fulfil the requirements identified above. Minimum protective system requirements for the embedded generators are given in the ensuing sections of these Guidelines.

B1.5 Voltage Levels

B1.5.1 Interconnection Voltage

Generating Company should choose the interconnection voltage in consultation with the DNO. Table A1 of Part A shows the guidelines for the selection of interconnection voltage.

The Generating Company should enter into a dialogue with the DNO to decide on the suitable voltage and the Point of Supply. Based on these discussions, the DNO shall define the Point of Supply and its nominal voltage at the time of issuing the LOI.

Once the Point of Supply (POS) is decided, DNO may carry out all necessary studies and shall provide the Generating Company with the applicable normal operating voltage, maximum normal voltage, maximum permitted voltage and information on the power factor limits at the POS.

B1.5.2 Voltage Flicker

The generator should not cause voltage flicker at the POS which exceeds the limits defined in *Engineering Recommendation P28*, "Planning limits for voltage fluctuations caused by industrial, commercial and domestic equipment in the UK".

B1.5.3 Voltage Rise

The voltage rise at the POS due to the generation must be within operational limits. The target bandwidth for voltage on the 33 kV and 11kV busbars of a grid substation is ±5%. The target voltage on the 33 kV and 11kV busbars of a grid sub-station is 33 kV and 11kV, respectively.

B1.5.4 Studies on Voltage Flicker and Voltage Rise

A two-stage approach will be required in conducting these studies:

Stage I: Exclude load connections to distribution lines and grid transformers
Stage II: Include load connections to distribution lines and grid transformers

The Stage II study will be required when the Stage I study indicates a potential problem.

B1.6 Earthing

The Generating Company shall provide information about the proposed earthing arrangement to the DNO. Guidance on the earthing system is given in Section B4.

B2 Fault Levels

B2.1 General

Fault levels in a distribution network must be maintained within design limits. Ratings of switchgear shall be in accordance with the declared design fault level to ensure healthy system performance.

The connection of an embedded generator to a distribution system will increase the fault level on the network when both the generator and grid are connected, and the effect of this change should be considered.

There may be protection problems such as under-reaching of 132 kV and 220 kV distance protection or possibly on 33 kV overcurrent protection when the embedded generator contribution is included.

B2.2 Fault Level Information

DNO shall provide the design fault levels at the POS to the Generating Company.

The Generating Company shall provide fault level contribution of embedded generators at the point of supply. The Generating Company shall provide tolerances on the fault level data provided.

The information requirements are specified in Annex A1 of Part A of the guidelines.

Asynchronous Generators

For asynchronous machines, the data set is not standard and, therefore, data requirements should be agreed between the DNO and the Generation Company.

B2.3 Fault Level Calculation

DNO shall be responsible for monitoring fault levels on the distribution network and performing detailed assessments as appropriate to ensure that fault limits are not exceeded.

Fault calculations shall be based on methods defined in the IEC 60909, Short circuit current in ac systems.

B2.4 Fault Level Reduction and Management

Connection of an embedded generator will always lead to an increase in the fault level. Where it has been identified that the resulting fault level would exceed the design fault level, following are the possible options to overcome this problem.

B2.4.1 Replacement of Switchgear and Components

Fault level capabilities of the network could be increased by replacement of switchgear with equipment with a higher design rating. This is the obvious and traditional solution, but will be expensive.

B2.4.2 Network Splitting/Changing System Feeding Arrangements

Splitting the network or at times by changing the system feeding arrangements, it is possible to achieve lower faults levels. This is a low cost solution and should be considered only if it does not lower the system reliability/stability/power quality below the desired levels.

B2.4.3 Increasing the Impedance

This may take the form of an isolating transformer, a current limiting reactor or additional length of circuits. A current limiting reactor could give rise to voltage problems and also increase in system losses.

B2.4.4 Short Circuit Current Limiters

Fault levels of a system will not remain constant but vary between certain definite maximum and minimum levels. This situation has given rise to the introduction of new devices which come into action when the fault level increases to a pre-determined value. Short circuit current (I_S) limiters, superconducting fault level limiters, solid state fault current limiting circuit breakers are ~~a~~ few examples, and of these, I_S limiters have found wide application.

B3 VOLTAGE REGULATION

B3.1 General

Control of voltage on the distribution system is affected by the connection of embedded generation. The power being fed into the grid from the EG will raise the voltage at the POS. This may be an acceptable support to local network voltage or it may cause the operational or statutory voltage limits of the local distribution system to be exceeded.

DNO will give careful consideration to the optimisation of network voltage control, possibly using AVC with line drop compounding settings for voltage boost and power factor droop, to encourage the connection of embedded generation without compromising statutory obligations to existing customers.

B3.2 Step Voltage Changes

The network can be subjected to step voltage changes when an induction generator is connected to the network. Energization of an EG transformer from the network or sudden tripping of an EG could also give rise to step voltage changes. Maximum step voltage changes are defined in the Engineering recommendations G75/1 and P28[1] and these are ±3% for planned switching and ≤6% for unplanned outages.

B3.3 Voltage Limits

Having determined an optimum target voltage and limits for voltage at the grid substation, these limits shall be declared and be available to all prospective Generating Companies. See section A5 on information to be provided by the DNO to a Generating Company.

Voltage at the Point of Common Coupling (PCC) should be in accordance with the statutory limits.

Non-statutory limits may be agreed between DNO and the Generating Company if no other customers are affected. For example, where the PCC is remote from the POS with a long line that only serves the EG or with no direct connection of customers at the line voltage, a non-statutory limit may be agreed.

DNO reserves the right to review and revise any such non-statutory limits. The Generating Company shall bear the costs resulting from any such revisions.

B3.4 Power Factor Requirements

The SPPA shall specify a power factor for the connection – this will be typically unity but may be lagging (EG supplying reactive power), depending on voltage regulation issues. It should be noted that this specified value will be subject to the tolerance of the generator power factor control unit. To derive maximum benefits, and to reduce generator and line losses, EGs need to be operated as close as possible to unity power factor.

B4 Reverse Power Flows

When the power generated by the EG exceeds the demand of the of the distribution system, surplus power will flow to the higher voltage system from the lower voltage network. It could be through the distribution transformer or even through the grid substation transformer. This is the opposite of what generally occurs in a distribution network and such considerations may have not been foreseen by distribution system designers.

[1] http://www.ena-eng.org/ENA-Docs/

Reverse power flows may cause voltage regulation problems, especially in systems with grid substations equipped with single resistor on load auto tap changers or where line- drop compensation is incorporated in fixed tap transformers.

B4.1 Embedded Generator Operation

Under reverse power flow conditions an EG may be required to operate at a power factor away from unity, and hence will prevent harnessing maximum benefits from embedded generation.

B4.2 Losses

When EG output is lower or equal to the distribution system loads, losses incurred in transmission and distribution system will decrease. However, under reverse power flows depending on the extent of EG generation and its location, system losses could increase and will result in higher system operational costs to the DNO.

B4.3 Protection

Often the LV winding of a grid substation transformer is protected with directional over current relays. If the reverse power flows exceed the limit on the setting of the relay, then the relays will initiate tripping, thus creating an unwarranted outage.

B5 Earthing of Electricity Networks and Embedded Generators

B5.1 General

Public electricity transmission and distribution networks are connected or referenced to earth as close to their energy source as possible. This is done by connecting the neutral point of the transformer or the generator winding to the ground directly or through an impedance. In addition, all non-current carrying metalwork of plant and equipment of the stations are also grounded. The main objective of such grounding is to control the voltage of the systems and metal work within predictable limits.

The Generating Company may use either separate earth electrodes for HV and LV systems or a single common electrode for both systems. Earthing systems for substations and plant in electrical networks have to be designed giving due consideration to the type of network, its protection policies and system parameters such as earth fault current magnitudes, resulting voltages appearing in earth systems and speed of protection.

Note that the term HV is used for all voltages above 1000 V, to be consistent with the other sections of these guidelines.

B5.2 DNO Electricity Supply Networks

The DNO's electricity supply networks are connected to earth at a single point or at two or more points. Multiple network earthing may exist at a single substation location or at different points in the network to facilitate interconnections and operational changes.

B5.3 Compatibility of Network and Generator Earthing

Arrangements should be agreed to earth the EG's system in a manner compatible with the DNO's supply. To accept additional points of network earthing such as generator parallel earthing, DNO will consider the following technical issues:

- Controlling the magnitude of earth fault currents
- Maintaining a predetermined path for earth fault current
- Adequacy of the existing earth fault detection systems in the DNO's network
- Limiting circulating currents at fundamental and harmonic frequencies
- Avoiding interference to communication systems
- When appropriate, maintaining the effectiveness of network earthing

Any system earths provided by the EG should be closed only when EG fed systems operate isolated from the DNO network or only if studies carried out show that it is safe to operate in the parallel mode.

Furthermore, appropriate protection will be required at the EG to maintain safe conditions in the DNO network, should its normal earth point become isolated or disconnected. The protection requirements are specified in these guidelines.

B5.4 Generator Parallel Earthing

Normally electricity is generated at or around 11kV or lower. When the generation voltage is lower than the DNO network voltage, a step up transformer is used to connect the generator to the DNO network. If the generation voltage is same as that of the DNO network, then direct connection could be allowed giving due consideration to earthing aspects.

B5.4.1 11kV Generators

Large generators, (larger than 1 MW) may be earthed through a neutral earthing impedance of value to be agreed, when operating in parallel with 11 kV networks.

If the DNO network is effectively earthed and the EG is impedance earthed, then appropriate protection schemes should be commissioned to prevent the EG operating under islanded conditions.

B5.4.2 LV Generators

Where a generator is connected to the DNO supply networks and at risk of being islanded, the preferred method for safe operating conditions is for the generator to be earthed at the PCC to the DNO supply.

Parallel earthing when operating in parallel with the DNO network will provide safer generator connections. To allow this, DNO will consider the technical issues listed in B5.3 above.

Use of a suitable transformer winding or the interlocking of switches and automatic earthing of the generator neutral (when the incoming mains are disconnected) may be required to avoid parallel generator earthing. Where a generator is required to operate independently of the DNO supplies, it must have an earth electrode system, which should be bonded to the DNO earthing system or terminal, wherever this is available and practical, provided the DNO's earth system will not transfer dangerous voltages to the generator earthing system. Alternatively where permitted, a generator may use a shared earth system.

DNO may decide that an EG must not have parallel neutral point earthing, when operating in parallel with the DNO supplies. In this case, appropriate protection must ensure that an islanded generator is automatically disconnected.

If an islanded generator is required to continue to operate and supply Local Captive Loads and some Line Captive Loads, any one of the following conditions should be fulfilled.

- The generator/network connection point may be appropriately parallel-earthed while the generator operates.
- The network at the PCC may be automatically earthed if islanded.
- Appropriate devices such as Neutral Voltage Displacement protection may be provided to ensure safe conditions, and disconnect the generator if an earth fault occurs in the DNO system or the generator system.

Where a generator is connected to the DNO LV supply network away from a substation, the preferred method to ensure safe operating conditions and remove risk of damage if neutral conductors become open circuit, is for the generator to operate without a parallel neutral earth connection.

Protective devices must disconnect an islanded generator under this condition.

Where the DNO gives a written approval for a parallel connection of earthing systems, then the following conditions apply:

- The EG's supply earthing must be of the type Protective Multiple Earth (PME)
- The generator star point must be connected to the EG's earth electrode and to DNO earthing terminal/neutral. If the DNO's earth electrode is at the POS then the EG need not provide an independent earth electrode subject to agreement with the DNO.
- The EG must not produce harmonic distortion greater than that allowed in G5/4-1

If the DNO supply is direct from a HV/LV substation situated in the EG's premises with the generating plant adjacent to the POS, the requirement for the EG to provide an earth electrode can be waived off and the neutral connected solidly to the DNO neutral earthing system.

The arrangement must ensure that the connection of the generator neutral point to the EG's earth system and the distribution network earth system/terminal is substantial, solid, direct and clearly identified.

Regular checks on the earthing system must be conducted by the Generating Company.

B5.5 Interconnection of DNO and Generator Earth Systems

Earthing an electricity supply network and a generator system requires the DNO, generating plant and electrical equipment to be connected to an earth system with appropriate earth electrodes.

Wherever networks operating with different voltages are in close proximity and resistance areas of their earth systems overlap, the overlapping earth systems should be interconnected and the resistance of the overall earth system should be reduced to a safe value considering the maximum prospective earth fault currents at the site.

HV metered supplies to generator premises require a combined HV earth system. The HV earth terminal will include an earth connection to a DNO earth electrode system and possibly provide a metallic path to the point where the DNO HV network neutral point is earthed.

LV supplies to generator premises from a dedicated, local DNO HV/LV transformer will normally have independent HV and LV earth systems. If combined, the rise of voltage and the transferred voltage to the LV neutral shall be within acceptable limits. If independently earthed, the DNO LV earth terminal should preferably be connected to the EG's earth system. This will minimise the risk of damage to plant in the EG's system.

The insulation of the supply transformer LV winding and terminals must be adequate to prevent danger from the rise of voltage on the HV earth system for an earth fault in the supplying substation.

Where the DNO LV earth terminal/system may not be made available to the EG (TT system) a metallic path to the DNO LV network neutral from the EG's earth system will not be available.

The design of all earth systems must ensure that all touch and step voltages are within acceptable limits. Transferred voltages to EG's plant must not create unacceptable touch and step voltages.

Precautions must be taken to prevent damage and remove danger arising from transferred voltages to and from external metallic services and metallic paths.

For descriptions, drawings and limitations of various low voltage earthing systems refer the latest revision of BS 7671 or its equivalent, and Electricity Supply Regulation 1988 (as amended) or its equivalent. Low voltage earthing systems should satisfy the above standards and regulations.

B5.6 Generator Circulating Currents in Earth Connections

Where two or more generators operate in parallel with their star points/neutrals connected to a common neutral conductor or an earthing busbar, harmonic currents may circulate between machines. Typical effects of harmonic current flowing in earth connections are telephone interference, heating of a neutral earthing resistor and the requirement to derate a generator. Harmonics also affect the sensitivity for earth fault protection or alarm devices.

B6 SYNCHRONISATION OF GENERATORS

B6.1 General

Synchronisation can be achieved either manually or automatically, the latter being preferable. If manual synchronisation is suggested for a particular reason, its safe and reliable operation should be seriously considered and implemented carefully.

B6.2 Voltage Fluctuation

During synchronisation of a single generator, the induced voltage fluctuation on the grid should not normally exceed 3% at the PCC, and should also meet the requirements of voltage step and flicker.

B6.3 Synchronous Generators

Before a synchronous generator can be connected to the grid, the generator must be run up unconnected and its speed adjusted to synchronise the generator output with the grid supply.

The voltage difference between the generator output and the grid supply should also be minimised. It is usual for the unconnected generator voltage to be set a few volts above the typical grid voltage.

B6.4 Asynchronous Generators

Asynchronous generators normally require special measures to minimise the inrush current taken by the generator from the grid at the time of connection in order to meet the voltage fluctuation requirements of Section B3. Suitable equipment and procedures may include:

- Electronic soft-start equipment
- Resistance starter
- Mechanically driving the generator up to near synchronous speed prior to connection.

B6.5 Other Types of Generators

Other types of generators, which will include static inverters will need to have their output synchronised with the grid before or during grid connection. The transient characteristics of the connection shall be submitted to DNO.

B6.6 Synchronising Check Relay

A synchronising check relay must be used to inhibit the operation of a synchronous generator connection breaker or contactor when the two supplies are outside pre-set limits. (Induction generators do not require synchronization check relays.)

B7 ISLANDED OPERATION

B7.1 General

In the context of embedded generation, an islanded network will typically comprise:

i) A single feeder or feeder section following a trip of the source circuit breaker or auto recloser.
ii) A primary network or bus-section following a trip of the incoming circuit breaker(s).

Embedded generation and islanding are defined in Section A3.3 of Part A of these guidelines.

It has been established that unplanned islanding is not acceptable, and hence protection is required to detect such situations and trip the generation within an acceptable time-frame.

B7.2 Hazards of Islanding

The potential hazards presented by operating a generator in an islanded situation are:

- Unearthed operation of the islanded distribution system
- Lower fault levels
- Out of synchronisation reclosure
- Voltage levels
- Quality of supply
- Risk to maintenance personnel

B7.3 EG Tripping due to Abnormal Conditions in the Network

Certain faults occurring elsewhere in the power system could cause tripping of embedded generators. These are

- Extraneous faults occurring elsewhere in the system
- Operation of under frequency load shedding relays of distribution feeders to which EG's are connected.
- Downstream faults on distribution feeders to which the EG's are connected
- Faults on other distribution feeders

B7.4 Restoration

In the event of an EG getting disconnected from the DNO system due to a DNO supply failure, EG shall ensure that reconnection of its generators are possible only after a minimum time delay of 1 minute after the restoration of the electricity supply by the DNO.

B8 PROTECTION METHODS AND RELAY SETTINGS

B8.1 General

The generating company is required to design its protection system to reliably detect faults or abnormal conditions and provide an appropriate means of automatically isolating the faulty equipment or systems selectively, and as fast as possible.

Following are the possible abnormal condition that could arise:

(a) Over current
(b) Earth fault
(c) Under frequency
(d) Over frequency
(e) Under voltage
(f) Over voltage
(g) Loss of mains
(h) Neutral voltage displacement
(i) Reverse power

B8.1.1 Over current and earth fault

Over current (preferably voltage controlled or voltage restrained over current) and earth fault protection, must be installed on the generator to detect the faults within the generator and the network, and should be coordinated properly.

B8.1.2 Over and Under Frequency

Over and under frequency relays should be installed to monitor system frequency excursions outside preset limits. Settings will be dependent on the generator characteristics, network connection arrangement and operating requirements. Protection settings need to be coordinated with the load shedding schemes of the DNO's system.

B8.1.3 Under and Over Voltage

Under and over voltage protection should be provided for the installation to monitor the voltages of all three phases.

Settings will be dependent on the generator characteristics, network connection arrangement and operating requirements. Protection settings can be determined at the design stage in consultation with the DNO.

B8.1.4 Loss of Mains

Purpose of loss of mains protection is to detect an islanded situation and disconnect the EG from the network.

The stand-alone detection of an islanded situation is based upon the detection of this electrical disturbance.

Rate of Change of Frequency

The most common and widely used methods used to detect loss of mains are Rate of Change of Frequency (ROCOF) and vector shift, and it is now common to use a relay based on both these principles. The settings of relays should be decided in consultation with the DNO.

Intertripping

The most reliable method of preventing an islanded situation is by inter-tripping the EG breaker with the opening of the DNO’s circuit breaker at the grid substation or the recloser.

Fault Thrower

This is a form of intertripping using the phase conductors as the medium for communication. The fault thrower would be installed at the source substation and would be operated following opening of an appropriate source circuit breaker. The device would either create a short circuit on the islanded feeder causing operation of generator protection it could create an earth fault on one phase, causing the operation of generator NVD protection.

B8.1.5 Neutral Voltage Displacement (NVD) Protection

This device does not detect islanding; its purpose is to detect an earth fault and an unsafe islanding condition.

An NVD scheme measures the displacement of the neutral on the HV side of the generator transformer and operates with a delay, when the displacement exceeds the trip setting.

The NVD protection should grade with the earth fault protection at the grid or primary substation.

B8.1.6 Reverse power

When a grid connected synchronous generator looses its driving force from the prime mover, it will continue to run as a synchronous motor drawing power from the grid. This is an undesirable condition and should be prevented. A true wattmetric relay should be used to detect this condition and the settings should be decided according to manufacturer's recommendations.

Table B 1 - Summary of Typical Relay Settings

Relay	Settings		Remarks
	Level	Time	
Over current and earth fault			In consultation with the DNO
Over frequency	+4% (52 Hz)	< 0.5 s	
Under frequency	-6% (47 Hz)	< 0.5 s	
Over voltage	110%	< 0.5 s	HV point connection
-do-	110%	< 0.5 s	LV point connection
Under voltage	90%	< 0.5 s	HV point connection
-do-	86%	< 0.5 s	LV point connection
Loss of mains			
Rate of change of frequency	2.5 Hz/s	< 0.5 s	
Vector shift	6^0 - 12^0 in half a cycle	< 0.5 s	
Neutral voltage displacement	25%	1-3 s	Effectively grounded systems
Reverse power	3-25% of the rating	2-10 s	Manufacturer's recommendations

B8.2 Protection Relays, Current and Voltage Transformers

EG may include any additional protection schemes to protect its generator from hazardous conditions a generator could be faced with.

Protection relays shall be of suitable quality to provide reliable and consistent operation. The performance levels of the relays shall be declared by the manufacturer. The performance of all protection relays shall be within the scope of the relevant IEC standards. Particular consideration should be made of the requirements for current transformers to sustain operation when fault currents occur. Current and voltage transformers should be appropriately selected and comply with the appropriate IEC standards.

B8.3 Interconnection Protection Requirements

In order to specify the type of interconnection protection requirements, embedded generator interconnections are classified into five cases, and four of these are illustrated in Figures B1 to B4.

However, DNO shall have the discretion to allow the EGs operate without some of the protection stipulated, depending on the captive load.

A summary of the Case definitions and protection requirements is shown in Table B2. The Cases are described subsequently.

Table B 2- Summary of Minimum Protection Requirements

	Case 1	**Case 2**	**Case 3**	**Case 4**	**Case 5**	
Generator type	**All**	**All**	**See Case 3 description**	**All**	**See Case 5 description**	**Self commutated static inverters**
Minimum captive load	L	L	L		L	
Maximum cumulative installed capacity	<0.5 x L	<0.8 x L	>0.8 x L		>0.8 x L	
Maximum site installed capacity	< 5 MW	< 5 MW	< 5 MW	> 5 MW		
Under and over voltage protection	●	●	●	●	●	
Under and over frequency protection	●	●	●	●	●	
Loss of Mains	*	●	●		●	
NVD protection			●	*(1)		
Intertripping				*		
Loss of Phase	●	●	●	●	●	●
Other	*		*	*	*	*

● Mandatory minimum requirement
* For other requirements and alternatives see the descriptions under the respective case descriptions and requirements

(1) NVD or parallel earthing

Table B2 summarises only the mandatory requirements of protection. Other mandatory requirements are described elsewhere in the guidelines.

B8.3.1 Case 1: Generation less than 5 MW, Comparatively High Captive Load

Generator Type
All types.

Conditions

- The installed generating capacity is **less** than half the minimum Captive Load (see note below), and
- The installed generating capacity is less than 5 MW.

Note: Minimum Captive Load is the sum of Minimum Captive Line Load and the Minimum Captive Local Load. The minimum Captive Line Load may be difficult to establish, in which case it may be assumed to be 50% of average line load.

In this case, following distribution line disconnection, the EG speed and voltage will fall rapidly as the generator(s) will be unable to supply the load.

Protection Required

Under and over voltage
Under and over frequency

Optional, at the Discretion of the Generating Company

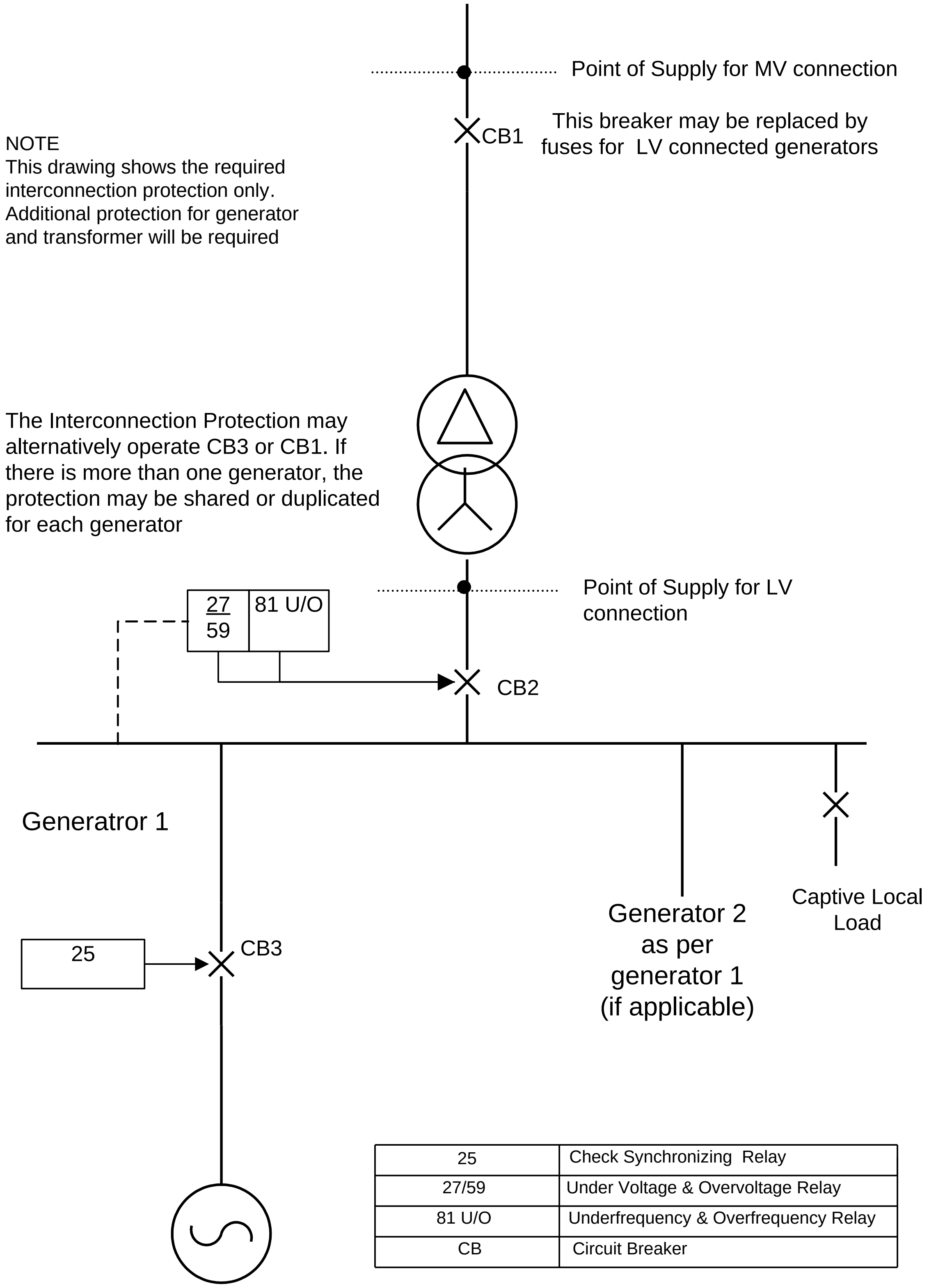
Three phase vector shift

Design Criteria

The minimum Captive Load is subject to change due to insertion of sectionalisers, reclosers, reconfiguration or reduction in customer load. DNO shall be informed of any modification made to the Embedded Generator for review, and to assess the need for any retrospective enhancement of protection. Similarly, whenever any changes to the DNO system affects the Captive Line Load, DNO shall review the interconnection protection and advice the Generating Company accordingly.

Auto reclosers must have a minimum reclose time of 1 second to minimise the possibility of out of synch reclosure. DNO shall verify that this reclosing time is adequate for interconnection protection to operate prior to reclosing.

Figure B 1- Interconnection Protection Arrangement for Case 1



25	Check Synchronizing Relay
27/59	Under Voltage & Overvoltage Relay
81 U/O	Underfrequency & Overfrequency Relay
CB	Circuit Breaker

B8.3.2 Case 2: Generation less than 5 MW, High Captive Load

Generator Type

All types

Conditions

- The installed generating capacity is **less** than 80% of the minimum Captive Load (see note below), and
- The installed generating capacity is less than 5 MW.

Note: Minimum Captive Load is the sum of Minimum Captive Line Load and the Minimum Captive Local Load. The minimum Captive Line Load may be difficult to establish, in which case it may be assumed to be 50% of average line load.

Protection Required

Under and over voltage

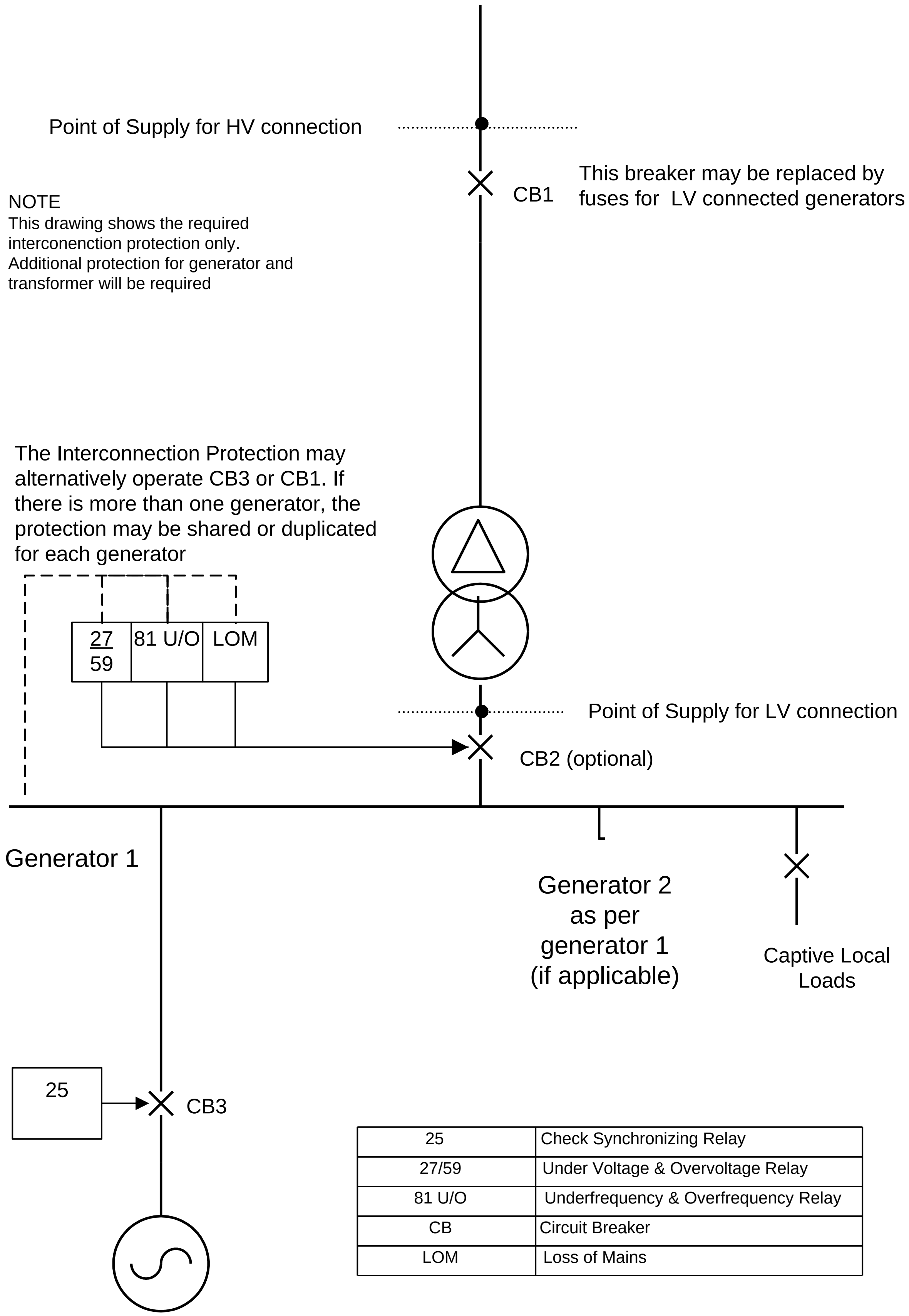
Under and over frequency

Loss of Mains, Optional, at the Discretion of DNO, when a balance between Captive Load and the installed generating capacity is very likely to occur

Design Criteria

As per Case 1.

Figure B 2 - Interconnection Protection Arrangement for Case 2



25	Check Synchronizing Relay
27/59	Under Voltage & Overvoltage Relay
81 U/O	Underfrequency & Overfrequency Relay
CB	Circuit Breaker
LOM	Loss of Mains

B8.3.3 Case 3: Generation less than 5 MW, Lower Captive Load

Generator Type

All types except mains excited generators defined in Case 5.

Conditions:

- The installed generating capacity is **more** than 80% of the minimum Captive Load (see note below), such that load/generator balance is possible, and
- The installed generating capacity is less than 5 MW.

Note: Minimum Captive Load is the sum of Minimum Captive Line Load and the Minimum Captive Local Load. The minimum Captive Line Load may be difficult to establish, in which case it may be assumed to be 50% of average line load.

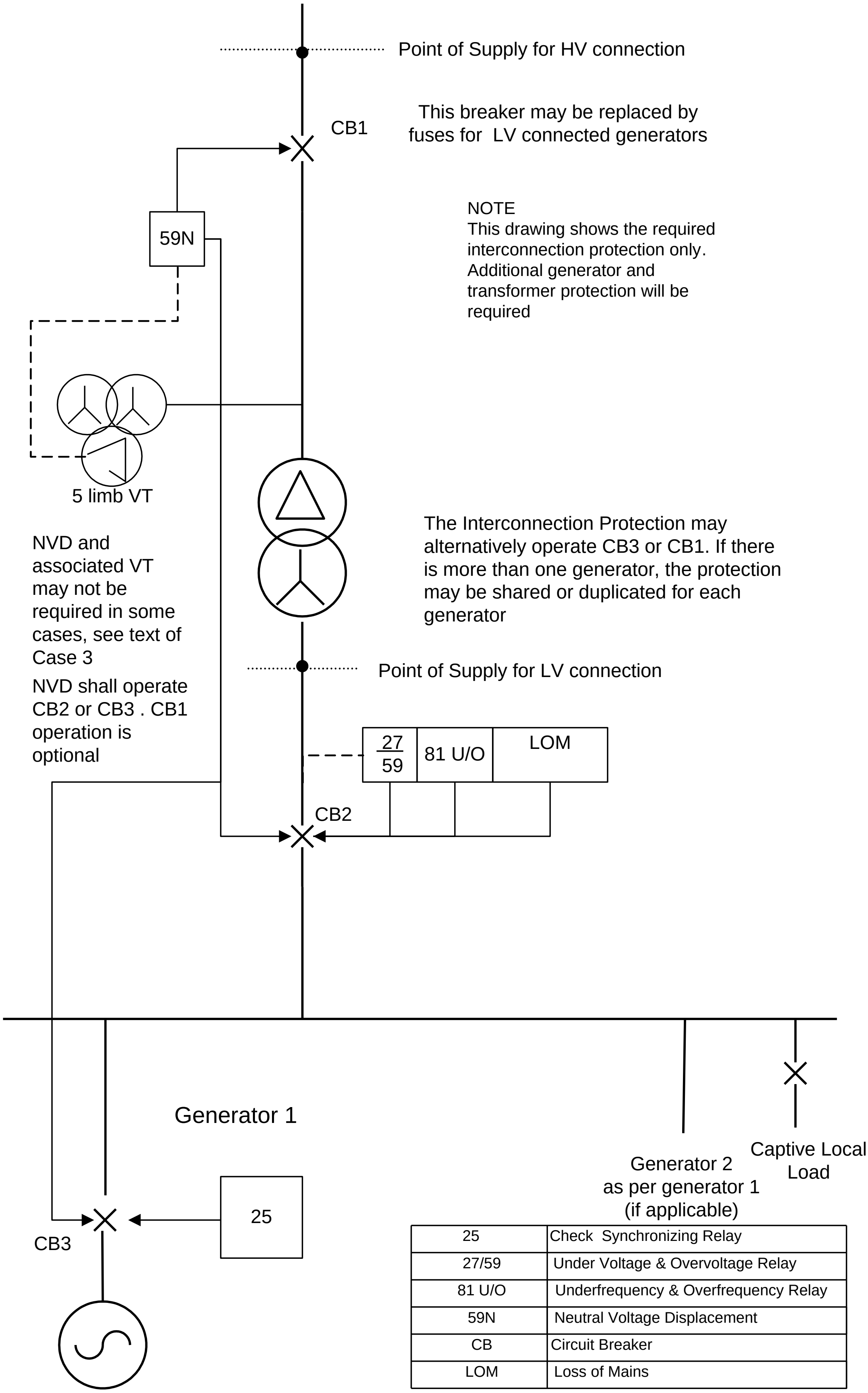
Protection Required

Under and over voltage
Under and over frequency
Loss of mains
NVD
Dead-line check

NVD protection is not required where the maximum site installed capacity is less than 1 MW, if the cumulative embedded generating capacity on a distribution line that does not have NVD protection is less than 0.8 times the minimum captive load.

The fitting of deadline check relays on upstream breakers or sectionalisers, or disabling of all upstream automatic reclosing devices should be considered.

Figure B 3- Interconnection Protection Arrangement for Case 3



25	Check Synchronizing Relay
27/59	Under Voltage & Overvoltage Relay
81 U/O	Underfrequency & Overfrequency Relay
59N	Neutral Voltage Displacement
CB	Circuit Breaker
LOM	Loss of Mains

B8.3.4 Case 4: Generation larger than 5 MW

Generator Type

All types

Conditions

The installed generating capacity of an Embedded Generation site is greater than 5 MW.

Configuration

It is preferred that the Embedded Generator is connected directly to the primary bus rather than teed into an HV distribution feeder.

Protection Required

Under and over voltage
Under and over frequency
Intertripping from grid substation bus intake
Parallel earthing or NVD protection

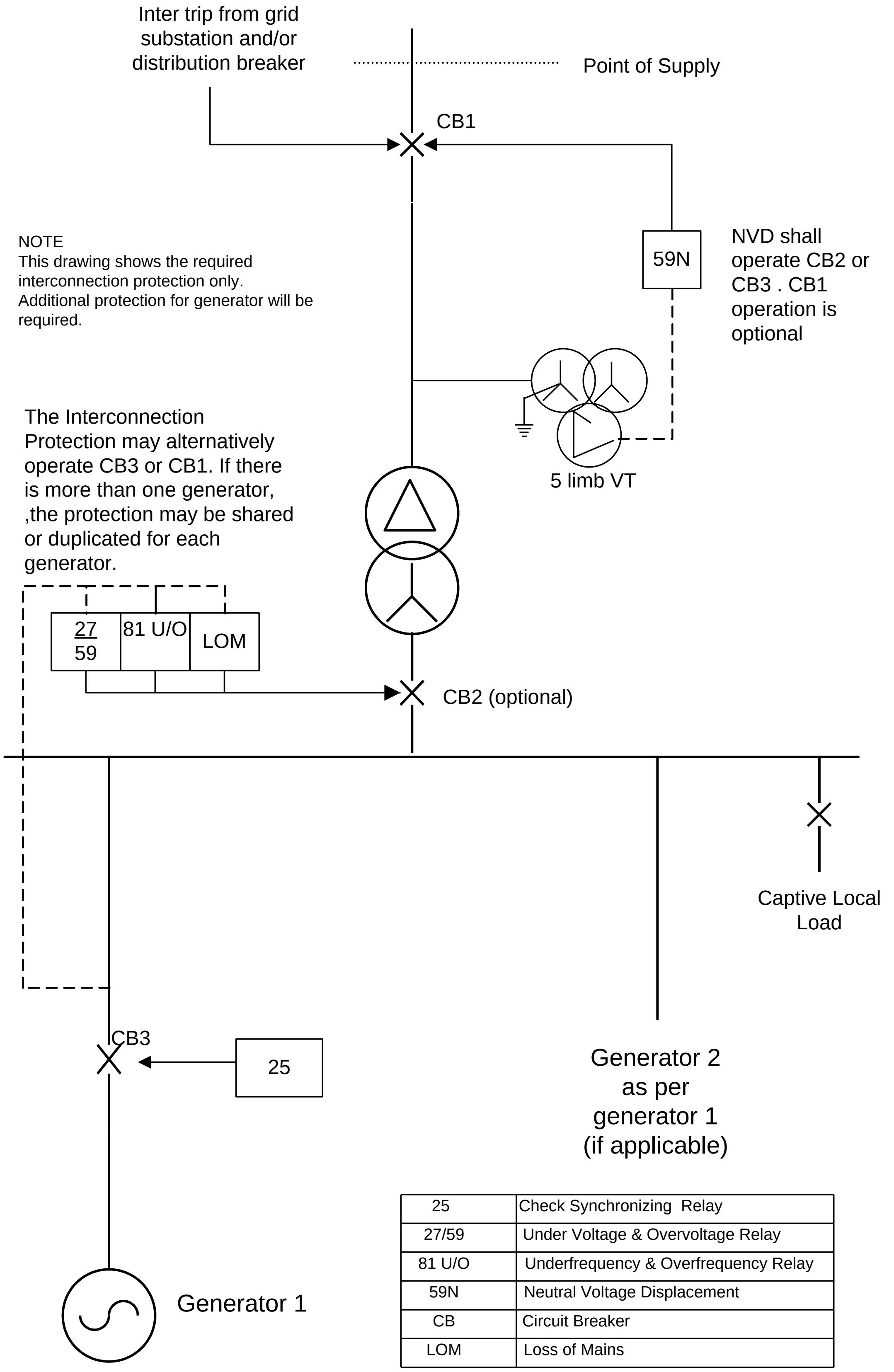
If the Embedded Generator is teed into a distribution feeder, the following is also required:

Intertripping from feeder breaker
or
Fault throwing

Design Criteria

Generators larger than 5 MW will be encouraged to obtain more secure connections. Insecurity is mainly a factor of the length and exposure of overhead lines to lightning and vegetation.

Figure B 4 - Interconnection Protection Arrangement for Case 4



25	Check Synchronizing Relay
27/59	Under Voltage & Overvoltage Relay
81 U/O	Underfrequency & Overfrequency Relay
59N	Neutral Voltage Displacement
CB	Circuit Breaker
LOM	Loss of Mains

B8.3.5 Case 5: Asynchronous Generators and Inverters, Low Captive Load

Generator Type

Mains excited asynchronous generator with local power factor correction less than the reactive power demand, or a line commutated inverter.
The DNO network/circuit capacitance is not sufficient to self excite the generator.

Conditions

- The installed generating capacity is **<u>more</u>** than 80% of the minimum Captive Load (see note below), such that load/generator balance is possible, and
- No synchronous generation or self-excited generation are connected.

Note: Minimum Captive Load is the sum of Minimum Captive Line Load and the Minimum Captive Local Load. The minimum Captive Line Load may be difficult to establish, in which case it may be assumed to be 50% of average line load.

Protection Required

Under and over voltage
Under and over frequency
Loss of Mains

B8.3.6 Self Commutated Static Inverters

Inverters commonly include proprietary protection methods including RoCoF. It is the responsibility of the Generating Company to demonstrate that the protection meets the acceptable levels of dependability and reliability.

B9 SURGE PROTECTION

Equipment associated with an embedded generator requires to be protected from hazardous effects of transient over-voltages.

Occurrence of transient over voltages can be due to external as well as internal causes. Lightning is the most common source for transient over-voltages. However, damaging transients could originate from within the grid system itself, due to switching operations, ferro resonance, etc.

Adequate measures should be taken to protect the insulation and equipment from being damaged due to the above conditions.

An LV/HV transformer usually connects the embedded generator to the grid system of the DNO. It is essential that the HV side of the transformer be protected from the transient over voltages by installing gapless metal oxide surge arresters with polymer housings.

Location of the arrestor, proper rating, connections to earth electrodes and the design of the earth system are critical factors that will maximize the arrestor effectiveness.

B10 HARMONICS

Harmonics are introduced by the non-linear devices drawing current from or injecting currents to the DNO's distribution system.

It is considered that harmonic generation through EGs is not a serious issue compared with other non linear loads that are connected to the distribution system.

However, to avoid excessive harmonic distortion on the DNO system, the EG installation shall be designed and operated to comply with the criteria specified in UK Engineering Recommendation G5/4-1.

B11 OPERATIONAL PROCEDURES AND REQUIREMENTS

The operational requirements and guidelines for an Embedded Generator following the commencement of commercial operation are given in the SPPA.

The Generating Company must give due regard to the requirements stipulated in the Electricity Act and the Electricity Regulations. They should also ensure that all operating personnel are competent, and that they have adequate knowledge and sufficient judgement to take the correct action when dealing with an emergency.

B11.1 Means of Isolation

All EGs operated in parallel with the DNO's system must include means of isolation (suitably labelled), capable of disconnecting the whole of the EG plant infeed from the DNO's system. This means of isolation must be lockable in the OFF position only, by a separate padlock. Access to the points of isolation should be kept clear and unobstructed.

DNO should have the rights of access to the means of isolation without undue delay. DNO has the right to isolate the EG's infeed at any time, should such disconnection become necessary for safety reasons and/or to comply with statutory obligations. The means of isolation should normally be installed close to the metering point, but may be positioned elsewhere with prior agreement with DNO.

A diagram showing all electrical infeeds should be displayed at the POS, or as near as practicable to it.

B11.2 Earthing Facilities for Maintenance

Adequate earthing equipment, fixed or portable, shall be provided to earth an HV section during maintenance. These shall be provided at all points of isolation of the respective section or between such point and the point(s) of work. In the case of LV points of isolation of HV equipment (such as transformers), if it is not practicable to apply earths, then precautions shall be taken according to safety rules.

B12 SAFETY ASPECTS

A Safety Code shall be implemented and used for operational activities. It shall basically contain:

- Responsibilities of persons and their definitions
- Levels of authorisation and competence
- Plant and equipment that are in operation and their definitions
- Voltage levels
- Safety rules which will clearly specify the actions that will be required to safeguard the person/s carrying out work on the plant and equipment from inherent dangers
- Training of staff to safely carry out authorised tasks to a satisfactory completion
- Specialised procedures for safety when work is carried out without isolation or earthing
- Documentation required to be completed before and after a job is carried out
- Management instructions on the application of the “Safety Code”.

Every employee shall be issued with a copy of the Safety Code and it is the responsibility of the Generating Company to ensure that all rules and procedures specified in the Code are strictly followed.

Instead of having its own “Safety Code”, the Generating Company has the option of adopting the DNO’s safety manual as its Safety Code. The Safety Code should include the relevant requirements of national electricity regulations that apply to electrical installations.

BIBLIOGRAPHY

The Electricity Act of No 10 of 2008.

Guidelines for Developers of Small Power Projects (SPP) in Tanzania, EWURA, 2009

Standardised Power Purchase Agreement for the Purchase of Grid-Connected Capacity and Associated Energy, EWURA, 2008

Standardised Power Purchase Agreement for the Purchase of Capacity and Associated Energy to Mini-grids, EWURA, 2008

UK Engineering Recommendation G.59/1: Recommendations for the connection of embedded generating plant to Public Electricity Suppliers' distribution systems, The Energy Networks Association, 18 Stanhope Place, Marble Arch, London W2 2HH, United Kingdom. http://www.ena-eng.org/ENA-Docs/

UK Engineering Technical Report No 113 (Revision 1) (1995): Notes of guidance for the protection of private generating sets up to 5 MW for operation in parallel with Public Electricity Suppliers` distribution systems, The Energy Networks Association, 18 Stanhope Place, Marble Arch, London W2 2HH, United Kingdom. http://www.ena-eng.org/ENA-Docs/

Engineering Recommendation G75/1 (2002): Recommendations for the connection of embedded generation plant, to Public Electricity Suppliers` systems above 20kV, or with outputs over 5 MW, The Energy Networks Association, 18 Stanhope Place, Marble Arch, London W2 2HH, United Kingdom. http://www.ena-eng.org/ENA-Docs/

UK Engineering Recommendation P.28 (1989): Planning limits for voltage fluctuations caused by industrial, commercial and domestic equipment in the United Kingdom public distribution systems, The Energy Networks Association, 18 Stanhope Place, Marble Arch, London W2 2HH, United Kingdom. http://www.ena-eng.org/ENA-Docs/

BS EN 61000-3-3:2008 Electromagnetic compatibility (EMC). Limits. Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection
Equiv: IEC 61000-3-3:2002

BS-EN 61000-3-2:2006 Electromagnetic Compatibility (EMC). Limits for harmonic current emissions (equipment input current ≤16A per phase)
Equiv. IEC 61000-3-2:2000 (2nd Edition) + A1:2001 + A2:2004

UK Engineering Recommendation P.29 (1990): Planning limits for voltage unbalance in the United Kingdom, The Energy Networks Association, 18 Stanhope Place, Marble Arch, London W2 2HH, United Kingdom. http://www.ena-eng.org/ENA-Docs/

UK EA Engineering Recommendation G5/4-1 (2005): Limits for Harmonics in the United Kingdom Electricity Supply System, The Energy Networks Association, 18 Stanhope Place, Marble Arch, London W2 2HH, United Kingdom. http://www.ena-eng.org/ENA-Docs/

UK Engineering Recommendation P.2/6: Security of Supply. (2005), The Energy Networks Association, 18 Stanhope Place, Marble Arch, London W2 2HH, United Kingdom. http://www.ena-eng.org/ENA-Docs/

European CENELEC Standard BS EN 50160: Voltage characteristics of electricity supplied by Public Distribution Systems.

IEC 60255 Page 79 -17.1.4, (BS 5992) Electrical Relays.

BS 7430 (1998) Code of Practice for Earthing.

BS 7671 (2008) Requirements for Electrical Installations; IEE Wiring Regulations, Sixteenth Edition.

Electromagnetic Compatibility; BS EN 61000-6-4:2001 Generic Standards Emission standards for industrial environments and BS EN 61000-6-1:2001Electromagnetic compatibility (EMC) - Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments

IEC 60909 (1988); Short-circuit current calculation in three-phase AC systems.

UK Engineering Recommendation G74: Procedure to meet the requirements of IEC60909 for the calculation of short-circuit currents in three-phase AC power systems, The Energy Networks Association, 18 Stanhope Place, Marble Arch, London W2 2HH, United Kingdom. http://www.ena-eng.org/ENA-Docs/