Scottish Hydro Power Distribution (SHEPD)

Isle of Coll Microgrid

Arinagour Islanding – switchgear arrangement

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2. INTRODUCTION

This chapter provides an overview of Arinagour microgrid, and explores the general requirements and features for creating an islanded microgrid.

Required features of the additional switchgear that should be considered for the changeover between the main grid and a standby generator are highlighted.

2.1. Scope

To ensure power supply reliability, a standby generator is planned to be installed during the winter period at Coll network to supply Arinagour village. The generator will mainly supply Arinagour village hall and the village housing estate comprising 59 houses at times of network outage, creating a Resilient Network Zone (RNZ). The maximum aggregated demand for the housing estate is 144 kVA, and for the village hall is 50kVA. A simplified schematic is shown in Figure 1.

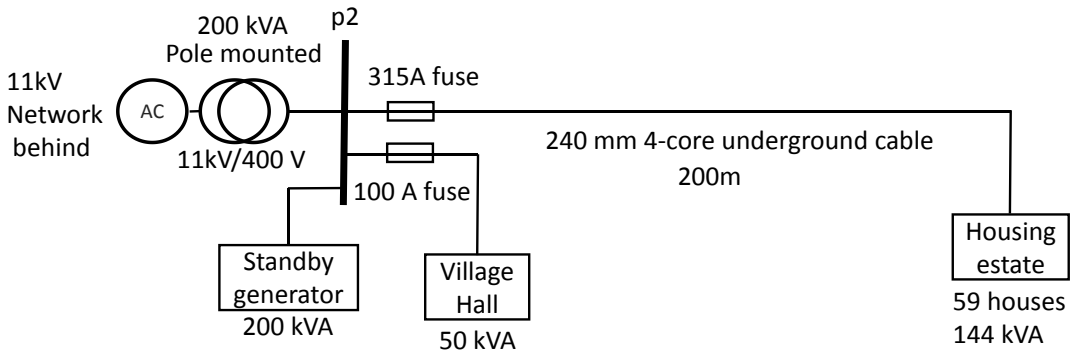

Figure 1. Simplified schematic of Arinagour LV network.

The connection of the standby generator is not a standard one, as the generator will not only supply a local load but also it will supply part of the LV network replacing the main grid during a grid outage. This is not a normal practice and special switchgear arrangements need to be considered for the safety of operation and protection of infrastructure.

The main objective of this study is to investigate the requirements for the switchover arrangement that needs to be in place to enable the standby generator to create a controlled and safe islanded network and achieve a controlled and safe transition between island-connected and grid-connected modes of operation.

This report may be read as a design consideration document which must be followed by a detailed design stage.

2.2. General requirements and features

The general requirements for creating an islanded microgrid, and required features of the additional switchgear that should be considered for the changeover between the main grid and a standby generator are explored below.

2.2.1. Steady state supply reliability

When considering steady-state operation in supply reliability calculations it is assumed that if a stable steady-state operation is possible then the source is reliable. It is necessary to examine the supply

reliability when considering an islanded operation. If instability conditions arise, they should lead to either supply tripping or further splitting of the islanded microgrid.

It is assumed here that steady-state operation is possible, when the following two criteria are fulfilled:

- The total load does not exceed the capacity of the island generation unit. This holds for active as well as reactive load. The capacity limits for active and reactive power may be linked through the current rating of the interface between the generator and the island. The active-power limit may be set by the interface or by the energy source. The latter is the case with renewable sources like solar and wind power. With combined heat and power the electrical capacity may be linked to the heat demand. Maintaining the energy balance in this way creates the foundation for managing frequency within limits.
- The voltage remains within acceptable limits for all loads. Undervoltage limits are likely to be the main limitation, but overvoltages could appear under certain load conditions together with certain voltage-control methods. The voltage criterion is only of importance for extended microgrids. When the microgrid is limited to local loads, it may be assumed that the voltage controller is able to keep the voltage within acceptable limits whenever active and reactive powers are within their limits.

2.2.2. Switching and earthing arrangements

The switchgear arrangement and specification needs to be carefully designed to ensure safe and successful transition between the grid-connected and island modes of operation.

Dynamic studies will need to be carried out to fully specify the switchgear. These are out of scope of this study, but are recommended as a next stage in the design process.

The switching arrangement that is considered in this study for the changeover between the main grid and the standby generator, is required to have the following features:

- It is adequate for a non-permanent connection of a standby generator, as the generator will be connected during the winter period only and operational for grid outage periods within the winter period, hence, when the generator is physically disconnected (and removed) there are no electrical hazards or safety issues;
- During grid connected operation, it does not impact the operation of the grid switchgear and protection;
- Its maintenance requirements shall not impact upon the normal operation of the grid;
- It can be removed from the grid with minimal disruption
- All its components are commercially available; and
- It ensures that the islanded network is not electrically floating, by incorporating an earthing point.

The following is not considered in this study:

- Detailed switching logic;
- Detailed components specifications; and
- Detailed system specifications.

2.2.3. Island fault detection and isolation

During islanded operation, the same safety and operational levels need to be ensured as for the grid-connected system.

A fault in part of the islanded network needs to be cleared locally so that the supply is continuous for the other parts of the network.

In this study, as the size of the electrical island is small, two cases are considered for network fault conditions:

- The case in which a fault on the island results in supply disconnection to the whole island; and
- That in which a fault on the island results in disconnection of the faulted network branch only.

2.2.4. Cost attractiveness

In general, there will always be a trade-off between cost and functionality. The more functionality a given solution can achieve, the higher its cost would be.

The objective in this study is to investigate solutions on the lower cost side. These will consider the use of electromechanical solutions, rather than hybrid or full solid-state solutions.

Hybrid and full solid-state solutions can potentially provide closed mode transitions, but will require higher investment than conventional electromechanical solutions. Closed mode transitions can provide a great benefit if the microgrid is mission-critical (with sensitive loads; e.g. hospitals), to guarantee the continuity of supply within the millliseconds time domain.

A closed transition is not required in the case of using a standby diesel generator (and non-mission critical microgrids) to supply the islanded microgrid, and hence electromechanical solutions are assumed as cost attractive for the intended implementation in this study.

2.3. Conclusions

General requirements have been set out in this chapter.

The supply reliability requirements are general requirements that apply for any power source connected to a network. The reliability is measured in general terms through achieving steady state stability of the network. A two criteria has been set out to determine the supply reliability.

Other specific requirements for the study here are the switchgear requirements and island fault detection and isolation.

It is assumed that the additional switchgear should invisible to the main grid, during grid connected operation. During islanded mode, it should provide the same level of protection to the islanded network. An island fault needs to be detected and isolated.

There are many solutions that can be adopted to satisfy all requirements and features for microgrids islanding. Solid-state solutions, providing closed transition between different modes of operation are considered less attractive, mainly from the cost point of view, for Arinagour microgrid.

All the requirements and features discussed in this chapter are presented in more detail for Arinagour microgrid in the following chapters.

3. STAEDY STATE SUPPLY RELIABILITY

As discussed in the previous chapter, the supply steady state reliability can be assumed if a stable steady state operation is possible.

The steady state stability is examined in this chapter with regards to the two criteria discussed in Section 2.2.1.

3.1. Grid-connected operation

Arinagour village LV network has been modelled in DigSILENT Power Factory to examine and set a base case for the steady state supply reliability regarding the two criteria listed in Section 2.2.1. The schematic is shown in Figure 2.

The reactive power demand of the load is assumed as 20% of its maximum value. The feeders' parameters to the village hall and housing estate are listed in Table 1.

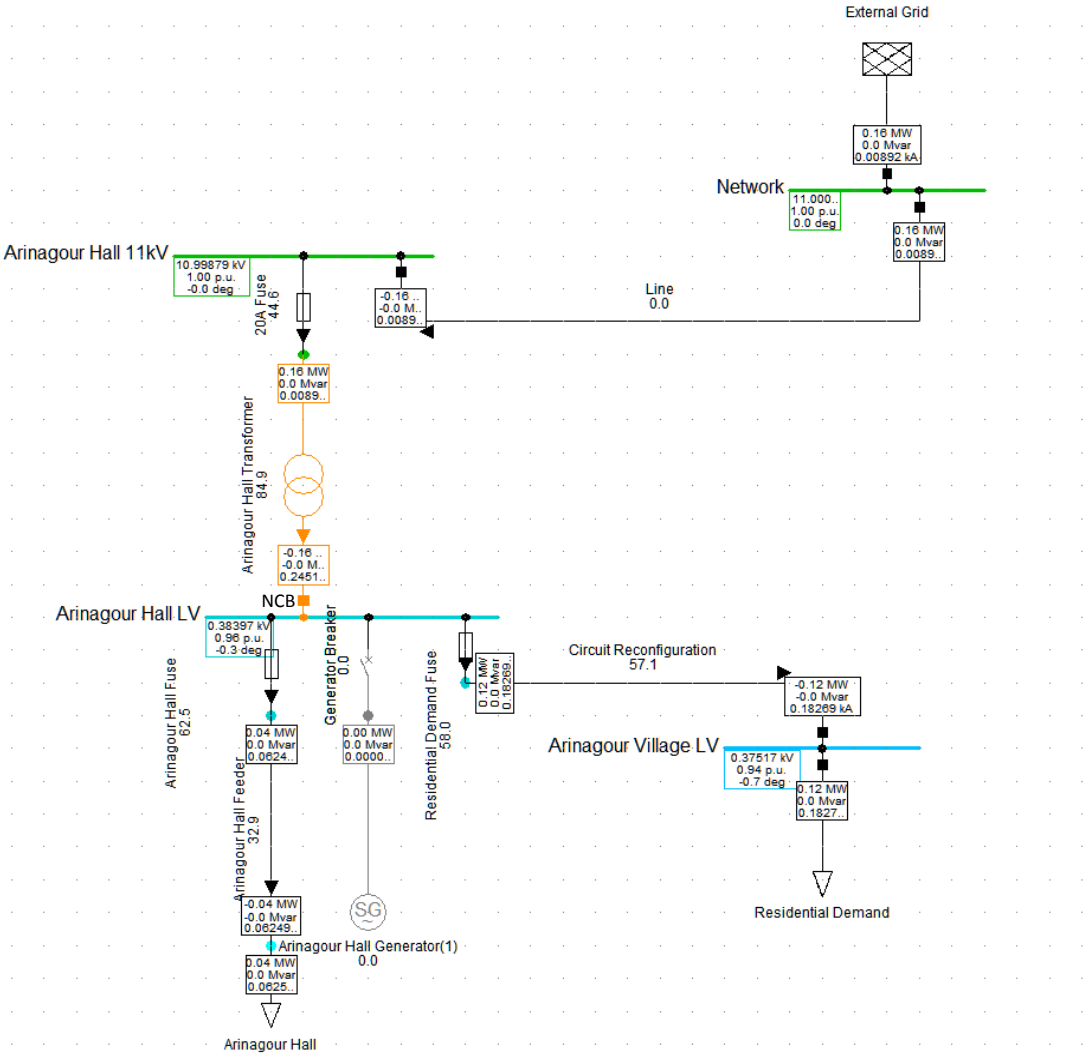

Figure 2. Arinagour village LV network.

Table 1. Feeder parameters.

Parameter	Arinagour hall feeder	Housing estate feeder
Cross-section	95 mm	240 mm
Length	87.5 m (inferred from map scale)	200 m
Resistance	0.320 Ω/km * 0.0875 km = 0.028 Ω	0.125 Ω/km * 0.2 km = 0.025 Ω
Reactance	0.0735 Ω/km * 0.0875 km = 0.00643 Ω	0.0730 Ω/km * 0.2 km = 0.0146 Ω
Current Rating	190 A	320 A

3.1.1. Local generation

A mobile standby diesel generator will be connected during the winter period at Arinagour Hall. The generator is rated 200 kVA, with continuous output power of 150 kW, 188 kVA (113.3 kVAr)[1].

The generator is modelled as a synchronous machine using generic data. It is electrically disconnected during grid-connected operation using a generator breaker (GCB), as shown in Figure 2 above.

During island operation, the main grid is disconnected using an additional normally-closed circuit breaker (NCB) while the standby generator is connected using the GCB.

3.1.2. Protection

Protection fuses are implemented for the feeders, and modelled as:

- 20 A fuse on the HV side of the transformer at Arinagour Hall
- 200 A fuse on the Arinagour Hall load feeder
- 315 A fuse on the Arinagour Village load feeder

The generator protection is not modelled, but the generator circuit breaker (GCB) is implemented for connection and disconnection of the generator in different modes of operation.

3.1.3. Steady state operation

The power flow results for steady state operation during grid-connected mode are displayed on Figure 2.

During steady state operation, the main grid supplies 160 kW to the loads.

The voltage amplitude at the end of the houses feeder is 375.22 V (0.94 pu) and at the village hall is 384.02 V (0.96 pu).

The two criteria for steady state supply reliability are assumed fulfilled during this mode of operation.

3.2. Island operation

The Arinagour LV network is disconnected using a normally-closed circuit breaker (NCB), and the generator is connected using the generator CB (GCB).

[1] Source: Aggreko data sheet

The steady state power flow results are captured as shown in Figure 3.

The results show that the steady state requirements are achieved, where:

- The standby generator is supplying the loads with 160 kW; and
- The voltage amplitude at the houses feeder is 391.56 V (0.98 pu) and at the village hall is 400 V (1.0 pu). Note that the voltage profile in this case is better than the grid-connected case, as the generator holds the voltage at the point of common coupling (PCC) at 1 pu.

The above two points fulfil the steady state supply reliability criteria for the generator.

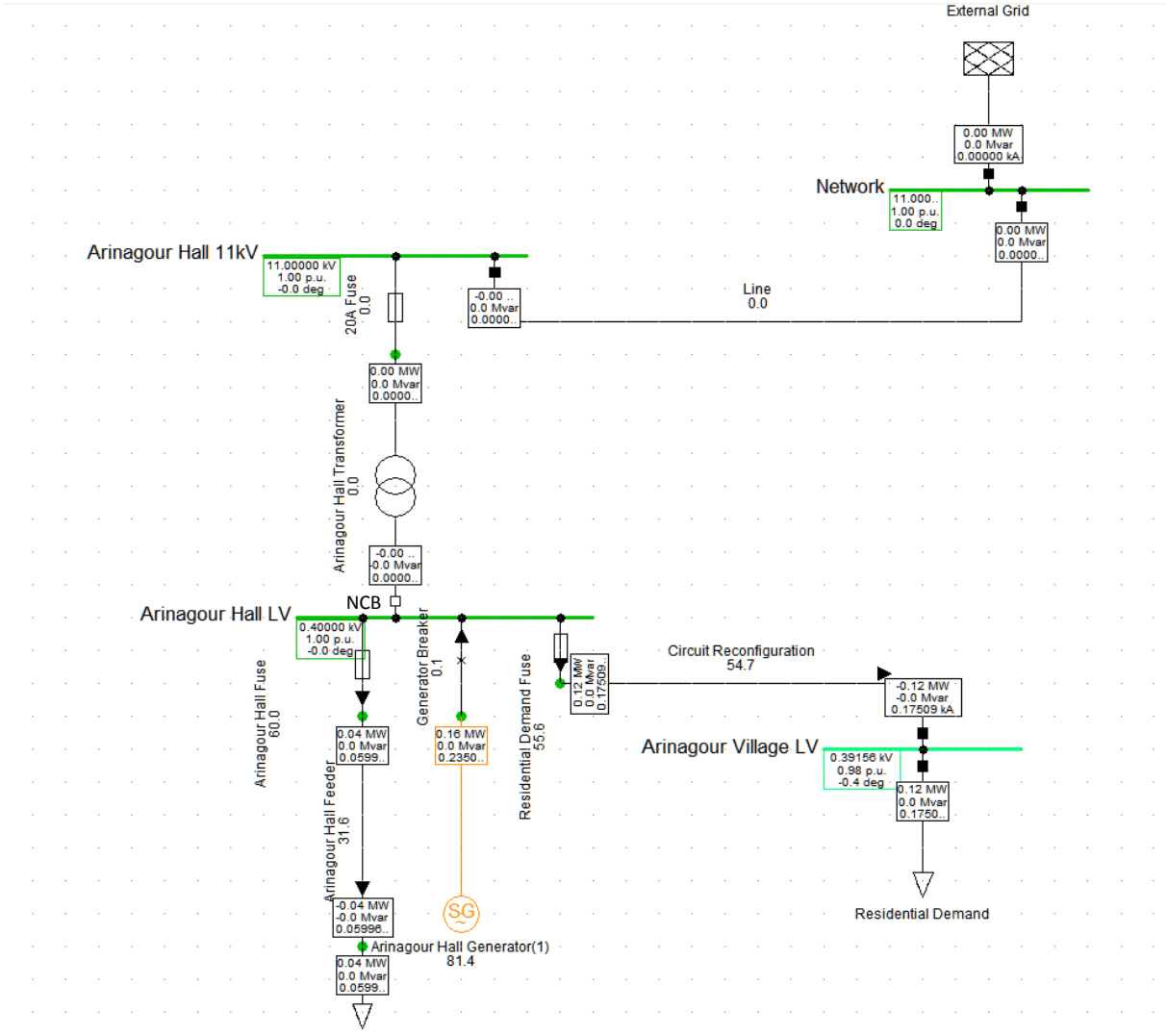

Figure 3. Power flow during island operation.

3.3. Conclusions

Arinagour village network has been modelled using DigSILENT Power Factory to examine the steady state supply reliability during island operation. Reliability during grid connected operation has been tested first to set a base case.

The standby generator was modelled using a generic synchronous machine model (and data available from Aggreko data sheet), and reactive power demand was assumed as 20% of maximum demand.

The generator supplied the required demand with adequate voltage profile (as compared to the grid-connected mode).

It is concluded that the standby generator is reliable to supply the island during steady state operation.

4. SWITCHING AND EARTHING ARRANGEMENTS

In this chapter two switching arrangements are proposed to switchover the power supply to Arinagour microgrid from the main grid to the standby generator; in case of grid outage (and vice versa; in case of grid recovery).

The requirements set out in Section 2.2 are assumed. The main components of the switching logic are also proposed and the earthing requirement is considered.

4.1. Switching arrangements

Conventionally, an automatic transfer switch (ATS) is utilised to detect the loss of the main-grid voltage and switch-in a standby generator to supply a critical load.

The ATS functionality is considered differently in this study. The ATS is used to detect the loss of the main grid voltage, as described above, but instead of switching in the standby generator it creates an electrical island. Once the island is created the generator switches-in to supply the demand on the islanded network.

The ATS continues to monitor the main-grid voltage in the islanded-mode, and when the main grid supply is available it switches back to the grid-connected mode as described in the next Section.

The ATS provides a time-delayed automatic transition through utilising electromechanical components.

It comprises Normal contacts (NCB), Emergency contacts (ECB) and ATS controller, as shown in Figure 4 for two arrangements.

The NCB is a normally-closed circuit breaker and the ECB is a normally-open circuit breaker (CB). Four-pole CBs are to be utilised. In general terms, the neutral poles need to make first and break last. The continuous current rating and the closing and withstand rating of the neutral pole should be identical to the rating of the main poles.

The NCB and the ECB are conventionally (in commercially available ATSs) interlocked mechanically and electrically to prevent simultaneous closing. This is however not required in the arrangements proposed in Figure 4 for Coll. On the contrary, a decoupled operation is required for island protection using only the ECB for the Switching Arrangement B shown in Figure 4 (b).

The LV fuses; L1 fuses and L2 fuses shown in Figure 4, are not part of the ATS. These are the LV fuses already installed to protect the village houses and hall during grid-connected mode. These fuses can be either located at the transformer pole where access to its terminals need to be provided for the ATS connection, or, more conveniently, at the same switching cabinet as for the ATS.

LV fuses are assumed to be disconnected following a grid fault; either blown up by a fault current or disconnected using a dedicated isolator that shall be activated by the ATS.

Specific details of these fuses will need to be checked during the detailed design stage (beyond the scope for this study) of the switching arrangement to ensure safety of maintenance personnel and the adequate integration of these fuses into the switching cabinet.

The generator circuit breaker (GCB) is not part of the ATS. GCB is an integral part of the standby generator. It is a 4-pole CB[2]. The GCB may be switched on using the generator local settings. A time delay will need to be in place for its operation, to ensure that the ATS has succeeded in building the

[2] Source: Aggreko data sheet

electrical island. In case of ATS failure, the generator will continue to be isolated and the switching on of the GCB will be on no-load if L1 fuses and L2 fuses are disconnected.

GCB may be, preferably, switched on after receiving a trigger signal from the ATS, so that the designed switching sequence is ensured. This will require a communication link to be established between the generator and the ATS[3].

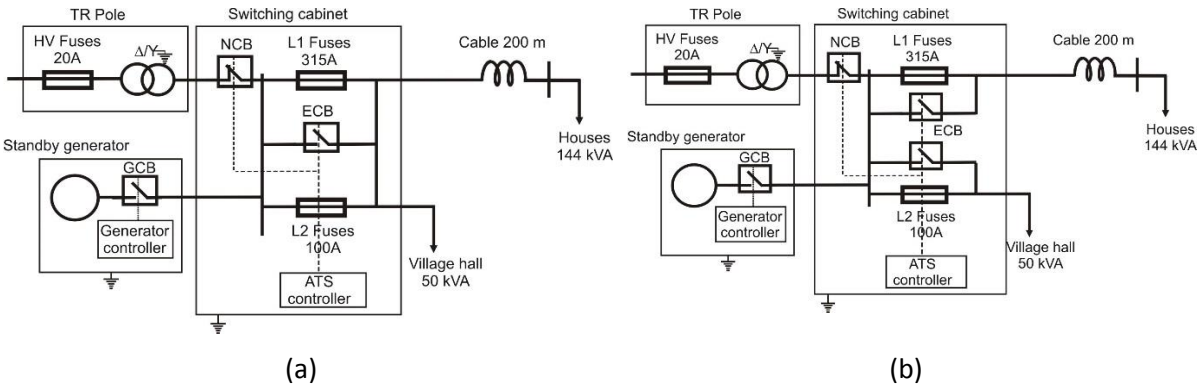

Figure 4. Two Switching arrangements for flexible connection of standby generator.

4.1.1. Switching Arrangement A

In Switching Arrangement A, one emergency circuit breaker (ECB) is implemented for both the feeder to the village houses and the village hall. In this arrangement, both the houses and the hall are treated as one load. The ECB is fully rated for the system.

During grid-connected operation, the power flows from the main grid to the loads as shown in Figure 5 (a). NCB is closed, ECB is open and GCB is open.

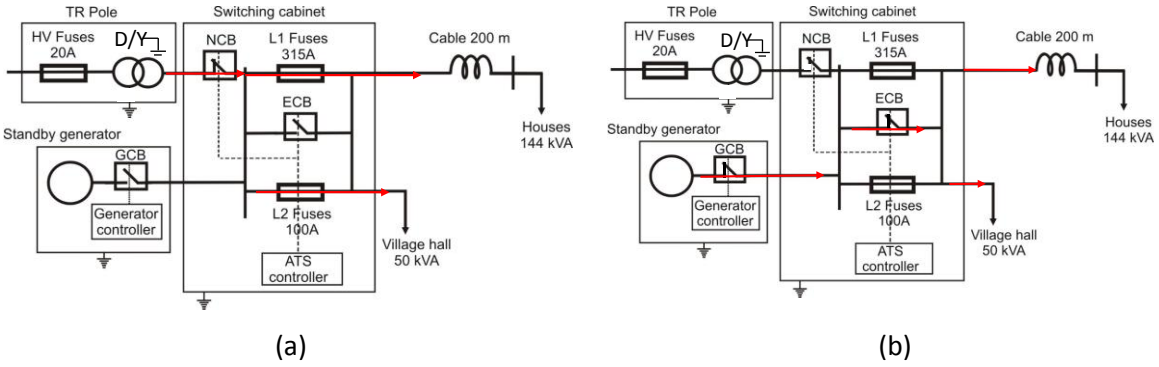

Figure 5. Switching Arrangement A: power flow in red arrows (a) during grid-connected operation (b) during islanded operation.

During island operation, and assuming the LV fuses (L1 fuses and L2 fuses) are disconnected, power flows from the standby generator to the loads through ECB, as shown in Figure 5 (b). The ATS

[3] It is not clear from Aggreko data sheet if this communication link is readily available.

protection will be activated to ensure the operational safety of the islanded microgrid. Additionally, the standby generator has its built in protection to ensure its safety of operation.

4.1.2. Switching Arrangement B

In Switching Arrangement B, shown in Figure 6, two emergency circuit breakers (ECBs) are implemented; one for the village houses and another for the village hall. In this case, ECBs can have lower rating than the NCB, and the ECB connecting the village hall can have lower rating than the ECB connecting the houses feeder in accordance with the fault level of the relevant feeder.

During grid-connected operation, the power flows from the main grid to the loads as shown in Figure 6 (a). NCB is closed, ECB is open and GCB is open.

During island operation, and assuming the LV fuses (L1 fuses and L2 fuses) are disconnected, power flows from the standby generator to the loads through ECB as shown in Figure 6 (a).

In this arrangement, a fault at the houses feeder during island operation will trip only the houses feeder ECB and leave the village hall supplied by the generator and vice versa.

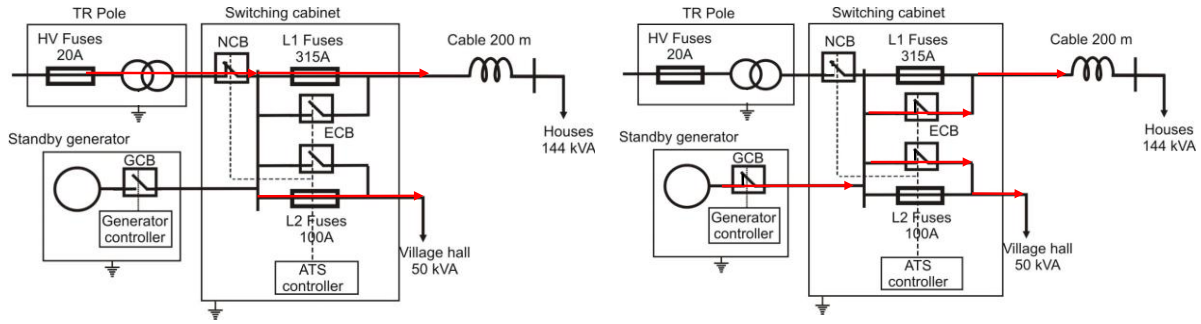

Figure 6. Switching Arrangement B: power flow in red arrows (a) during grid connected operation (b) during island operation.

4.2. Switching logic

A simplified flowchart of the main parts of the switching logic is shown in Figure 7. It should be noted that this is not a detailed design. Additional manual inputs are not considered. Normal maintenance procedures and sequence interruptions are not regarded.

The switching logic for both the generator and the ATS shall be similar, yet differ in that the generator logic shall have a delayed transition to allow the ATS to firstly build the electrical island.

During grid-connected operation, both the ATS and the generator monitor the grid voltage.

If a loss of the grid voltage is detected, the ATS will open the NCB and close the ECB. A check that the switching operation is established can be performed locally at the ATS. If the switching operation is not established, an ATS fault is flagged and no island will be created. If the switching operation is established, a “trigger signal” will be sent to the generator CB (GCB) if a communication link is established.

The Generator controller may switch on the GCB after a set time delay, “OR” on receipt of a “trigger signal” from the ATS. The “OR” path shown in Figure 7 for this transition is to provide robust operation if the communication channel between the ATS and the Generator cannot be achieved.

When the GCB closes, the generator will start supplying the islanded microgrid.

During island operation, both the ATS and the generator will continue monitoring the grid voltage. Additionally the ATS and generator protection will ensure safe islanded operation.

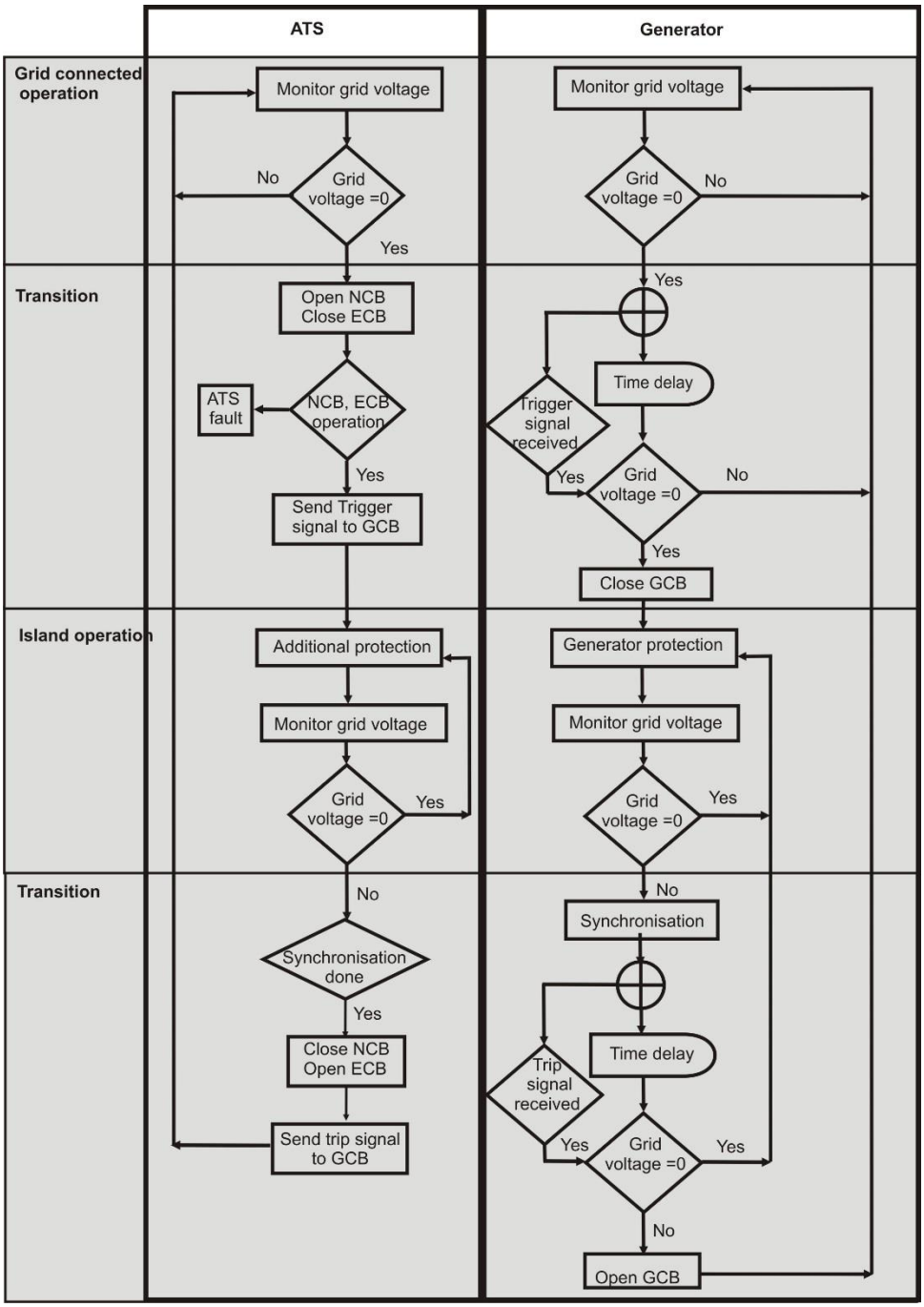

Figure 7. Simplified flowchart of the switching logic.

Ground fault protection (GFP) is assumed for the ATS as discussed later in Section 5.3.2. For Switching Arrangement A, the GFP will disconnect the islanded microgrid in case of island fault by opening the ECB. For Switching Arrangement B, the GFP will selectively trip the faulty path by opening the corresponding ECB.

When the grid voltage is recovered, a parallel operation is possible if the generator synchronisation equipment is utilised according to G59/1 for a short period (1-5 min). This will allow a closed transition to grid connected mode. In this case, the generator will synchronise with the grid voltage before the ATS connecting back the main grid. After the synchronisation is established, the generator controller may send a signal to the ATS to return to grid-connected mode. On receipt of the signal, the ATS closes the NCB and opens the ECB (assuming the LV fuses are connected). The ATS sends a trip signal to the generator to disconnect from the grid. The GCB opens.

4.3. Earthing

In general terms, low voltage generators need to be solidly earthed to provide the same supply characteristics when operating from the generator in island mode as provided by the normal grid power source.

The earthing principles of an electric system affect the electrical equipment rating. The earthing principles define the personnel safety and the system protection principles which have to be applied. A high impedance earth system will result in significant voltage stresses during grid contingencies, meanwhile in the case of a low impedance earth, the system will experience significant current stresses.

Low impedance earthing is recommended for Arinagour microgrid (solid neutral grounding) as the main protection during islanding is an overcurrent protection (or ground fault protection) requiring more significant fault level to activate the protection, as discussed later in Section 5.3.

When a solid neutral earthing is implemented, a fully rated bus bar with required Al/Cu neutral lugs shall be utilised.

4.3.1. Grounding switch (GS)

In normal operation (grid-connected operation), if a neutral earthing point exists in close proximity, a controlled grounding switch (GS) needs to be put in place. This will mainly be of special importance in case of implementing a Ground Fault Protection (GFP) for the ATS control. GFP will be triggered using the current measured at the neutral, and may not operate at certain conditions if a neutral/ground loop exists – as shown in Figure 8. In the figure the earthing points are assumed in close proximity. In this case the neutral current sensor will measure less current in comparison to the protection settings, hence tripping will not be established.

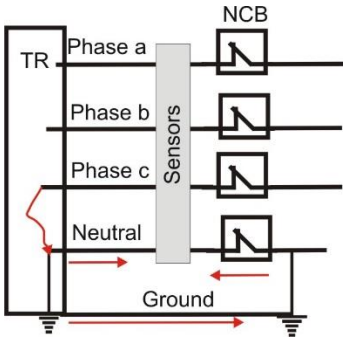

Figure 8. No ground switch, fault current path in case of phase c to ground fault. Sensors on the neutral measure less current depending on the location of the fault and distance between earthing points.

The GS prevents mixing of ground and neutral currents during grid-connected operation.

Additionally, a GS allows the neutral to be either grounded at the generator or not, without impacting the fault level settings of the ATS.

In the case of Arinagour microgrid, the generator neutral does not need to be grounded at the generator, as shown in Figure 9, however, as the generator is close enough to the ATS and there are no loads in between. Additionally, a GS is not required as:

- The ATS implements loss-of-voltage protection rather that GFP on the grid side, during grid connected operation.
- During island operation, the only neutral earthing point is at the ATS (as the rest of the upstream system is isolated), hence an earthing loop cannot be established and a GFP can be implemented.

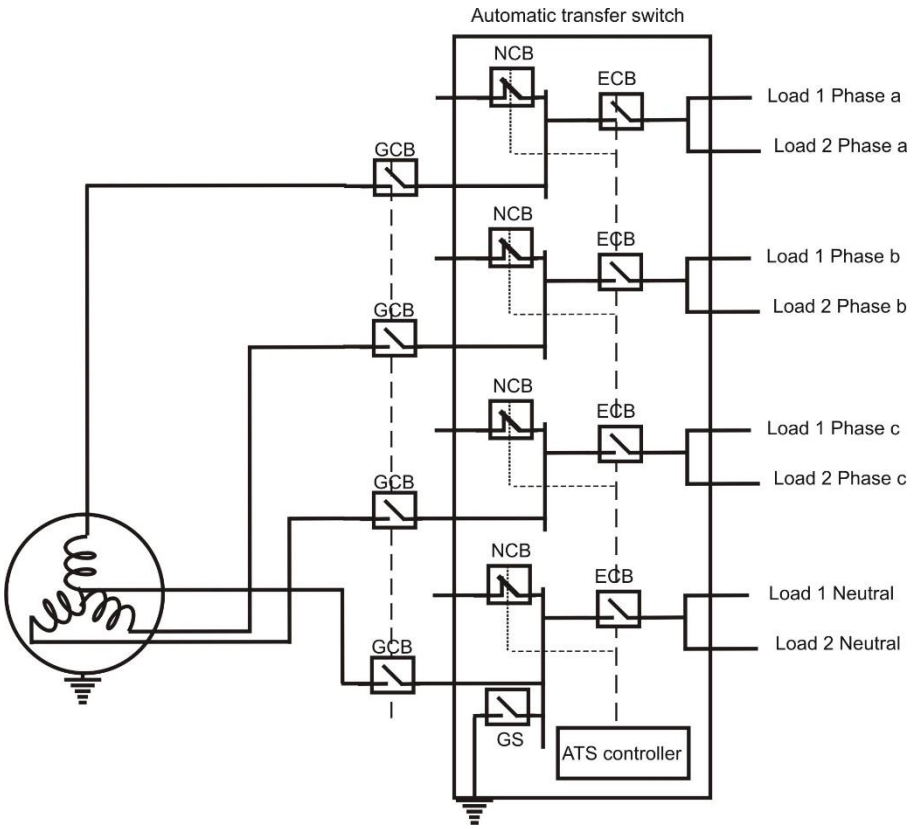

Figure 9 Three phase diagram with earthing implemented using a ground switch.

4.3.2. Cable discharge

If the generator neutral is grounded at the generator, and if the GCB closes before the ECB for any unforeseen reason, the cable may discharge through the generator and depending on the settings it may activate the generator protection. This is an unwanted operation, and hence it is recommended not to ground the generator neutral at the generator.

4.4. Conclusions

Two switching arrangements for the changeover between the main grid supply and a standby generator, to ensure supply continuity for Arinagour village, have been considered in this chapter. These arrangements utilise commercially available electromechanical switchgear components.

In Switching Arrangement A, Arinagour microgrid is considered as a single load. A fault during island operation will result in disconnection of the microgrid. Switching Arrangement B provides isolation of the faulty path only during and island operation, ensuring higher resiliency for a part of the islanded network.

While Switching Arrangement A may satisfy the requirements for Arinagour microgrid, Switching Arrangement B is recommended for bigger microgrids.

Earthing for these arrangements has been considered. It has been recommended that a solid neutral earthing is utilised at the switching cabinet, without the need for a grounding switch or generator neural grounding.

5. ISLAND FAULTS DETECTION AND ISOLATION

Successful fault detection and isolation during islanded mode is a primary requirement. Fault levels during grid-connected mode and during islanded mode are examined in this chapter, in simulation, to determine the impact on the protection equipment settings for the two modes.

Additionally, this chapter provides an overview of the protection schemes that need to be considered for protecting the system.

5.1. Fault levels

To calculate the fault levels for Arinagour village, the following assumptions have been implemented in the simulation model:

- The fault-level impedance infeed from Dervaig 11kV was set to 3.74 Ohms and represented as reactance only. This was calculated assuming 1.7kA three-phase RMS break current. This was assumed as the main infeed for Arinagour village.
- The standby generator stator resistance is assumed as 0.01 p.u. and subtransient reactance 0.074 p.u. These are calculated using 4kA as the upper range of the generator short circuit protection as extracted from Aggreko generator data sheet (provided by SSE). The stator resistance was assumed as 15% of the subtransient reactance.

The fault levels at the connection point of the generator (PCC), where the switchgear for the changeover is to be implemented, are examined in simulation for different (three-phase to ground) fault locations, as listed in Table 2, for grid-connected and islanded modes.

Table 2. Fault levels in MVA at PCC.

Fault location	Grid-connected mode (MVA)	Islanded mode (MVA)
Load end of village feeder	2.23	1.97
Middle of village feeder	2.91	2.33
Hall	2.23	2.11

As expected the fault levels decrease when in island mode. They do not decrease as much as expected however.

It can also be noticed that the fault levels at the PCC for a fault at the hall and at the end of the village feeder are not very different. It can then be concluded here that the fault ratings for all switchgear components of the switching arrangements will be similar. This will need to be revisited/confirmed however, in the next stage when:

- The infeed fault level/system strength is confirmed; and
- Dynamic simulations are performed.

5.2. Fault isolation

5.2.1. Switching Arrangement A

If a fault occurs at the feeder of the houses during islanded operation, the whole microgrid will be disconnected from the standby generator.

5.2.2. Switching Arrangement B

Selective isolation can be carried out using the ECBs, in this arrangement. Detailed dynamic simulation will be required in a subsequent follow on study to determine the settings required for this operation.

5.3. Protection

Protection logic is not discussed here in details. The main objective of this section is to list the basic protection schemes that need to be implemented.

5.3.1. Voltage loss

The main protection that triggers the ATS operation is voltage loss; which can be detected using voltage sensors and a set trigger threshold (less than 50% of nominal line voltage is recommended in some literature).

No time delay will be implemented after the detection.

5.3.2. Ground fault protection (GFP)

Figure 10 shows the GFP sensors location. These are current sensors.

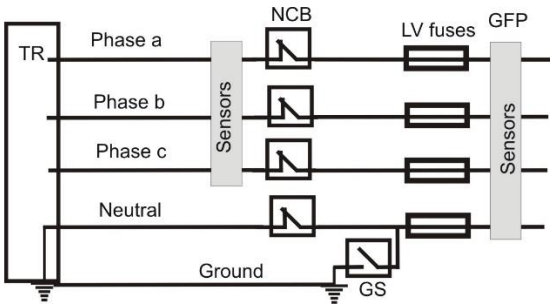

Figure 10. Location of GFP sensors.

During grid connection, GFP is redundant as the ECB is open.

During islanded operation the GFP will open the ECB in case of neutral overcurrent.

5.3.3. ATS fault

An internal fault at the ATS shall fail to open ECB and closed NCB. This will disconnect the generator if in island operation, and will not disturb the grid if in grid-connected operation.

Most commercially available ATSs comprise a manual by-pass switch, which would potentially by-pass the whole unit for regular maintenance or in case of faults.

It is recommended to consider further safety aspects for maintenance personnel for the disconnection of the switching cabinet and replacement of any component in the cabinet.

5.3.4. Fused switch

A fused switch (FS) might be implemented for the low voltage fuses and electrically interlocked with the ECB for:

- Electrical disconnection of the LV fuses so that controlled protection operation can be achieved during the islanded operation.
- Safety replacement and maintenance of the LV fuses, while the ECB is conducting.

The switch in series with the LV fuses can be an isolator, regarding the proposed switching sequence where the ATS will operate first at the grid outage before the standby generator supplies the island. In this case the FS will open on zero-current.

Once opened, it can be left open until manually switched on to close position by a maintenance engineer. The ECB can then be opened.

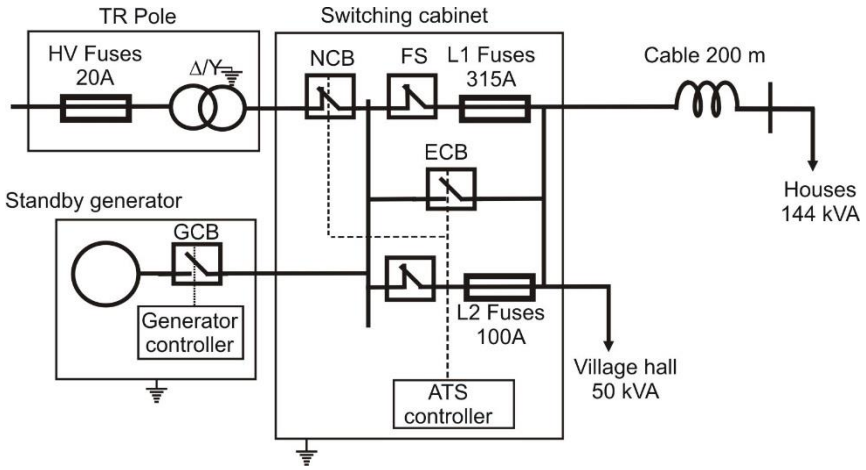

Figure 11. Switching Arrangement A with a fused switch.

5.3.5. Generator protection

The generator is assumed to have the following local protection active at all times:

- Overvoltage
- Undervoltage
- Over-frequency
- Under-frequency
- Overcurrent

The protection settings for these should be designed for island operation only, as the generator will work in parallel operation only for a very short time during the transition from island-mode to grid-connected mode.

The GCB should open in case of any triggering of local protection. Local generator protection tripping should take priority over a tripping signal from the ATS.

5.4. Conclusions

In this chapter, fault levels at the point of common coupling (PCC) of the standby generator have been examined in simulation for grid-connected operation and island operation for a three phase to ground

fault. Fault levels have been found to be very close regardless of the location of the fault and the operational mode. This suggests that the ratings for various switchgear components for the two proposed arrangements will be similar.
The protection schemes to be implemented have been discussed. While undervoltage protection is the main protection scheme for the ATS during grid-connected mode, an overcurrent protection scheme (or ground fault protection) is recommended as the main protection scheme during island mode.

Additionally a fused switch has been recommended to disconnect the LV fuses during islanded operation.

6. COST ANALYSIS

Cost estimation is provided in this chapter. The cost figures are not precise as the final specifications of different components have not been determined at this stage of the study. The cost figures are only meant to be used for the comparison purposes between the two proposed switchgear arrangements.

6.1. Main components cost estimation

Two switching arrangements are proposed for the safe changeover and operation of Arinagour microgrid as described in the Chapter 4.

Initially Switching Arrangement A was considered as a first option, as it treats Arinagour microgrid as a single load and hence it was thought that an off-the-shelf automatic transfer switch (ATS) can be utilised with minimum changes. Commercially available ATSs normally designed for two sources and one load.

The use of the ATS for microgrids is however different operationally, as its primary function is not to switch the power supply between the two sources but rather establish the islanded infrastructure. In brief, even with commercially available ATSs some engineering work will be required to adapt its functionality to the microgrid requirements.

Some cost estimates for Switching Arrangement A are listed in Table 3, only for comparison purposes with Switching Arrangement B – as the detailed specifications of the different components are out of scope of this study.

Switching Arrangement B will require a bespoke ATS and is consequently assumed to require more system integration labour time, as shown in Table 4.

Note that Table 3 and Table 4 are not meant to provide a detailed bill of material (BOM). Final cost may vary according to the components specifications.

Table 3. Estimated cost of Switching Arrangement A. Note: cost of footprint not considered.

Element	No of pieces	Estimated cost per piece [k£]	Estimated total cost [k£]	Comments
Off the shelf ATS – (275-500 A)	1	5-7	5-7	These are provided as stand-alone units in enclosures and front panels for monitoring and limited control changes. To adapt for Coll scope (microgrids scope), some additional engineering services are considered
FS	2	0.2	0.4	4-pole isolator for disconnection of the LV fuses
System integration	NA	10	10	Labour time for system integration
Auxiliaries	NA	2	2	Cabling, line sensors, etc..
Power supply	1	0.5	0.5	24 Vdc power supply with battery (UPS) for the control and protection
Cabinet	1	4	4	Street-furniture grade cabinet

Total			21.9 – 23.9	

Table 4. Estimated cost of Switching Arrangement B. Note: cost of footprint not considered.

Element	No of pieces	Estimated cost per piece [k£]	Estimated total cost [k£]	Comments
NCB	1	0.3	0.4	4-pole CB – 280 A
By-pass switch	1	0.3	0.4	4-pole manual breaker
FS	2	0.2	0.4	4-pole isolator for disconnection of the LV fuses
ECB for line 1	1	0.2	0.2	4-pole CB – 200 A
ECB for line 2	1	0.1	0.1	4-pole CB – 80 A
System integration	NA	20	20	Labour time for system integration
ATS controller	1	4	4	For multiple switchgear installations. Comprehensive parameters for accurate, reliable and maintenance free mains (utility) monitoring and control. Remote communications and PLC functionality.
Auxiliaries	NA	2	2	Cabling, sensors, etc.
Power supply	1	0.5	0.5	24 Vdc power supply with battery (UPS) for the control and protection
Cabinet	1	3	3	Estimated dimensions
Total			31	

Comparing the cost of the two proposed switching arrangements and with account of functionality and scalability, Switching Arrangement B is recommended for Arinagour microgrid for a follow-on detailed design.

6.2. Conclusions

From the above cost estimation for Switching Arrangement A and Switching Arrangement B, it is estimated that the main cost difference will lie in the system integration cost, which might double for Switching Arrangement B.

However, as all components are commercially available the difference in labour cost is not regarded as high. With the additional feature of Switching Arrangement B of better handling the island faults, this switching arrangement is preferred. Additionally, Switching Arrangement B may require less footprint than Switching Arrangement A as all elements shall be integrated as one product.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

In this study, switching arrangements have been proposed and design considerations have been discussed for the changeover arrangement for a standby generator to supply an islanded Arinagour microgrid.

Two switching arrangements have been considered:

- Switching Arrangement A: using a normally-closed circuit breaker at the main-grid feeder, and one normally-open circuit breaker that bypasses the LV fuses.
- Switching Arrangement B: using a normally-closed circuit breaker at the main-grid feeder and two normally open circuit breakers; each one bypasses LV fuses of a downstream feeder.

It was considered important to have an isolator connected in series with the LV fuses, so that these fuses can be electrically disconnected from the circuit on the occurrence of an upstream fault that results in an islanded operation. This is mainly to enable the protection of the downstream network during islanded operation.

The switching arrangements implement loss-of-voltage protection during grid-connected operation, and ground fault protection during islanded operation.

Earthing at the switching cabinet was recommended to ensure proper detection of ground faults. Grounding of the generator neutral has been considered not necessary.

Fault level analysis at the generator connection point has resulted in similar fault levels in different operational modes and applying faults at different locations. The ratings of the components of the switching arrangements can be similar.

Cost estimation analysis has showed that the cost of the two switching arrangements is similar, as both arrangements will require modification and system integration of off-the-shelf components. Switching Arrangement A is estimated to be less expensive (£22-24k) compared to Switching Arrangement B (£31k) however.

7.2. Recommendations

Taking into account the additional features of Switching Arrangement B in that it allows for further split of the islanded microgrid and is scalable, it is recommended that this arrangement be investigated in more details as a next step. The final recommended arrangement is shown in Figure 12.

However, with a small amount of further study it is believed that a decision could be made to implement Switching Arrangement A as a less expensive option if the cost/benefit case can be made in relation to SSEPD objectives to enhance supply reliability on Coll under regulatory obligations and incentives.

Dynamic system studies (power system transient analysis and calculations) need to be conducted to fully specify the different components of the switching arrangement and ensure successful transition between the different modes of operation. This can be followed by detailed protection and control logic design.

It is also recommended that a design procedures specification document is developed for Switching Arrangement B for wider roll out.

It is finally recommended to investigate solid-state solutions for closed transition for mission-critical microgrids.

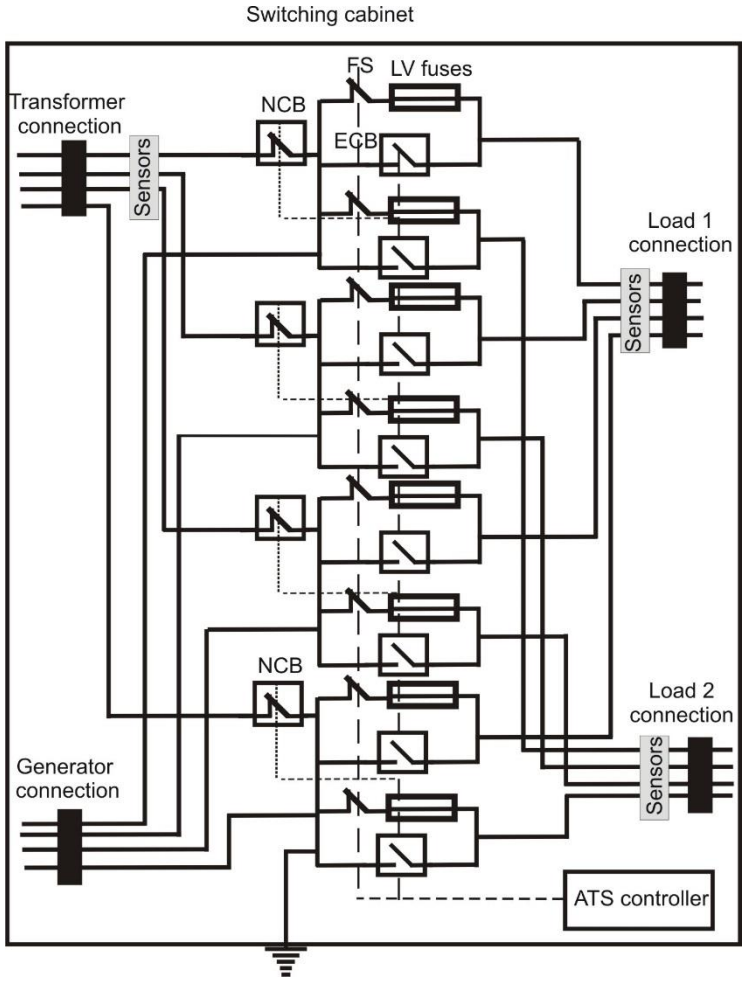

Figure 12. Proposed switching and earthing arrangement (only main components shown).