

PROTECTION CONCEPTS FOR MV ISLAND GRID – AN APPLIED APPROACH

Christina TZANETOPOULOU
BKW Energie AG – Switzerland
Christina.Tzanetopoulou@bkw.ch

Matthias DIETRICH
BKW Energie AG – Switzerland
Matthias.Dietrich@bkw.ch

Luigi SCOCA
BKW Energie AG – Switzerland
Luigi.Scoca@bkw.ch

ABSTRACT

The continuously increasing penetration of renewable energy resources has brought up the subject of intentional islanding operation. Islanding operation refers to supplying parts of the grid exclusively through distributed energy generation (DEG), without connection to the main grid.

Considerable penetration of DEG creates a reverse power flow, which challenges the traditional protection schemes. Intentional islanding operation creates additional challenges.

This work aims at highlighting the factors, which need to be considered upon designing protection concepts for intentional islanding operation on Medium Voltage (MV) Grids.

INTRODUCTION

According to 1547.4 IEEE Standard [1], the term “distributed resources island systems”, sometimes referred to as micro-grids, is used to describe parts of the electrical grid which include both DEG and load and have two modes of operation. They can operate connected to the main grid, but they can also operate after intentional disconnection from the main grid. We will refer to these modes as “grid-connected” and “island” mode respectively. The term “island systems” might refer to Low Voltage (LV) and Medium Voltage (MV) network.

For an island grid to be able to operate autonomously, without connection to the infinite bus, certain requirements regarding the installed capacity, mix of DEG technology etc., need to be considered during the planning phase. In addition, a microgrid controller needs to be employed to manage the energy balance, power balance and power quality under normal operation [1, 2]. A protection scheme is expected to protect the grid from faults under both modes of operation. For the design of the protection concept, the part of the grid which is expected to operate under island mode (we will refer to it as “island area”) is considered a given.

The conventional MV grid protection concepts are based mainly on overcurrent (OC) protection schemes, hence on detection of high fault currents. These, however, do not suffice to guarantee proper protection of the grid under both modes of operation. Overall, an MV island grid protection concept requires additional consideration

regarding to the following points:

- (a) Sensitive tripping (fault detection) under low fault currents
- (b) Selective tripping under bidirectional power flow and under both modes of operation
- (c) Tripping speed requirements, which do not endanger the DEG
- (d) Loss of the main grid’s neutral point connection, under island mode
- (e) Automatic reclosing over fault clearing

The purpose of this work is to highlight the factors, which need to be taken under consideration when designing a protection concept for an MV island grid.

DISTRIBUTED ENERGY GENERATION AT BKW ENERGIE MV GRID

The MV grid of BKW Energie AG is a 16-kV radial grid with isolated neutral point. The DEG connected to the MV grid are most of the time connected at the MV bus through a MV/LV transformer. According to the present protection requirements, faults inside the DEG zone, are cleared by the DEG zone protection in less than 0.1s. Faults between the MV substation and the DEG coupling point are cleared by the protection of the MV feeder at the MV substation side, and by the DEG protection [3, 4]. For faults at the rest of the grid, DEG bigger than 1 MVA are expected to be employed with a fault ride through capability (FRT). Meaning that, depending on the DEG type and size, DEG are expected to disconnect after approximately 1s in order to support the grid. For deep voltage sags DEG can disconnect faster to avoid damage [4].

PROTECTION CONCEPT FOR MV ISLAND SYSTEMS

MV island grids include part of the MV grid and the respective LV feeders. Therefore, the coordination of the protection scheme of the LV feeders, DEG zones, MV feeders is necessary. It is of interest to proceed to the least possible adjustments in relation to the existing protection schemes and, for the new schemes, to maintain a conformity with the present ones.

In accordance to the present requirements for the connection of DEG to the MV level, faults in the **DEG zone** (“inner” faults) are cleared locally in less than 0.1s. Compliance with FRT is also expected. In the frame of this work, it is suggested that a reserve two-stage under-voltage ($U_{<}$) function is added. Its slow tripping time (t_{trip}) is assumed to be in the range of 0.9-1.6s, so that it

does not interfere with the FRT demands. The fast stage protects DEG from deep voltage sags. This function ensures sensitive tripping also for DEG technologies with low fault currents.

Very often **MV/LV transformers** are protected by fuses. These require a minimal short-circuit (SC) current of approximately 5 times their nominal, so that a tripping within 1s is possible. In cases where DEG cannot reach this fault current level, under-voltage protection of lines and/ or of the DEG will respond reliably.

The reliable protection of the **LV feeders** through fuses or through the under-voltage function of the DEG area, is case-specific. In addition to the SC level and the fuse rating, the length and technical characteristics of the LV line play a significant role. If a minimum SC current cannot be guaranteed, voltage protection on the LV feeder is recommended as long as it can be selectively set across the feeder.

Faults in the **HV/MV Transformer** zone are to be cleared by the CBs of this zone. Faults on the **MV bus** are to be cleared by the CB on the MV side of the HV/MV and by interrupting the DEG power flow to this point. To fulfill these tripping requirements, under both modes of operation, under-impedance protection with reverse interlocking would be a reliable alternative.

ISLANG GRID SCENARIOS

This section focuses on the selective tripping of the MV CB sections. Depending on the predefined island area, protection schemes are described for the following scenarios:

(a) **Basic Scenario:** Refers to cases where the DEG infeed of a MV feeder in-between two consecutive a CBs ("CB section" for simplicity) can, only marginally or not at all, cover the demand of this section. Under faults, DEG is allowed to stay connected and supply critical loads. The island area corresponds to the respective CB section.

(b) **Advanced Scenario:** Refers to cases where the predefined island area includes more than one CB sections, meaning that DEG infeed can sufficiently cover the demands of adjacent sections. The protection scheme should support the selective tripping of the sections. The limitations of OC and under-voltage protection are presented.

(c) **Premium Scenario:** A protection scheme is suggested to cope with high DEG infeed. The island area might include all the MV feeders (i.e. the entire MV station). The limitations of the "advanced" scenario can be fulfilled. Highest flexibility is reached.

From the first to the last scenario, DEG infeed increases and the respective island grid area grows (in terms of CB sections). As the application requirements increase, the protection scheme increasingly deviates from the conventional, which implies higher cost but also higher flexibility.

PHASE-TO-PHASE FAULTS

BASIC SCENARIO - small DEG infeed

Figure 1 demonstrates the protection concept on an example grid. For selectivity under grid-connected mode, a directional OC scheme ($I >$) with time staggering along each feeder, is employed. Faults are selectively cleared by OC scheme and the two stage under-voltage protection of the DEG. As the island area consists of only one CB section, no additional adjustments are required. The total amount of CB sections that time staggering allows is restricted to a max t_{trip} due to the short circuit rating (SCCR) of the equipment.

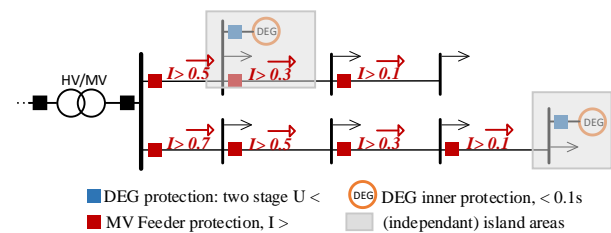


Figure 1: Basic scenario, $I >$ with time staggering

ADVANCED SCENARIO - medium DEG infeed

In this case, two approaches are suggested depending on the short circuit current of DEG, therefore also the DEG technology, size and location on the grid. The DEG which supply the grid through power electronics as well as the induction generators provide a short circuit current in the area of $1.1-1.2 \times I_{nominal}$ after the first 40ms [3-5]. The OC protection is not sensitive enough to differentiate this fault current from the load current. On the other hand, these currents although in the range of nominal current need to be cleared for safety reasons [5].

First Approach: OC with time staggering

If sensitive tripping of the OC protection is possible in both direction of power flow, under *both modes of operation for each CB of the MV Feeder and at its respective tripping time*, then a bidirectional OC protection scheme allows selective tripping of the CBs on the MV feeder under both operations.

Whether this condition is feasible or not, depends on the mix of DEG technologies and implicitly on their coupling point on the MV feeder. If the DEG mix of a CB section consists exclusively of inverter-based DEG and doubled induction generators the condition cannot be fulfilled. That is unless exceptional measures are taken to guarantee a certain SC current level (oversized inverters, SC contribution through flywheels etc.) [5]. The SC current of the rest DEG types decay (slower) over time, therefore it is emphasized that the t_{trip} setting needs to be coordinated with the respective machine time constants. The maximum number of participating CB zones is limited by the max t_{trip} , as in the previous schemes.

Second Approach: Low SC currents

This approach explores the limitations of a protection

scheme based on under-voltage ($U <$) tripping with time staggering. Upon grid-connected operation, the protection scheme is the same as for the basic scenario. By switching to island operation, a binary control signal is sent to the protection relay of the MV feeder to deactivate the OC settings and activate the voltage-tripping settings (Figure 2).

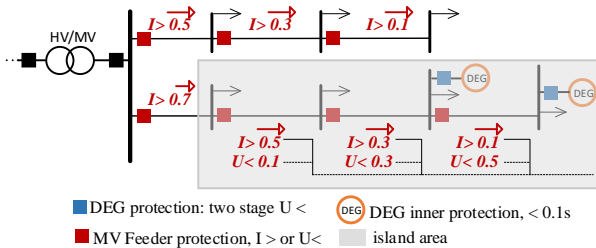


Figure 2: Advanced scenario, protection for DEG with low SC currents

Voltage-based tripping is reliable even for low SC current contribution, hence independent of the DEG mix. On the other hand, voltage functions cannot identify fault direction. Faults are cleared by sequential tripping the CBs of the MV feeders. Therefore, limited selectivity is feasible. The location of DEG on the island area defines the adequacy of the scheme. The scheme is therefore, only to be considered if the DEG infeed is concentrated at the end of the island area (one or consecutive CB sections). Further, the size of the island area is limited by the maximum t_{trip} for under-voltage time staggering.

PREMIUM SCENARIO - high DEG infeed

Protection functions based on impedance measurements increase the cost of the protection scheme but can reliably identify small SC currents with direction. The limitation of the sensitivity is 5 - 10% of the nominal current of the current transformer. Adding communication channels between the relays, selectivity requirements can be fulfilled irrespectively of the DEG technology, DEG infeed, grid topology and island grid size.

First Approach: under-impedance with time staggering

In cases where the OC protection with time staggering (advanced scenario, first approach) fail because of limited SC current, the same protection scheme can be used by replacing OC time staggering with under-

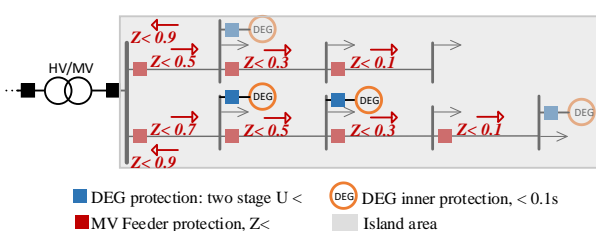


Figure 3: Advanced scenario, $Z <$ with time staggering

impedance ($Z <$) time staggering. The concept, however, remains restricted as for the island grid size. A directional (Figure 3) or bi-directional staggering can be employed, depending on the size of the grid and the selectivity requirements. Moreover, for a faster fault clearing a staggering with distance zones can be employed. It is noted that the impedance of the lines might be inaccurate and the effect of blinding must be consider.

Second Approach: under-impedance with communication scheme

Enriching the previous protection scheme with bidirectional communication between the relays (Figure 4), the limitations that time staggering implies are eliminated, as universal tripping time on the MV feeder can be set. Fast tripping setting, hence fast fault clearing, facilitates grid stability.

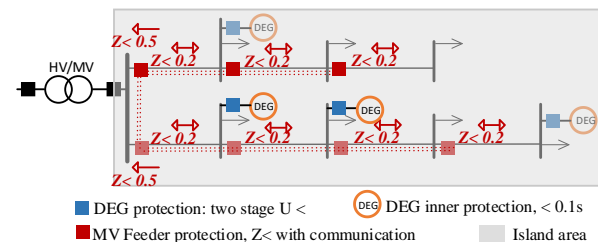


Figure 4: Advanced scenario, $Z <$ with communication scheme

It is noted that line differential protection for the MV feeder, although based on communication channels, is not recommended as it would demand an additional device at each line end and at the coupling points to the LV feeders.

Figure 5 presents a decision diagram, which points out the simplest protection scheme (among the advanced and premium schemes), given the application-specific requirements.

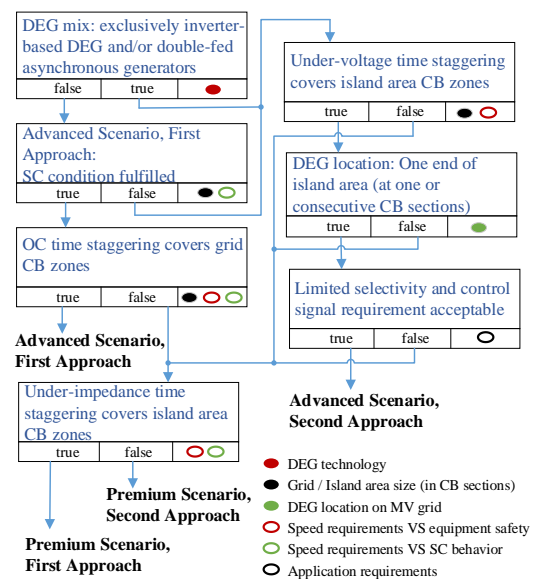


Figure 5: Decision diagram

PHASE-TO-EARTH FAULTS

The star point treatment (SPT) in distribution networks of the medium voltage is usually defined by the feeding substation. The most common SPTs are isolated star point, resonant earthing (compensated grid) and low impedance earthing.

For grids with low impedance earthing, fast clearing of the fault by means of short-circuit protection is required. In the other two cases, faults might either be cleared by a “ground-fault” protection within a few seconds or further operation of the grid under ground fault might be permissible, so that the grid operator identifies the fault without interrupting the power supply (“ground fault search with uninterruptible power supply”). The choice is influenced by the respective ground fault current, the grounding system’s quality and the resulting touch potential. Furthermore, by compensated grids, ground faults with arc are often self-extinguishing. The maximum permissible clearing time is defined, for all earthing systems, as a function of touch potential (EN 50522).

For the ground fault protection of MV island grids, the location of the SPT on the MV grid plays a decisive role as it might or might not be part of the island area. If the HV/LV transformer is included in the island area, meaning that the latter covers the entire MV station, then the SPT remains connected under both modes of operation. The same applies if the SPT treatment is located at the MV station bus, if the MV station bus is included in the island area. In all other island area cases, the resulting island grid is isolated, unless the SPT is decentralized located, at the MV/LV stations.

SPT Island Area		Isolated		Resonant	Low Imped.
SPT MV Station		(a1)	(a2)	decentr. (b)	decentr. (c)
Ground fault search with uninterruptible supply		Yes	No	Yes	No
Isolated	Yes	✓	✓	✗	✗
	No	✓	✓	✗	✗
Resonant HV/MV Transf. or MV bus	Yes	✓	*✓	✓	✗
	No	✓	✓	✗	✗
Resonant decentralized	Yes	✓	✓	✗	✗
	No	✓	✓	**✗	✗
Low Impedance HV/MV Transf. or MV bus	Yes	✓	✓	✗	✗
	No	✓	✓	✗	✗

* only with changing protection setting ✓ technically feasible ✗ no additional components
 ** case sensitive ✗ technically out of scope ✗ additional components

Table 1: SPT for grid-connected and island operation

Table 1 shows a comparison of various combinations of MV grid SPT and island area SPT. The suitability of the combinations is marked, taking into account the possibility of “ground fault search with uninterruptible supply”. The latter requires that a ground fault alarm is sent to the operator, upon identification of critical $U_{0>}$. Isolated island SPT provides overall a suitable, easy to implement solution. Case (a1) is the simplest alternative, for any grid SPT, if the conditions for ground fault level

and resulting touch potential are fulfilled. If the isolated island grid is large and the resulting ground fault current does not fulfill the condition for further operation over ground-fault search, there are two further strategies (case a₂): tripping of DEG via “ $U_{0>}$ ” protection function or tripping of MV feeder protection over “sin (φ) measurement” function, optionally supplemented with a communication scheme. Case (b) implies decentralized installation of Peterson-coils through neutral point transformers. This is a suitable but cost intensive alternative. Finally, low impedance earthing for island grid (case c) is only to be considered for MV grids with the same SPT.

AUTOMATIC RECLOSING

In MV grids with overhead lines, automatic reclosing (AR) with or without synchro-check is often employed in order to increase the security of supply, as very often faults extinguish themselves during the AR break. In island grids though, where faults are supplied by both sides, the AR is expected to be much less successful. Hence, in island grids, AR should be supported by the protection concept, so that a fast tripping of power supply is achieved at both sides of the CB before the AR break time begins. Synchro-check is necessary.

CONCLUSIONS

The technical limitations and critical parameters of several protection schemes for MV island grids have been emphasized. It is shown that the choice of protection scheme depends on the grid topology, the participating DEG and trade-off between application requirements (in terms of selectivity) and costs. Under-impedance protection with communication scheme is found to cover even the most challenging requirements, while it is also the most cost intensive one. Regarding the disconnection of the island grid from the main grid’s SPT, it is argued that the isolated island grid is in general preferable.

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