OPTIMAL CONTRIBUTION OF DISTRIBUTED GENERATION IN MEDIUM VOLTAGE GRIDS DURING A FAULT, NOW AND IN THE FUTURE

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ABSTRACT

Due to the increase of distributed generation in medium voltage grids, the short-circuit current flow is changing. Within HV-grids fault ride through capabilities are demanded of distributed generation to maintain stability during disturbances. Generators connected to MV-grids are smaller and have less fault ride through capabilities. Still the distribution system operator must look forward to future MV-grids and the corresponding protection schemes. This paper describes three scenarios with different kinds of fault ride through capabilities for distributed generation. From all scenarios the advantages and disadvantages are given. The main conclusion is to change the protection schemes of DG connected to the station with dedicated feeders. This will allow larger DG to stay connected and contribute to the voltage level during adjacent faults.

INTRODUCTION

The introduction of more and smaller Distributed Generation (DG) connected to Medium Voltage grids (MV-grids) is increasing the need to change the way MV-grids are protected.

The current MV-grid is capable to connect most of the DG, as long as the DG will disconnect in case of a multi-phase fault in the grid. This prevents problems such as blinding, false tripping and islanding in the uni-directional protection scheme. The grid connection codes within The Netherlands leave a gap how to connect DG smaller than 5 MVA connected to voltages between 1 to 110 kV. The questions are: “What is the best solution of connecting DG to the grid?” and “Should the DG contribute during the fault or disconnect as soon as possible?”. To answer these questions it is important to look at several issues like:

- Changes of the grid (configuration, protection schemes)
- Costs (Protection co-ordination, fault ride through adjustments)
- Influences on the grid (voltage level, stability, short circuit levels)

First the present connection of DG is addressed. Then the expectations of the Distribution System Operator (DSO) with respect to DG in the MV-grid are given. This is followed by three possible scenarios for the protection scheme. Finally a future grid is proposed where MV-grids can operate autonomously.

PRESENT PROTECTION SCHEME DSO-DG

The present protection strategy for customers connected to the MV-grid is to switch off at the connection point faster than the protection relays of the DSO. The clearing of a fault is fully selective in this way, when the customer only has a traditional load. But due to the introduction of DG the power flows have changed. This can introduce problems such as voltage stability and non-selective tripping.

Nowadays DG units will be disconnected from the network immediately in case of a disturbance, due to their overcurrent, over&under-frequency or over&under-voltage relays. This prevents non-selective tripping of the relays of the DSO and islanded operation. Due to the low penetration of DG, the contribution of DG to the grid stability will be minimal and thus disconnection of DG is no problem at the moment. But the MV-grid can possibly become unstable with the increasing numbers and concentrations of DG.

Within the Netherlands the grid codes regulate the integration of DG into the power system to ensure the security of supply, reliability and power quality. For DG connected to the High Voltage grid (≥ 110 kV) there are requirements that the DG contributes to the stability of the grid by remaining connected during external faults. For the Low Voltage grid (LV-grids < 1 kV) the codes also regulate the integration of small DG, by requiring immediate disconnection in case of a disturbance. For DG connected to the MV-grid (1 – 110 kV) smaller than 5 MVA the codes leave a gap. The only requirement is that after 10 seconds the voltage should be higher than 85% of the nominal voltage to comply with the Grid code. If not, the DG is allowed to disconnect.

These small to medium size DG can also contribute to the voltage stability during a fault. The disadvantage is the possible non-selective tripping with the present protection schemes and the need of the owner to adjust the Fault Ride Through (FRT) capabilities of the unit. In this paper the definition of the under-voltage protection and FRT are identical.

EXPECTATIONS OF THE DSO

The contribution of the DG to the stability and reliability of the grid can be an advantage for the DSO. It can give the DSO more control of the voltage level within the MV-grid. The DSO also expects a fully selective protection scheme, which guarantees the safety of personnel, the security of supply and prevents damage to equipment.

The worst case scenario for the DSO is an under- or over-voltage in the MV-grid, due to the disconnection of DG. In this case the voltage level has to be adjusted by the tap-changer of the HV/MV transformer. This adjustment is quite slow however and for some time the voltage in the network might be too high or too low. The loss of generation is not expected to cause stability problems. The HV-grid in Europe is reliable enough to supply the lost capacity if all DG units are disconnected in the local MV-grid. Faults in an MV-grid result only in the disconnection of DG in that MV-network. DG in neighbouring MV-grids are normally not affected. Also faults in the HV-grid normally have a limited effect and will not trip the DG in all MV-grids connected to it, as shown in [1].

Experiences in the field show that with 3 phase and 2 phase faults the voltage dip at the station bus bar is relatively deep (0 – 50 %). While single-phase faults will have a shallow voltage dip and the contribution of the DG to the short-circuit current is limited. Due to the star-delta windings of the step-up transformer most DG will hardly notice to the single-phase to earth faults. Most faults start as a single-phase fault and should therefore be cleared as soon as possible, before it develops into a multi-phase fault and trips the DG. Also low impedance earthed MV-grids will help to prevent unnecessary trips of DG in adjacent feeders.

The expectation is that there are three scenario's feasible for connecting the increasing amount of DG to the MV-grids. The first scenario is to disconnect all DG during a disturbance in the grid. The second scenario is to use the contribution of all DG as long as possible to maintain voltage stability. A third scenario is to use only the DG which is connected by dedicated feeders (see red feeders in Figure 2) to a station for voltage stability and disconnect all other DG during a fault. Each scenario has its advantages and disadvantages, which will be described in the next sections.

SCENARIO 1

In this scenario, DG smaller than 5 MVA is equipped with an under voltage relay with the Fault Ride Through (FRT) capability shown in Figure 1. These relays are shown as 27 in Figure 2. Below the FRT characteristics the DG must disconnect. The additional setting is for voltages below 70% of the nominal voltage, which trips the DG instantly. After 10 seconds the voltage should be higher than 85% of the nominal voltage to comply with the Grid code. No changes are made to the uni-directional protection schemes of the MV-grid.

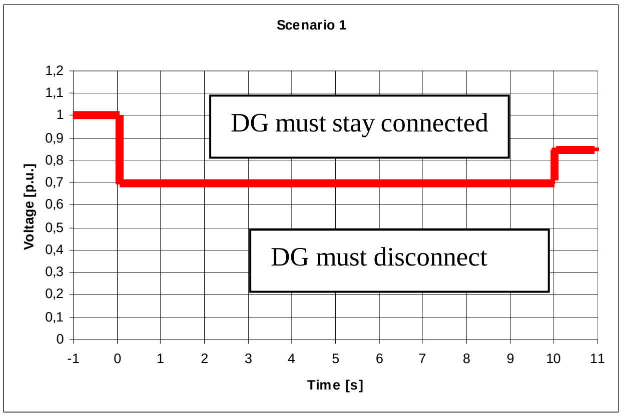

Figure 1: FRT scenario 1

For all fault locations that are shown in Figure 2 all DG units will immediately trip if the voltage drops below 70%. This allows the grid protection to operate without interference of the DG like blinding, false tripping and islanding.

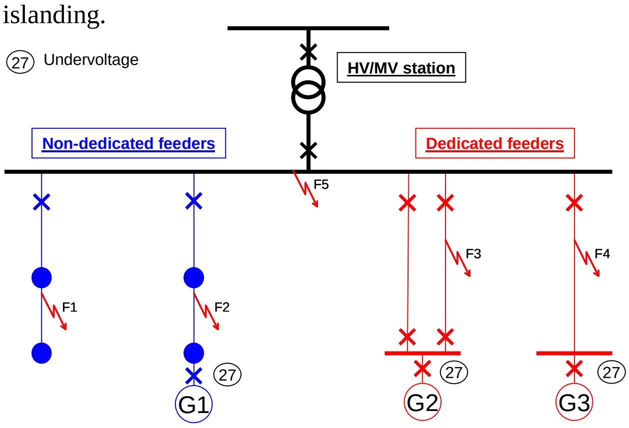

Figure 2: Scenario 1, line diagram

As mentioned in the previous section, the impact on the system reliability is limited to a possible supply voltage variation (-10% stated in EN50160). This can be adjusted by the tap-changer of the HV/MV transformer. However this is a slow process. The costs for the DSO and DG are limited, only the installation of the under-voltage protection should be considered, but normally this function is already available.

SCENARIO 2

A second scenario is to limit the outage of DG due to a fault in adjacent feeders. In this scenario all DG connected to the MV-grid has to contribute to the short-circuit current of a fault. The contribution of the DG will depend on the type of generator (synchronous, converter based or a-synchronous) and the critical clearing time (CCT) of the DG. Normally this CCT is between 0.2 and 0.3 seconds for small DG. The fault should therefore be cleared by the protection scheme within 0.2 seconds. Line faults in HV-grids are normally cleared in less than 0.1 seconds and in extreme cases in 0.3 seconds.

The DG has to stay connected to the grid during a fault in the grid. The DG only trips instantly on nearby faults, where the voltage is less than 20% of the nominal voltage as is illustrated in Figure 3. The value of 20% is chosen to prevent the DG to become out-of-phase after the clearing of the fault.

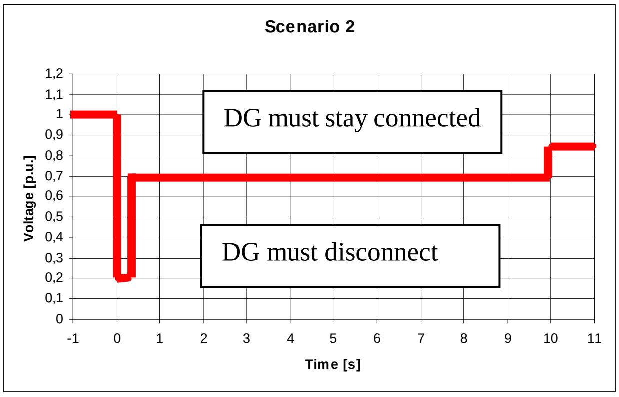

Figure 3: FRT scenario 2

In the scenario where the DG stays connected, the grid protection has to be bi-directional and needs to clear all the faults on all locations shown in Figure 4, before the DG protection operates. Therefore the MV-grid shall have a fast bi-directional protection scheme (for example a bus bar differential, distance, line differential or directional overcurrent protection). Dedicated parallel feeders to DG shall be protected with a differential protection for optimal clearing of faults within the parallel feeders. The total costs to adapt the protection schemes will be much larger in comparison to scenario 1.

The disadvantage of fast clearing of faults is that there is a possible danger of islanding. Islanding should be detected and when it occurs the DG should be disconnected for safety, prevention of out of phase switching and power quality requirements. A Loss Of Mains (LOM) protection (rate of change of frequency and/or voltage vector shift) shall be used to avoid islanding.

The short-circuit power will increase by the contribution of the DG (especially synchronous generators). The short-circuit resistance of the equipment in the MV-grid must be checked against the new values. If the grid is not capable to withstand the short-circuit power, the grid has to be reinforced or the DG shall limit their short-circuit power contribution.

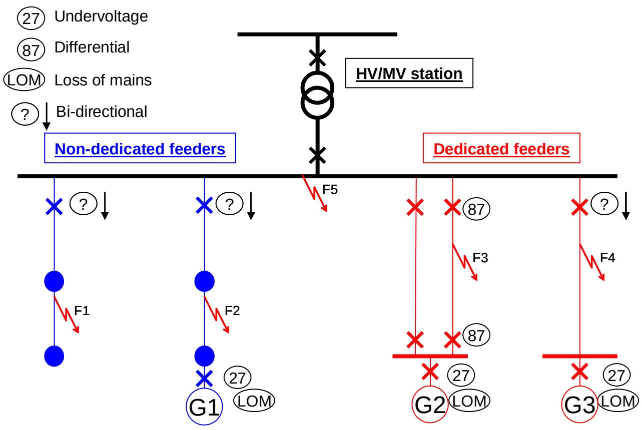

Figure 4: Scenario 2, line diagram

The advantage of the contribution of DG, during and after the fault, will be the maintaining of the voltage level within the limits of the Grid code. Also the influence of the voltage dip is reduced due to the fast clearing time of the faults.

SCENARIO 3

In this scenario a difference is made between DG that is connected by dedicated and non-dedicated feeders. A DG connected with a dedicated feeder to the station (red feeders in Figure 5) is normally above 2 MVA and has a custom made protection scheme. With this larger DG it is easier to adapt the protection scheme of the grid, causing the DG to stay connected to the grid during a fault shown in Figure 3. The smaller DG connected with non-dedicated feeders (blue feeders in Figure 5) to the station will disconnect instantly shown in Figure 1.

The protection of the dedicated feeders shall be selective with the protection of the non-dedicated feeders, while faults within the dedicated feeders shall be cleared as fast as the non-dedicated feeders. For fault 1 and 2 in Figure 5 the generator G1 will disconnect instantly and the generators in the dedicated feeders (G2 and G3) will stay connected. For fault F3 within the dedicated feeder, the adjacent generator G1 will disconnect immediately. After the fault is cleared by the DSO protection, the generators G2 and G3 will stay connected. Only with fault 4 also G3 will disconnect by the detection of an LOM protection. For a bus bar fault (F5) all DG will be disconnected due to the LOM protection.

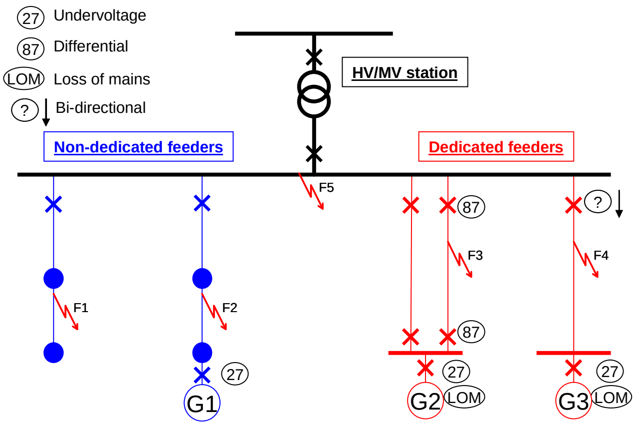

Figure 5: Scenario 3, line diagram

The advantages are the costs regarding the protection adjustments for both the DG and DSO. For the DSO it means an adjustment of the protection schemes of the dedicated feeders. The small DG will have minimal costs to invest to protect their units in comparison to scenario 2. Furthermore larger DG can benefit of the time delay to stay connected with adjacent faults and the DSO can benefit from the voltage stability of the connected DG after a fault is cleared.

SMARTER GRIDS

A future MV-grid with a balanced amount of loads and generators could operate autonomously if the islanded grid meets the requirements of a normal grid. An accidentally energized grid should be avoided or detected for the safety of personnel working on the grids. The legal obligation of the DSO to maintain the system stability and power quality of the grid still holds for the islanded grid. This means that the DSO should have local (autonomous) control options for the voltage, frequency, short-circuit levels and synchronous reconnection as described in [2]. The protection within an islanded grid will be fully bi-directional with adapted settings for the short-circuit current that can be delivered by the local DG.

Table 1: Difference of the three scenarios

	Change grid	Influence grid	Cost
Scenario 1	Low	Low	Low
Scenario 2	High	Medium	High
Scenario 3	Medium	Medium	Medium

The choice how to protect MV-grids now with the increase of DG has to be ready for future grids. Table 1 gives an overview of the three scenarios with the different issues concerning the changes of the grid, influences on the grid and costs. Scenario 1 has less impact on the grid and low costs, but will introduce problems in future grids. Scenario 2 is ideal for future grids, but has a large impact on the grid and the costs. A good start can be made with the DG connected by dedicated feeders as is described in scenario 3 and will stimulate the transition from the MV-grid to a smarter grid.

CONCLUSIONS

The increasing growth of DG results in the increasing demand to reconsider the current protection schemes. For low concentrations of DG in a MV-grid, the fast disconnection of DG in case of a fault is the most interesting option. For the DSO and DG this option has a low impact on the grid and the costs. With larger concentrations of DG the benefits of using DG to improve the performance of the grid should compensate the costs of changing the protection scheme and the FRT capabilities of the small and medium sized DG.

Looking at the future of MV-grids the installation of DG will increase and autonomous operating grids will emerge. Changing the protection relays and settings is a slow process and therefore the choices made today should contribute to future grids. For DG connected with dedicated feeders the first steps can be taken now. The changes to the grid are low, and allow the DG to stay connected and contribute to the voltage stability during adjacent faults.

REFERENCES

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[2] F. Provoost, 2005, "Self controlling autonomous operating power networks ", *International Conference on Electrical Distribution*