IMPACT OF DISTRIBUTED GENERATION ON GRID PROTECTION

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ABSTRACT

Needs of renewable energy will even more increase in the next years. Means to produce this energy are very often small or middle power production units which are located where the resources are available: wind, sun, etc.. The power of the smallest unit begins already from some kVA. The small generation units can be connected to the low voltage grid or to the medium voltage grid. This distributed generation has an impact on the grid: very often the medium voltage grid is not built for distributed generation. The medium and low voltage grid is normally only built for load flow. Another point is the impact on the stability of the grid. One power unit alone has no influence on the stability. The sum of a lot of small power units is a relatively high percentage of the whole produced power. Therefore, also small production units have to respect some conditions for the grid.

Reliability of the grid is a keyword for each electricity distributor. Therefore, production systems have to work with high requirements for the grid in different domains in order to avoid disturbances on the distribution and transmission grids.

The distributed generation is a veritable challenge for the utilities and specially for the protection specialists.

The objective of this paper is to list and explain some technical requirements for protection, which are considered by BKW FMB Energie AG as a Swiss utility company.

INTRODUCTION

BKW FMB Energie AG is a Swiss utility company active in generation, transport and distribution of electricity. Its grid is composed of following voltage levels: transmission grid: 380/220kV, over-regional distribution grid: 132/50kV and regional distribution grid: 16kV and 0.4kV. Its production is mainly composed of hydraulic and nuclear generation. During the last decades, the need of new renewable energy has been developed. The company extended his production with Distributed Generation (DG). They are very often small or middle power production units which are located where the resources are available: wind, sun, etc.. Most of them are connected to the 16kV regional distribution grid. This 16kV grid has a radial topology and an isolated star point.

Due to the installation of such distributed generation, the "conventional" power flow in the grid can be changed. Indeed, distribution grids are often only built for load flow, that means that the conception of the grid is based on the fact that the direction of the power is going from higher to lower voltage levels. However, distributed generation can invert and change this direction.

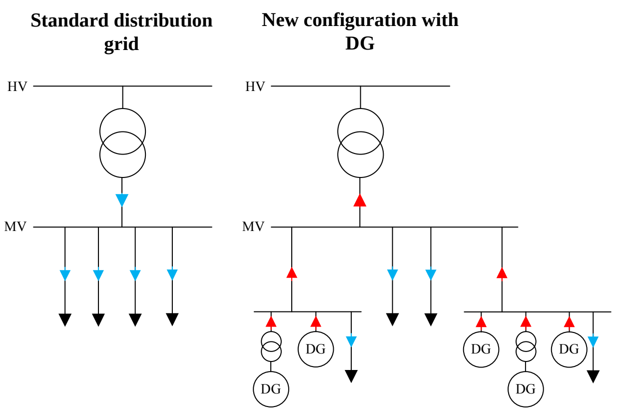

Figure 1: Power flow

Distributed generation can not only create a change of load flow, they also generate a fault current in case of a fault in the grid.

From a certain size of the generated energy, there are different advantages not to mix load and distributed generation on the same bay in the substation. This has different reasons: e.g.: Distributed generation can increase the voltage in some points of the grid. This can create difficulties for the compliance of the "power quality".

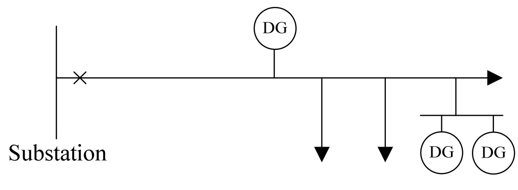

Figure 2: DG and load on the same line

In the distribution grid of BKW FMB Energie AG, different companies and organizations plan and build distributed generation. In order to uniform the conditions for all the partners, the company defined some requirements for DG-protection systems. Some of these requirements are mentioned below:

- Requirements on the protection by faults on the DG-side:
  - DG-protection systems have to recognize earth-faults and short-circuits on the production side. In this case, the circuit breaker of the DG must be quickly tripped (e.g.: with a time-delay of ≈0.1s).
  - Other faults have to be protected, according to the state of the art.

- Requirements on the protection by faults on the grid-side:
  - DG-protection systems have to recognize earth-faults and short-circuits in the grid. For this requirement, several cases have to be considered.
  - A communication between the substation and the DG is required to realize an "intertrip" of the DG circuit breaker from the protection in the substation.
  - DG-protection systems have to recognize over and under frequency and also over and under voltage. They have to stay connected with the grid if the frequency is over 47.5Hz and the line-to-line voltage is over 80% of the rated voltage.

Some of these requirements are parts of the "Transmission Code" of Switzerland[1].

The following parts of this paper will explain how and why BKW FMB Energie AG considers these requirements.

SHORT-CIRCUITS AND EARTH-FAULTS

Figure 3 shows the necessary different protection zones in an electrical distribution network. It is necessary to have a circuit breaker with protection at the beginning / end of each protection zone.

In principle, all the earth-faults in the 16kV grid of BKW FMB Energie AG must be cleared.

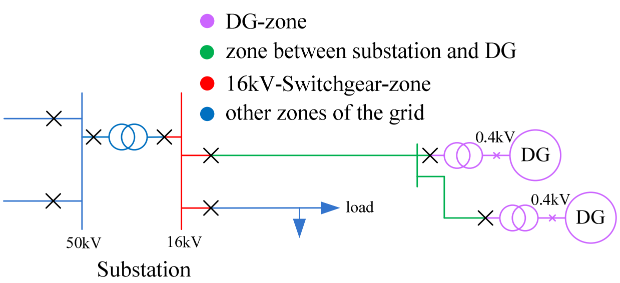

Figure 3: Protection zones

Faults in the DG-zone

The protection for faults on the DG-zone is realized in the protection-system of the DG. In the relays in the substation, some backup functions are integrated.

The protection of the DG has to recognize earth-faults and short-circuits on the DG-zone (cf. Figure 3). In case of faults in the DG-zone, this protection has to quickly trip the 16kV-circuit breaker of the DG, e.g.: with a time-delay of 0.1s. A directional phase over current function (67) is preferred to detect short-circuits in the DG-zone. A non-directional sensitive earth-fault function (51N) has to be activated to detect earth-faults on the 16kV-side of the DG-zone. The condition to recognize an earth-fault with this function is that enough capacitive earth-current comes from the capacities of the 16kV-grid. A residual overvoltage protection (59N) is activated as backup earth-fault protection. This functions has to let enough time to the other relays to clear any faults in the grid.

In case of faults in the DG-zone, the **protection on the 16kV-bay in the substation** represents a backup protection. Therefore, the following functions are used: directional and non directional over current (67, 51), directional and non directional earth-fault protection (67N, 32N, 51N, 59N) (cf. Figure 4).

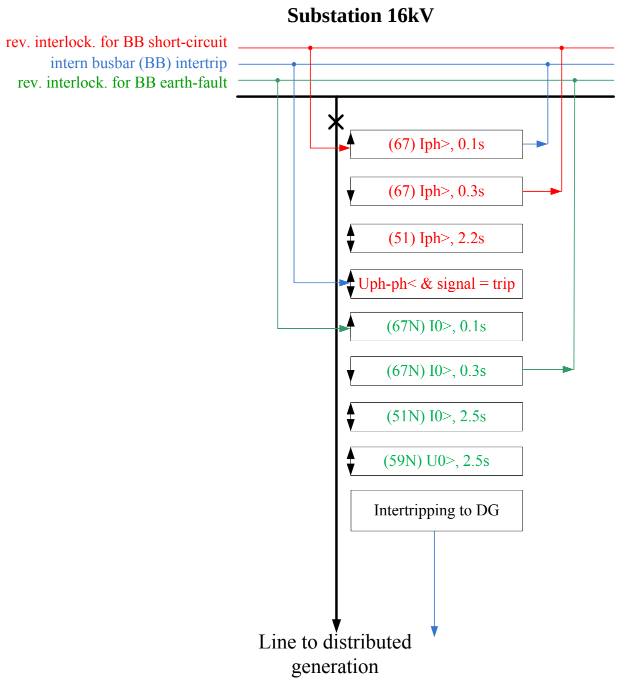

Figure 4: Example of protection functions on the bay in the substation

Faults between substation and DG

Short-circuits between the substation and the DG (cf. Figure 3) have to be fast cleared by the bay protection in the substation and the protection in the DG.

In case of short-circuit on the line between the substation and the DG, the directional over current protection in the substation will cut the current coming from the grid. The DG will also provide current for the fault. The over current function alone on the DG will probably not recognize the fault, because the current coming from the DG is too low: depending on the short-circuit behaviour of the DG, it is probable that in case of short-circuit, the DG provides a current lower or not much higher than its rated current (cf. Figure 5). Therefore an "intertrip" to the DG is normally required. As alternative, it can make sense to use a distance protection in the protection system of the DG. The parameters of the distance protection have to be chosen in order to clear the short-circuits on the line (between substation and DG) and in the 16kV-switchgear of the substation with a short time (e.g. 0.1s). However, with this concept of distance protection it is possible that in certain cases, the protection is not selective. In the substation, a directional earth-fault over current protection (67N) is activated. This function generates also an "intertrip". Additional backup protection functions for earth-faults and short-circuits have to be activated, also in the DG.

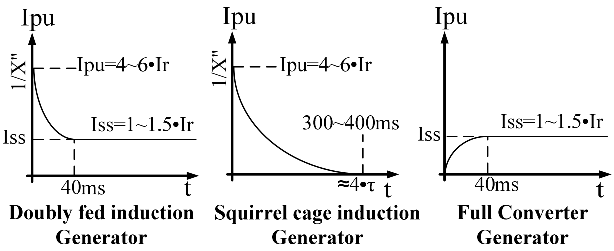

Figure 5: Example of short-circuit behaviour of wind turbine generators[2]

Faults in the 16kV-switchgear

Faults in the switchgear have to be cleared by the relays of the switchgear. The new 16kV-substations built by BKW FMB Energie AG are often Gas Insulated Switchgears (GIS). These equipments have normally a rated arcing duration of 1.0s. It means that the internal faults in the GIS have to be cleared within 1.0s. Against internal short-circuits, a basic busbar protection by reverse interlocking is normally used. If the current coming from the DG is lower than the setting of the over current protection, the protection by reverse interlocking will not clear the short-circuit in the switchgear. Therefore, a special busbar-intertrip in the substation will be implemented: if one of the over current functions which are set in direction of the busbar trips, an intern busbar-intertrip-signal is sent to the relays in the other bays (cf. Figure 4). These relays trip their circuit breaker, when at the same time an undervoltage condition is fulfilled (in case of short-circuits on the busbar, the phase-to-phase voltage drops). Against internal earth-faults, a basic busbar protection by reverse interlocking is used. However these busbar protections only protect the busbar and open the circuit breakers in the substation in case of faults. This will not cover the whole GIS: faults on the part between circuit breaker and cable termination are not covered. This is another reason why the "intertrip" to the DG is required. Each protection function which trips on the bay in the substation sends an intertrip-signal to the circuit breaker on the DG-side. The duration between "appearance of the fault, recognition, trip in the substation, sending of signal, trip on the DG-side" must be under 1.0s. Thus, the whole GIS will be covered by a fast protection and the rated arcing duration-requirement of 1.0s will be fulfilled. A distance protection in the DG can be, as mentioned in the previous chapter, an alternative for this "intertrip" to the DG.
Of course, additional backup protection functions are activated.

Faults in the over-regional distribution grid and in the transmission grid

The protection system in the DG has also to detect faults on the grid-side. In case of faults in the over-regional distribution or in the transmission grid, the production units have to stay connected with the grid for a certain time to support it: they have to let enough time (normally more than 2s) to the grid protection to clear the fault. In case of faults on the line between the DG and the substation or in the 16kV-switchgear of the substation, they have to quickly trip (e.g. with a time-delay of 0.1s). These two conditions are often not easy to fulfil but they are important to limit the damages near the DG and for the reliability of the grid. The shutdown of the sum of a lot of small distributed generators can be equivalent to the shutdown of a large power station.

ADDITIONAL FUNCTIONS

Auto-reclosure

For overhead lines between substation and DG, it is often suitable to activate an auto-reclosure function in the substation. However, already a short time after the trip of the circuit breaker, the probability is high that the voltage of the grid and the voltage of the generation unit are not more synchronous. Therefore, to have more chance of a successful auto-reclosure, the generation units have to be disconnected of the grid before the check of the synchronism.

Frequency

It is allowed to disconnect power plants within a few seconds only if the frequency is over 51.5Hz or under 47.5Hz. Between these two frequencies, the generation has to support the grid if the voltage of the generator is higher than 80% of its rated voltage. This is one of several important conditions to ensure stability of the grid, in case of drop in frequency due to a large disturbance. To control extreme situation in the grid, a certain amount of load connected to the transmission grid has to be disconnected in case of collapse of the frequency. This to avoid a total collapse of the interconnected grid. This is the so called Under Frequency Load Shedding (UFLS). A disconnection of generators with a frequency over 47.5Hz can break the successful effect of UFLS.

Stage	Frequency [Hz]	Action	Load shedding [%]
1	49.8	Activation of reserve production	
2	49.5	Disconnection of pumps	
3	49.0	Load shedding 10-15%	10-15%
4	48.7	Load shedding 10-15%	20-30%
5	48.4	Load shedding 15-20%	35-50%
6	48.1	Load shedding 15-20%	50-70%
7	47.5	Disconnection of the power plants	

Table 1: Load shedding[1]

Example

The following example shows why the frequency settings and the ability of the DG to work between 47.5Hz and 51.5Hz are important regarding the UFLS-system.

The normal state at 50Hz is:
- Production: 100MW with DG
- Load: 200MW

→ A resulting load in the transformer is 100MW

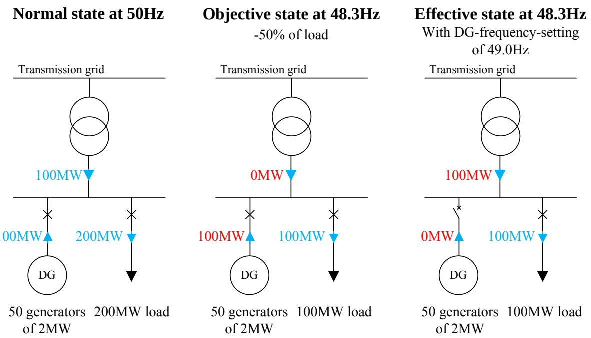

Figure 6: Example UFLS

If the frequency collapses to 48.3Hz, the objective is to reduce the load: bandwidth from -35% to -50% with the UFLS-system (cf. Table 1). For this example, the assumed load reduction is -50%. This will decrease the power injected in the distribution grid and avoid a total collapse of the frequency.

Objective if the frequency drops in 48.3Hz:
- Production: 100MW with DG
- Load: 200 MW reduced to 100MW (UFLS)

→ A resulting load power in the transformer is 0MW

However, if the protection settings of the DG or the DG itself do not allow a frequency between 47.5Hz and 51.5Hz, and the protection already tripped at for example 49.0Hz, the following behaviour will happen:
- Production: 100MW with DG reduced to 0MW (trip of the DG)
- Load: 200 MW reduced to 100MW (UFLS)

→ A resulting power in the transformer is 100MW to supply the distribution grid

In this example, the objective was to reduce the load from 200MW to 100MW, without disconnection of the production. This should result in a load power of 0MW in the transformer connected to the transmission grid. However, due to the not appropriated settings of the frequency protection (in this example 49.0Hz), the DGs were separated from the grid. The resulting load power in the transformer is 100MW. There is no difference on the resulting power in the transformer before and after the disturbance. The outcome is that it is important that the DGs stay connected if the frequency drops in 47.5Hz. Otherwise, it will reduce or destroy the effect of UFLS.

CONCLUSION

Generation has a crucial role and participates actively in the stability of the grid. In the future, distributed generation will contribute even more to ensure the need of energy. The reliability of the distributed generation, when disturbances occur, is one of the challenge for the future. A negligence regarding this point can have repercussion on the transmission grid.

Along this paper, it is also shown that some of the requirements mentioned are not easy to fulfil. Therefore, the collaboration between the partners (distributor, production-planer, etc.) during a project including DG is essential to ensure a successful issue regarding the grid configuration, the protection concept, the protection settings and also the control of the DG.

Several topics are not explicitly mentioned in this paper: over- and undervoltage protection, other frequency protections, power quality, harmonics, testing, etc.. They also have to be carefully considered.

LIST OF ABBREVIATION

DG	Distributed Generation
UFLS	Under Frequency Load Shedding
HV	High Voltage
MV	Medium Voltage
LV	Low Voltage
GIS	Gas Insulated Switchgear
BB	Busbar
67	Directional phase over current function
51	Non-directional phase over current function
67N	Directional earth-fault over current function
51N	Non-directional earth-fault over current function
59N	Residual overvoltage earth-fault function
32N	Wattmetric earth-fault function

REFERENCES

[1] 2010, "Transmission Code 2010", TC version 23 November 2009

[2] C. Molina Zubiri, I. De La Fuente del Castillo, S. Lopez Barba, M.A. Ordunez Del Pino, 2010, "Impact on the power system protection of high penetration of wind farms technology", CIGRE 2010