EFFECT OF DISTRIBUTED GENERATION ON PROTECTION OF MEDIUM VOLTAGE CABLE GRIDS

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ABSTRACT

Due to several reasons Distributed Generation, DG, is increasing. Most of the DG units are small in size and connected to medium voltage grids (MV-grids). DG units change the operation of MV-grids on several aspects such as voltage control, fault current level and protection. This paper focuses on the effect of small CHP units on the protection of MV-cable grids. After a brief introduction of the influence of DG on the protection of MV-grids, the effects will be illustrated by simulation. A comparison is made between a MV-grid containing only cables and a MV-grid containing overhead lines.

INTRODUCTION

In the near future the amount of distributed generation (DG) connected to medium voltage grids increases rapidly. This development influences the performance of the complete power system. DG is normally connected to medium voltage grids (MV-grids) which distribute the electric power to the consumer. The power flow in the MV-grid is usually uni-directional. However when DG is introduced the power flow can become bi-directional. In MV-grids DG also influences fault current levels. The contribution to fault currents depends strongly on the type of DG. Rotating DGs (CHP plants, wind turbines e.g.) contribute much more to the fault current than statical DGs (fuel cells, solar panels e.g.). The latter DGs are normally connected to the MV-grid by a power electronic converter. In this paper only CHP plants including synchronous machines will be discussed.
Due to the simple topology of MV-grids the protection scheme is also simple [2]. To protect a radial feeder normally the feeder is equipped with an over current relay. The introduction of DG in MV-grids can affect proper operation of the protection scheme. In this paper the effect of DG on protection of MV-grids will be addressed. A distinction is made between MV-grids including cable connections and MV-grids containing overhead lines.

PROTECTION OF MEDIUM VOLTAGE GRIDS

In this section a brief overview of protection of MV-grids is given. Detailed information can be found in [1-2]. Most of the ring shaped and meshed MV-grids are operated radial and allow a simple protection scheme since there is only one direction of supply [2], [4]. Common protection schemes mainly consist of definite or inverse overcurrent relays, sectionalizing devices, switch gears and reclosers. In most cases these devices are located in the main substation. The feeders out of this substation can consist of overhead distribution lines or underground cables and, depending of the type of connection, temporary faults can occur (lightning, flash over to trees e.g.). Most of the time this happens on feeders built of overhead distribution lines. In this situation there is no need to switch off the feeder permanently and to limit the interruption time automatic reclosing is applied. The recloser acts after a brief time delay to allow time for the arc to deionize. For MV-grids containing cables only, temporary faults do not occur, so automatic reclosing equipment is not installed.
The main strategy protecting MV-grids is to ensure maximum protection at minimum total cost [2]. As mentioned above, in MV-grids containing mainly overhead lines most faults are temporary of nature so the first requirement of radial system protective strategy is immediate clearing of all faults. The second requirement is to isolate permanent faults such that the line section involved is as short as possible and easy to locate. To meet these requirements a relay coordination study has to be done. Such a study consists of:

- Calculation of minimum and maximum fault currents
- Establishing tentative locations for relays, sectionalizing devices, switch gears and reclosers
- Coordination of the settings of these devices

To ensure an appropriate relay coordination scheme the relay pickup current, I_{pickup}, is set to 50% of the minimum end of line phase to phase fault. To prevent unnecessary tripping of the feeder I_{pickup}>200% maximum load current is chosen. To protect the MV-grid against severe disturbances instantaneous elements can be applied. These elements are usually set to six times the load current or 125% of the maximum three phase fault current at the first downstream protective device [1-2].

INFLUENCE OF DG ON PROTECTION SCHEME

In literature a couple of problems to protect MV-grids including DG is mentioned. Problems that can occur are [3], [9]:

- False tripping
- Blinding of protection
- Unwanted islanding

- Prohibition of automatic reclosing
- Unsynchronized automatic reclosing

Two serious problems, false tripping and blinding of protection, are studied in more detail.

False tripping

False tripping, also mentioned unnecessary disconnection of a healthy feeder, occurs due to the contribution of DGs to the short circuit current in an adjacent feeder. The contribution of the DGs can exceed the pickup current of the over current protection and can lead to a trip of the healthy feeder before the actual fault is cleared. This situation is most probable when the distance of the DG and the fault location is close to the substation [5]. The principle of false tripping is depicted in figure 1.

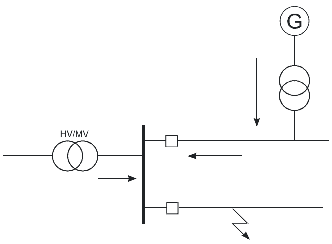

Figure 1 *Principle of false tripping*

A simple and effective solution to the problem is to make use of a directional relay on the feeder including DG. In comparison to a normal overcurrent relay a directional relay is more expensive. When applying a directional relay a couple of remarks have to be considered [3]:

- Directional relays are slower
- The solution differs from the normal situation grid operators are used to

Blinding of protection

When a fault occurs in a feeder including DG, both the grid and DG contribute to the short-circuit current. The division of the current contribution depends on the network configuration, grid impedance and the size of the DG [3], [5]. To explain the influence of the parameters on the short-circuit current distribution, the following situation is considered and depicted in figure 2a. The Thevenin equivalent of the MV-grid with a three phase fault is shown in figure 2b.

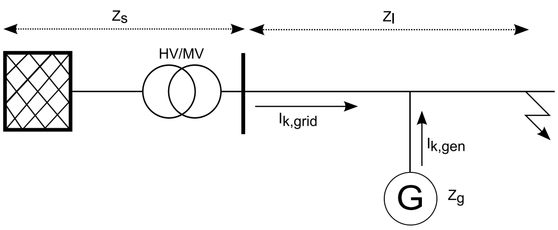

Figure 2a *MV-grid including DG*

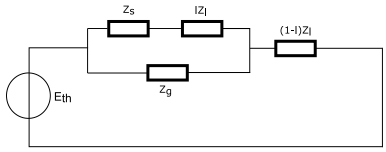

Figure 2b *Thevenin equivalent*

The Thevenin impedance Z_{th} is:

$$Z_{th} = \frac{(Z_s + l \cdot Z_l) Z_g}{Z_s + l \cdot Z_l + Z_g} + (1 - l) Z_l \quad (1)$$

In equation (1) Z_s is the grid impedance (including transformer impedance), Z_g is the generator impedance and Z_l is the line or cable impedance. l is the relative length of the line with $0<l<1$. The total short-circuit current in each phase can be calculated by:

$$I_{k,3ph} = \frac{U_{th}}{\sqrt{3} \cdot Z_{th}} \quad (2)$$

For the grid contribution holds:

$$I_{grid} = \frac{Z_g}{(Z_s + l \cdot Z_l) + Z_g} \cdot I_{k,3ph} \quad (3)$$

The value of Z_s is determined by the local short-circuit power, S_k'', of the transmission grid. In the ideal case $S_k'' \to \infty \Rightarrow Z_s \to 0$ then:

$$I_{grid} = \lim_{Z_s \to 0} \frac{Z_g}{Z_s + l \cdot Z_l + Z_g} \cdot I_{k\infty} \quad (4)$$

$$I_{grid} = \frac{Z_g}{Z_g + l \cdot Z_l} \cdot I_{k\infty}$$

$$I_{grid} = \frac{1}{\frac{l \cdot Z_l}{Z_g} + 1} \cdot I_{k\infty}$$

In the theoretical case of $S_k'' \to \infty$ it can be concluded of (4) that the size of the generator and the location of the generator in the feeder determines the grid contribution to the short-circuit current. When $l \cdot Z_l / Z_g$ is small, then $I_{grid} \approx I_{k\infty}$. This happens when the generator is located near the substation (small l) or when a generator with a small capacity is installed (large Z_g).

In the real world $S_k'' \to \infty$ never happens. Especially in a rural MV-grid S_k'' can be low so the grid impedance cannot be neglected anymore and (4) no longer holds. In this case the effect of DG on the grid contribution of the short-circuit can be explained with (3). The total short-circuit current, I_k, is determined by (2) and (1) and the latter equation is non-lineair with the location and size of the DG, so I_{grid} is non-lineair as well. Because of the weak grid, Z_s can be as large as Z_g and the grid contribution to the short-circuit current decreases. Hence it is possible the short-circuit stays undetected because the grid contribution to the short-circuit current never reaches the pickup current of the feeder relay.

This mechanism is called blinding of protection and is also known as protection underreach [5-7], [9].

Case studies

To determine the impact of DG on the short-circuit current a test grid is defined and modeled in DIgSILENT's software package 'Power factory'. The test grid consists of an external grid, three MV-nodes which are connected by cable connections. At busbar 2 a synchronous generator is connected. The test grid is depicted in figure 3.

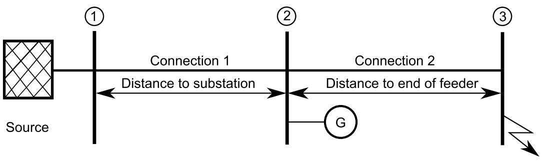

Figure 3 *MV-test grid including a synchronous generator*

As stated in equation (4) the effect of DG on the grid contribution to the short-circuit is determined by the size and location of the DG. In the test grid the location and size of the generator are modified to investigate this effect. 'Powerfactory' offers a possibility to write scripts to perform repetitive calculations. To explain the structure of the script in figure 4 a flow chart is shown.

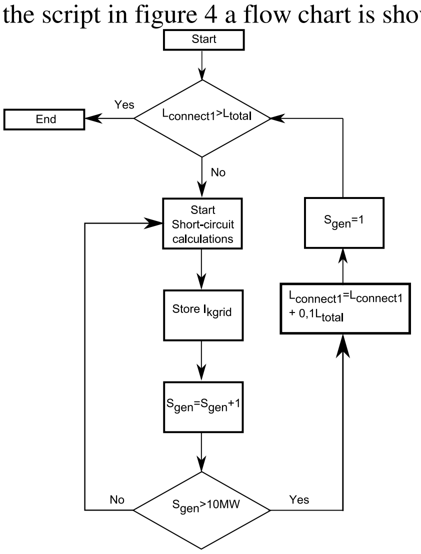

Figure 4 *Flow chart of the script*

The script contains two loops to modify the length of the connections and the size of the generator. The length of both connections is adjusted by 10% of the total feeder length. To keep an equal total feeder length, connection 1 is increasing and connection 2 is decreasing with the same step size. In this way node 2 is shifting from node 1 to node 3 and the effect of the location of the generator can be observed. After the modification of the length of the connections the second loop is entered. This loop performs a three phase fault calculation at busbar 3 and increases the generator size. The short-circuit calculation is based on the well known IEC 909 method. In the loop, the grid contribution to the short-circuit current is stored. When the loop is completed the first loop is entered again and the process starts all over. The results of the script are checked by applying equations (1), (2) and (3) in a regular spread sheet program.

It was concluded that the calculations perfectly matches the results of the script.

With the aid of the script the following cases are studied:

1. Test grid, S_k'' =200 MVA including 15 km cable connections
2. Test grid, S_k''=200 MVA including 15 km overhead line

The cable connection is modeled as a regular XLPE 630 mm^2 Al cable type. To compare the result of both cases a line type which is equivalent with the cable type is chosen. The electrical characteristics are given in table 1.

Table 1 *Electrical characteristics*

	R[Ω/km]	X[Ω/km]	Inom [A]
XLPE 630 mm2 Al	0.063	0.109	575
DINGO 19/.132	0.218	0.311	525

For both cases the grid contribution to the total three phase short-circuit current is shown in figure 5a and b.

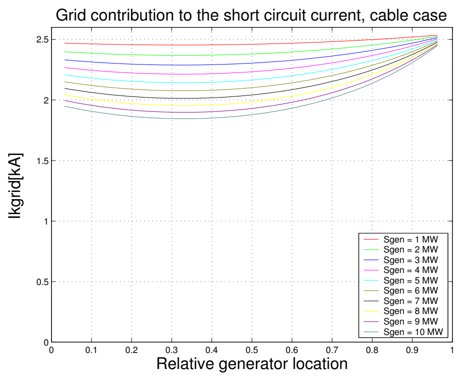

Figure 5a *Results for cable connection*

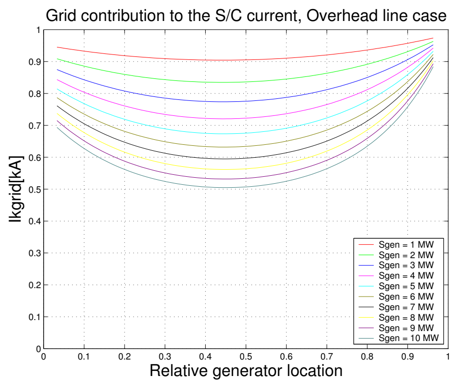

Figure 5b *Results for overhead line*

In the previous section was indicated that for proper protection of radial feeders, I_{pickup} should be set to 50% of the minimum end of line phase to phase fault. For convenience a definite overcurrent relay is applied and the relay is set as mentioned. In table 2 for both cases an overview is given of the phase to phase and three phase fault current. These currents are calculated without the contribution of the generator.

Table 2 *Fault currents and relay settings for both cases*

	$I_{k,3ph}$ [kA]	$I_{k,ph-ph}$ [kA]	I_{pickup} [kA]
Cable	2.646	2.291	1.145
OH-line	1.030	0.890	0.445

When studying figure 5a in more detail it shows that the minimum grid contribution is approximately 1.9 kA. This value occurs when a 10 MW generator is connected at a distance of 6 km from the substation. If the grid contribution is compared with the relay setting it can be concluded that all the faults in the grid will be detected and switched off by the protection.

On the contrary of the cable case, problems arise in the OH-line case. The pickup current is below the nominal ampacity of the OH-line and at nominal loading the feeder is switched off unnecessary. To protect the grid properly the relay setting has to be changed. To prevent unnecessary tripping and ensure detection of all the faults I_{pickup} should be $I_{nom}<I_{pickup}<I_{k,ph-ph}$. The window is projected in figure 6 and it follows that not every fault will be detected and switched off.

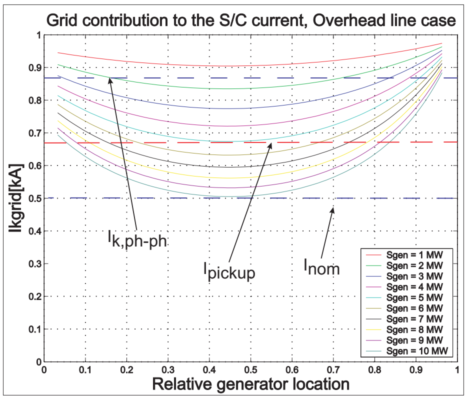

Figure 6 *Limits of I_{pickup} to avoid unnecessary tripping*

Allowing an overload of the feeder of 30% I_{pickup} must be at least 0.68 kA. This setting limits the amount of DG connected to the feeder. Figure 6 shows that at the relay setting of 0.68 kA blinding of protection will not occur when S_{gen}<5 MW. Larger unit sizes can be allowed but it depends than on the location of the unit.

As stated in [10] protection devices in a multisource system have to be direction sensitive. In both studied cases the generator contribution to a fault in an adjacent feeder exceeds the relay setting. It is recommended to install direction relays.

CONCLUSIONS

In this paper the effect of DG on the protection of MV-grids is studied. A couple of problems that can occur in protecting MV-grids including DG are described. The emphasis of the paper lays on blinding of protection and false tripping. To investigate these mechanisms a test grid is defined and modeled in DIgSILENT's 'Powerfactory'. Distinction is made in MV-grids containing cable connections and MV-grids containing overhead lines what leads to two case studies. The influence of DG on the short-circuit current depends on location and size of the unit. Besides this, feeder and grid impedance play an important role. The overhead line case shows that connection of DG is limited due to blinding of protection. This is caused by the relative high impedance of the overhead line. In the cable case this effect is not observed. In general terms it can be concluded that no protection problems may be expected in MV-cable grids with a high penetration of DG and high short-circuit level. The paper also demonstrates that the results can be checked by applying the presented equations in a regular spread sheet program. In this way specific cases can be studied when there might be a problem with the protection.

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