NEW REQUIREMENTS FOR SYSTEM PROTECTION CAUSED BY DISTRIBUTED GENERATION

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INTRODUCTION

The requirements for the protection of distribution networks are considerably changing due to the increased share of distributed generation (DG). Protection schemes and practices designed for unidirectional power flow may become ineffective. The purpose of this paper is to present results of simulation analyses of the impacts of DG. The emphasis lies on three problems:

• Impact of DG on the fuse based protection of low voltage networks
• Impact of DG on automatic reclosing
• Loss-of-mains requirements and methods.

Additionally, the impact of small low voltage connected units on the protection of medium voltage feeders as well as aspects of the aggregate impact of several small DG units have been discussed.

In this study the commercial transient simulation tool PSCAD™ has been applied. For this environment an extensive collection of simulation models has been developed. This collection includes models of MV and LV networks, different types of DG units, protection relays and fuses. Performance of system protection including interconnection protection has been analysed with various combinations of network parameters, relay settings, loads and faults.

METHODS AND TOOLS

Typical for the events dictating the performance of relay protection is their dynamic nature. In order to thoroughly analyse the effects of distributed generation on the requirements for the protection of distribution networks, detailed simulation studies are necessary. Dynamic modelling of various types of DG technologies is required as well.

This paper is based on simulation studies carried out by VTT Technical Research Centre of Finland. In these studies PSCAD™ transient simulation software has been applied. The component libraries and network models used in this study have been developed by VTT and University of Vaasa.

IMPACT OF DISTRIBUTED GENERATION ON FUSE BASED PROTECTION OF LOW VOLTAGE NETWORK

Very few papers have been published on the impact of DG on the fuse based protection of low voltage networks. In reference [1] it is concluded that no major changes in the protective devices are required and that the fuse based protection is not disturbed by distributed generation. However, theoretical studies of the impact of DG on the current seen by protective devices indicate that DG may blind overcurrent protection [2]. E.g., short-circuit current fed by a synchronous generator can decrease the current seen by the feeder relay or fuse, preventing or retarding correct operation.

The impact of DG on fuse based protection was studied using a real world based low voltage network model, shown in Figure 1. This network is in rural area and the most part of it is overhead lines.

![Figure 1. Scheme of the analysed low voltage network.](image)

The examined production units were a small synchronous generator (40 kVA) and an inverter based unit (S_in=100 kVA, operating at 50 kW). They were equipped with voltage, frequency, and overcurrent relays. 1- and 3-phase faults were applied in the point indicated with an arrow.

Figure 2 illustrates the impact of a small synchronous generator on the current seen by the feeder fuse and how the operation of the fuse is disturbed.

![Figure 2. Impact of a synchronous generator on the operation of the feeder fuse.](image)
The simulated fault case was a single-phase short-circuit fault close to the end of the feeder. When there was no generator running, the current seen by the feeder fuse was ca. 216 A (3.4 x Iₚ of the fuse), and the fuse operated after 6 seconds. When the generator was running, the current seen by the feeder fuse was only 129 A, and the fuse did not operate in a reasonable time.

Figure 3 shows currents of simulated 3-phase short-circuit fault cases with and without generation. The production unit is an inverter based unit, operating at constant output of 50 kW. The fault starts at t = 0.5 s. Although the inverter does not produce high current, it clearly retards the operation of the feeder fuse. After the operation of the feeder fuse, the inverter is tripped by its voltage relay.

These simulations confirm that DG units may disturb the operation of fuses in low voltage networks. A very interesting finding is that also inverter based units may have a significant impact, although they do not supply high short-circuit current.

DETECTION OF MEDIUM VOLTAGE EARTH FAULT ON THE LOW VOLTAGE SIDE OF THE TRANSFORMER

There is a particular difficulty in earth faults in unearthed or resonance-earthed systems. When using delta-wye (Dyn) connected distribution transformers, it seems to be impossible to detect medium voltage earth fault on the low voltage side of the transformer.

Large generators with a dedicated transformer can be equipped with zero sequence voltage measurement in medium voltage network. In order to avoid unnecessary tripping when the fault is in adjacent feeder, the time delays of the generator relays should be coordinated with time delays of feeder relays. When high-speed reclosing is applied this coordination is very difficult.

Small production units deep in low voltage networks are even more problematic. Disconnection must be based on islanding detection, after the MV feeder breaker has tripped. When designing loss-of-mains protection, it should be noted that it is not adequate to analyse only the operation of a single production unit. The aggregate impact of several units and mutual interaction should also be analysed.

THE AGGREGATE IMPACT OF SMALL UNITS

In this study the impact of small units on the voltage of the islanded medium voltage feeder was simulated. The effect of small production units, inverter based units and synchronous generators, is shown in Figure 4. The simulated fault cases were single-phase to earth faults in medium voltage network. The fault occurred at t = 1.6 s and the feeder tripped at t = 2.1 s. There was one wind power plant (induction generator, 1.65 MW) operating and responsible for the major part of the sustained voltage.

The simulations of Figure 4 reveal how the small units contribute to sustaining the voltage in the islanded medium voltage feeder. Although the current supplied by the inverter based units is less than 2Ixₚ, the inverters clearly support the voltage. The impact of small synchronous generators is recognisably larger.

The simulations confirm that the aggregate impact of even very small units should not be underestimated. The voltage supported by DG units sustain fault arc in typical arc faults. This is detrimental especially when automatic reclosing is applied. In practice this should be taken into account when defining loss-of-mains protection requirements to the DG units.

AUTOMATIC RECLOSING AND DG

In medium voltage overhead networks all over the world automatic reclosing is a prevalent and very effective method of fault clearing. Distributed generation seems to be rather incompatible especially with high-speed reclosing. It may sustain the voltage and fault arc, preventing successful reclosing. Prevention of successful reclosing leads to longer outage and causes extra stress to network components.

During the autoreclose open time the generators connected to the feeder may either decelerate or accelerate out of phase. In the worst case the reclosure of the feeder circuit breaker occurs when the islanded feeder is in phase opposition with the main network. Out-of-phase reclosure can be very detrimental to both production units and the components of the neighbouring network.
Simulation Studies of Automatic Reclosing and DG

The impact of DG on automatic reclosing was studied using a simplified model of overhead medium voltage network. The network model was equipped with overcurrent and earth-fault relays, and high-speed 3-pole reclosing. For earth-fault protection directional earth-fault relays were applied since the earthing practices of the simulated cases included earth-isolated and resonant earthed systems.

The generator types applied in the simulations were asynchronous generator and synchronous generator. The asynchronous generator (wind power plant, 1.65 MW) was applied in a directly connected fixed speed wind generator. The diesel power plant (7.94 MVA) model was based on a synchronous generator and the model was developed together with a power plant manufacturer. In the simulations one or several generators could be connected to any point of the network model. The DG units were equipped with voltage and frequency relays. In these simulations specific loss-of-mains relays were not applied.

The simulations clearly confirmed that distributed generation can sustain arc faults, prevent successful reclosing and cause out-of-phase reclosing. An example of out-of-phase reclosing is shown in Figure 5. The fault case is a single-phase to earth fault, and there are three wind power plants running. Figure 5 presents the simulated phase difference between the islanded feeder and the main grid. The phase difference at the reclosure is ca. 170 degrees.

![Simulated phase difference between the main grid and the islanded feeder](image)

**Figure 5. Simulated phase difference during autoreclosing sequence.**

More detailed results of simulation studies, including a prototype model of the fault arc, have been presented in reference [3].

To prevent problems in high-speed autoreclosing, several methods have been proposed. Increasing autoreclose open time would leave more time for the generators to disconnect, but this would have adverse impact on supply quality, and it would not guarantee disconnection in cases where the load and the power of the generators match.

Synchro-check and voltage check relays could be applied to prevent out-of-phase reclosing. These could be seen as backup for fast and reliable loss-of-mains protection that would rapidly disconnect all the production units connected to the islanded part of the network.

ISLANDING DETECTION

Loss-of-mains protection is probably the most challenging protection issue coming up with distributed generation. Many methods have been introduced but it seems that a totally satisfying method is still missing, especially when high-speed automatic reclosing is applied.

Most passive anti-islanding methods are currently based on voltage, frequency or their derivatives. ROCOF (df/dt) and voltage vector shift methods can to some extent be considered as de facto standards. However, these methods have well known drawbacks. They have a non-detection zone close to the point where both active and reactive load match. If relay settings are very sensitive, these methods tend to cause nuisance tripping. These problems have been verified both theoretically and by practical experience. [4], [5], [6]

An example of the difficulty to detect islanding by monitoring the frequency is shown in Figure 6.

![Figure 6. Frequency when an earth fault occurs and the feeder becomes islanded.](image)

In the simulated case there is a diesel generator, and the output of the generator and the load of the feeder are about the same. The earth fault starts at t = 10.1 s and the feeder breaker trips at t = 10.6 s. The changes in the frequency measured at the diesel generator are so small that it would be very difficult to detect islanding relying on frequency or df/dt measurements. On the other hand, short-circuit fault in adjacent feeders cause clearly larger change in the frequency, which makes selective loss-of-mains protection challenging.

Simulations with prototype models of ROCOF and vector shift relays support the estimation that these methods are rather effective but they have their non-detection zone and are vulnerable to false tripping. Further studies are needed to estimate the limits of these methods.

NEW SOLUTIONS REQUIRED

When distribution systems are changed from traditional radially fed systems into active systems with significant share of distributed generation, new protection solutions are required. The analysis above indicates that in systems using overhead lines and automatic reclosing, fast and reliable loss-of-mains protection is needed.
Passive loss-of-mains methods have their drawbacks, and active methods don’t have general acceptance. Only communication-based transfer trip method is considered reliable and selective. Traditional intertripping is cost effective only for large units, but new types of communications based methods are being developed. Method prototypes based on carrier signal have been described in references [7] and [8]. The basic idea is based on detection of network continuity signal.

Preliminary Simulation Results of a Method Based on Ripple Control Type of Signal

One alternative utilising network continuity detection principle could be the use of ripple control type of signal. In this method a low frequency (<1000 Hz) signal would be continuously transmitted to medium voltage network or even to high voltage network in the primary substation. Low frequency signal would pass the network easily and reach also the micro-scale DG units connected to the low voltage network.

The principle of ripple signal based method was examined using simulations. A model of a transmitter injecting 168 Hz signal was placed in the HV/MV substation and the measurement simulating the receiver was connected deep in the low voltage network. Figure 7 presents results of a simulated case.

Figure 7. Example of ripple signal behaviour in islanding.

In the simulation of Figure 7, the transmitter is disconnected at \( t = 0.6 \) s and reconnected at \( t = 0.8 \) s, to see how it can be detected by the receivers. The fault was a single-phase to earth fault, occurring at \( t = 0.9 \) s. The medium voltage feeder trips at \( t = 1.4 \) s, and the decrease of the signal level rapidly indicates the islanding.

Short-circuit fault on adjacent feeder would decrease ripple signal level. This could cause unnecessary tripping. This problem can be solved by rapidly increasing the transmitter signal level when a voltage dip is detected and by using instantaneous tripping of MV feeder in high-current faults.

Network continuity signal method seems to have advantages over traditional anti-islanding methods. However, further simulation studies as well as field tests are needed to verify the feasibility of the method.

CONCLUSIONS

Most of the studies of the impact of distributed generation on distribution network have been concentrated in medium voltage networks and rather large individual production units. The simulation results presented in this paper indicate that there are challenges also in the protection of low voltage networks and that the aggregate impact of small units should not be underestimated.

One of the most challenging problems is the incompatibility of high-speed reclosing and distributed generation. Because the most common present-day anti-islanding methods are not comprehensive while they are prone to nuisance tripping, new loss-of-mains methods are needed. Communication-based methods have some advantages over algorithm-based methods and are an interesting alternative.

REFERENCES


