LOSS-OF-MAINS PROTECTION – STILL AN ISSUE WITH DISTRIBUTED GENERATION

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ABSTRACT

Connection of distributed generation makes power systems more complicated. This paper summarises the most important potential consequences to power system protection that have to be taken into account when connecting distributed generation (DG) into distribution networks. Both MV and LV networks are discussed, and possible solutions to the protection problems are suggested.

Most of the problems caused by DG can be solved by traditional means, but there is one exception. There seems to be no satisfying solution to the Loss-of-Mains (LoM) protection. In this paper the importance of LoM protection is discussed. As a solution to the problem this paper introduces and argues for a universal, power line signalling based LoM method.

INTRODUCTION

Traditionally electricity distribution systems have been rather simple, because the power flow has been unidirectional. Connection of distributed generation, normally not controlled by network operator, makes the systems more complicated. This is especially true with protection issues. Most of the challenges DG causes to the protection of distribution network can be solved using conventional methods, but protection against unintentional islanding (anti-islanding protection, Loss-of-Mains protection, decoupling protection) requires new solutions. During the last ten years, many LoM methods have been proposed, but a universally acceptable method is still missing.

THE IMPACT OF DG ON PROTECTION

It has been shown that DG may cause the following challenges to the protection of distribution systems:

- The systems will be more complicated. The risk of accidents increases when there are multiple sources.
- System earthing may change when a part of the network is tripped and operates islanded.
- Because of the fault current fed by DG, the operation of the protection (relays or fuses, MV and LV) may be prohibited or delayed.
- False tripping of healthy feeders is possible.
- Distributed generation may require upgrading of the busbar protection of primary substations.
- DG units may trip in faults where they should not trip (nuisance tripping), causing power quality problems.
- Fault level of networks changes. Fault level can either increase or decrease due to distributed generation, and there may be significant variation in fault level of a certain part of the network, depending on the number and type of generators operating.
- Especially intermittent DG may increase voltage variations in the network.
- DG increases the risk of ferroresonance.
- DG may be very problematic, if automatic reclosing is applied. DG may sustain fault arc and thus prevent successful reclosing. In the worst case DG units may cause reclosing in a phase opposition.
- The fault clearing time may become indefinite, especially in the case of earth fault. Without anti-islanding protection DG units may sustain the voltage of downed conductors.
- Especially if the DG units are connected to the LV side of a Dyn-connected distribution transformer, it is impossible for the DG units to detect earth faults in the MV network. The DG units may thus sustain MV earth fault. The cumulative impact of many small generators cannot be neglected. [1],[2]

Most of the problems can be solved by traditional methods, by, e.g., applying directional protection. For Loss-of-Mains protection, however, there is a special need, and despite of many suggestions, adequate solutions are still missing.

THE IMPORTANCE OF LOM PROTECTION

Faulted parts of networks are disconnected from the healthy network by the operation of protection equipment, e.g., feeder circuit breaker. When there is DG connected to the network, the islanded part may keep on operation. In most cases islanding is not desirable for the following reasons:

- Safety problems to maintenance personnel arise when disconnected circuits may be back-fed.
- Network operator is unable to guarantee the power quality in the island. There could be abnormal voltage or frequency, and the fault level may be too low, so that the overcurrent protection will not work the way it is designed.
- Reconnection of the islanded part becomes complicated, especially when automatic reclosing is used. This can lead to damage of equipment and decrease of reliability.

Sustained islanding is a rare event while short-time islanding is a common phenomenon, and it can be very detrimental. Especially when high-speed automatic reclosing is applied, DG may sustain the voltage and fault arc during the autoreclose open time causing failure of the reclosure and out-of-phase reclosure. Figure 1 illustrates torque transient of a wind generator during a simulated out-of-phase reclosure.

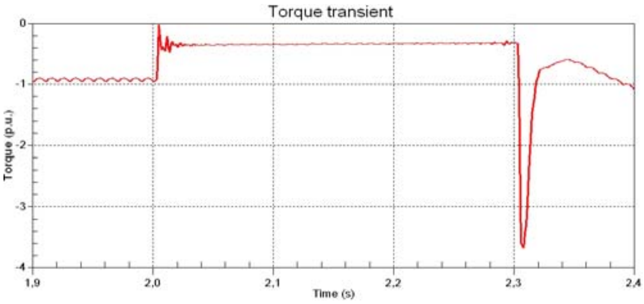

Figure 1. Simulated torque of a wind power generator in an out-of-phase reclosing.

In order to achieve adequate safety and reliability level of the distribution system, anti-islanding protection is usually considered necessary. It is even specifically required in many of the relating rules. The rules and guidelines vary from country to country but requirements similar to the following are often given:

- DG should be disconnected from the network in the case of abnormality in voltage or frequency.
- If one or more phases are disconnected from the grid supply the DG units should be rapidly disconnected from the network.
- If automatic reclosing is applied, the DG units must disconnect before the reclosure. In fact, DG units should be disconnected clearly before the reclosure, so that there will be a long enough dead time needed for extinguishing of the arc. This means that the LoM protection should operate very fast.

In [3], LoM protection is considered a key requirement for the connection of generation. According to [4] LoM protection should able to detect also islanding situations without faults. This essential requirement is very interesting from the present LoM methodology point of view.

LOM METHODOLOGY

A good overview of anti-islanding methods has been given in [5]. LoM methods can be divided into passive and active local detection methods, and communication based schemes.

Active methods

Active schemes are based on active island de-stabilization, monitoring the response of the system to a change created by the anti-islanding protection equipment. Active methods have been criticized for being often only suitable for inverter-based systems and for deteriorating power quality [6]. One of the worries is the possible interference if there are other DG units, and this is one of the reasons why active schemes have been considered unreliable. [5]

Passive methods

Passive schemes are the most common LoM methods. They are based on monitoring local quantities at the DG units, normally voltage or frequency. Two of the most widely applied are ROCOF (rate of change of frequency) and voltage vector shift. However, according to [7], any single passive scheme that relies on detecting voltage and frequency or their derivatives can fail. The ineffectiveness of passive methods has been also theoretically verified [8].

The following example illustrates this phenomenon. In this case the DG unit is connected in a feeder as presented in Figure 2. The aim is to find out whether the generator is able to detect the feeder circuit breaker operation (islanding of feeder 2), when the load of feeder 2 and the production of the generator match. This example is valid with base frequency.

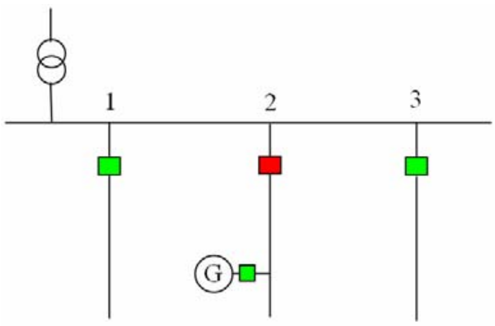

Figure 2. The examined connection of a DG unit.

If there is no current when the circuit breaker 2 opens, the generator will not be able to detect the change in the impedance of the network. Thus all passive LoM methods based on power, voltage or current measurement have a non-detection zone.

Simulations with PSCAD™ have verified the non-detection zone of ROCOF and vector shift methods [8]. The non-detection zone of these methods has also been confirmed, e.g., in [9] and [10]. Testing of LoM methods gives another point of view. According to [11], motor load affects the performance of both passive and active methods. Passive load may not be adequate to evaluate the effectiveness of LoM schemes. It should be noted that motors account for a significant portion of the total load.

A more practical problem with passive methods is nuisance tripping. There are claims from the field that ROCOF relay is causing a lot of unnecessary tripping.

Communication based methods

Communication based LoM methods are superior to passive methods, because they don't have non-detection zone and they don't cause nuisance tripping. There are two different approaches: traditional Transfer trip and Power line signalling. The main drawback of transfer trip is the high cost. It can hardly be justified for small DG units connected to the LV network.

The principle of power line signalling based LoM methods has been known for a long time. In the following the potential of this promising concept is discussed.

POWER LINE SIGNALLING

The principle of the method

The simple basic idea of power line signalling is presented in Figure 3.

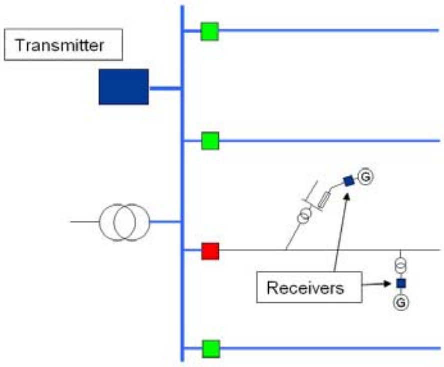

Figure 3. The principle of the power line signalling method.

The transmitter sends signal to the network, and the DG units are equipped with receivers. As long as the receivers detect the signal, they will stay connected to the main network. The disappearing of the signal indicates islanding. The signal does not have to carry any information.

Benefits

Power line signalling based LoM method has several benefits:

- It does not have a non-detection zone and detects also islanding in no-fault situation.
- If the signal level remains high enough during faults on adjacent feeders, there is no risk of nuisance tripping.
- Motor load does not have an impact on its efficiency.
- Changes in network configuration do not require changes in communication.
- There is no need of separate communication channel.
- Islanding caused by operation of any switching device (circuit breaker, recloser, disconnector, MV fuse, LV fuse) will be detected.
- There is no need to detect MV earth faults on the LV side of distribution transformers, because the islanding detection is not based on fault detection.
- The receiver technology can be standardised, and a uniform network company wide LoM system can be applied instead of different relays for different types of DG units.
- The operating time of DG disconnection can be very short, so that DG will be disconnected before high-speed autoreclosure.

Signal frequency

Signal frequency is an essential choice for power line signalling based LoM systems. Ropp [12] suggests low frequency signal, below 500 Hz, to avoid signal attenuation. Benato [13] proposes high frequency (72kHz).

Low signal frequency is superior for the following reasons:

- It passes the distribution transformer and can thus be detected also in the LV network. This means that simple and cost effective receivers can be used also with very small DG units.
- There is a lot of experience on the propagation of low frequency signals in traditional ripple control systems.

THE PROPOSED LOM METHOD

Special properties of the proposed method

A universal LoM method could be based on power line signalling. The risk of signal absorption can be reduced by using multiple frequencies. During system voltage dips caused by short-circuit faults on adjacent feeders, the adequate signal level can be guaranteed by boosting the signal temporarily.

Simulations of the power line signalling

The performance of the power line signalling based LoM method was verified by simulations with PSCAD™ simulation software. Signal propagation was simulated using several network models, including IEEE 13 Node Test Feeder. Most of the simulations were run applying the Finnish rural network model shown in Figure 4.

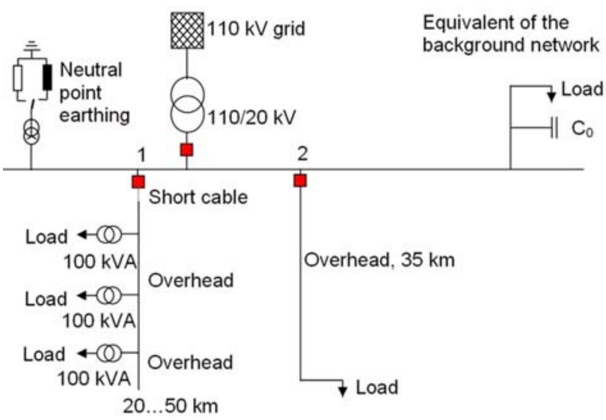

Figure 4. The Finnish rural network model.

A low frequency signal (168Hz) was injected into the MV bus. The level of this ripple signal was 2% of the nominal voltage. The receiver models measuring the signal strength were connected to both MV and LV network.

The simulations confirmed that the signal easily propagates through the distribution transformer and can be detected at the end of LV network. Figure 5 illustrates the behaviour of the signal detected in the LV network during an earth fault in the MV network. The fault occurs at t = 1.0 s and the MV feeder is tripped at t = 1.5 s. The measured network continuity signal disappears rapidly after the receiver loses the connection to the transmitter.

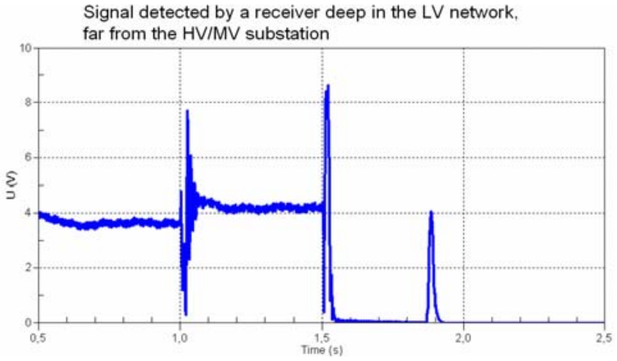

Figure 5. Simulated signal level measured in the LV network during an earth fault in the MV network.

CONCLUSIONS

A satisfying solution for LoM protection is still missing. The most common passive methods have a non-detection zone and they are prone to nuisance tripping.

A power line signalling based universal method suitable for all types of DG is proposed and its operation has been demonstrated with simulations. Further research is needed to find the optimal signal injection technology and to verify the method in practice.

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