IMPACTS OF DISTRIBUTED GENERATION ON EARTH FAULT PROTECTION IN DISTRIBUTION SYSTEMS WITH ISOLATED NEUTRAL

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ABSTRACT

The propagation of distributed generation (DG) located in the distribution networks sets new requirements for the protection of the networks. This will be especially true in the future as the amount of DG increases. Problems related to the short-circuit protection have been analyzed quite extensively. The impacts of DG on earth-fault performance have not yet been studied as widely. This paper focuses on medium voltage networks with isolated neutral which are applied for instance in Nordic countries.

INTRODUCTION

The traditional methods for using and controlling the electrical distribution network are based on the assumption of unidirectional power flow. Distributed generation (DG) located in the networks changes this fundamental basis. The typical schemes applied may thereby become inoperative. DG offers some certain benefits; it enables local effective power production, it can reduce losses in the network, it can provide stand-by supply in suitable circumstances, etc. The main drawbacks for DG include more complex control and protection of the network.

The implementation of earth fault protection varies according to the structure of the network. In networks with isolated neutral, earth fault currents are very low and conventional earth fault protection can thus not be applied. Instead, the protection is based on asymmetry produced by the fault. A directional element is needed to achieve a selective operation. Zero voltage measurements at the substation's bus and zero current measurements at feeder relays are used for this. [1]

PROTECTION DEVICES FOR DG UNITS

The connection point of distributed generation is equipped with certain protection devices including features such as overcurrent, under-/overvoltage, under-/overfrequency and reverse-power. An additional earth fault relay may also be used. The possibility of unintended islanding can be handled with specifical loss-of-mains (LOM) relay.

LOM is difficult to detect as it can not be unambiguously detected from the DG unit's connection point. Thereby LOM detection is usually based on power imbalance occurring as the connection to the primary network is lost. Traditionally, the power imbalance has been commended to frequency and voltage protections. The imbalance may, however, be small and these quantities may thus change too slowly for fast enough island detection. The development of distribution level generation is complicating the implementation of LOM protection with traditional methods. Modern generation units may be more capable of maintaining the frequency and voltage than in the past. [2] The aggregate impact of small DG units must also be taken into account.

New methods such as ROCOF (rate of change of frequency) or vector shift have been developed for these purposes. Unfortunately these new techniques still suffer the non-detection zone as the remaining load of the network can match the DG production too precisely. However, the sensitivity problems are much more uncommon when compared to the conventional methods. New methods are also prone to nuisance trippings in some situations, which may be problematic. [2], [3]

EARTH FAULTS IN A NETWORK INCLUDING DISTRIBUTED GENERATION

In a distribution network applying an isolated neutral point, the block transformer used to connect the DG unit to the network is typically of a delta-wye type. In such a configuration, the transformer forms a point of discontinuity in the zero sequence network. This means, that the zero sequence values measured on the low voltage (LV) side can not be used to detect the earth faults occurring in medium voltage (MV) network [4], [5]. The discontinuous zero network means also, that the DG unit will not interfere the operation of feeder protection as it has been observed to do in the case of overcurrent protection [6].

At the present situation the earth fault protection of DG units is typically implemented with LOM protection. The DG unit is assumed to become disconnected due to the island formed after the operation of feeder's earth fault protection. This has been observed to be adequate method in many cases. On the other hand, as it was mentioned earlier, the present LOM protection techniques are not considered reliable under all circumstances. The island may thereby remain longer resulting in sustained earth-fault and further in high touch and step voltages. In such a system, it is important to note that the DG unit always reduces safety of the network even in the case of correct operation of protection. This is as the voltages remain higher at least for the operation delay of LOM protection.

Due to the risks mentioned, a fast and reliable LOM protection is a minimum requirement in order to maintain the safety of the network. This is also important to assure the correct operation of fast autoreclosings used for clearing temporary faults. Further, it would be a better solution if the DG unit could be tripped due to the earth fault instead of the resulting islanding. Thereby one challenging issue is the DG unit's possibility to detect the fault.

One promising solution is measuring the zero voltage on the utility side of the DG unit's transformer. [5], [7] This method can not be easily applied in the case of DG located further in the LV network with other customers. Disconnecting these units would practically require communication between the transformer station and the unit. Another option would be to disconnect the whole LV network, which is usually not acceptable.

Another question rising for achieving a reliable protection is the operation during faults elsewhere in the network. DG must not become tripped when there is no need for it.

EXAMPLE STUDIES

An example case shown in figure 1 was used to illustrate the issues studied. The case comprises of two MV feeders fed from the same substation. The DG unit was connected to point 2 of feeder F1. Earth faults were simulated for points 1, 3 and 4. Fault located in point 4 is a fault occurring on an adjacent feeder.

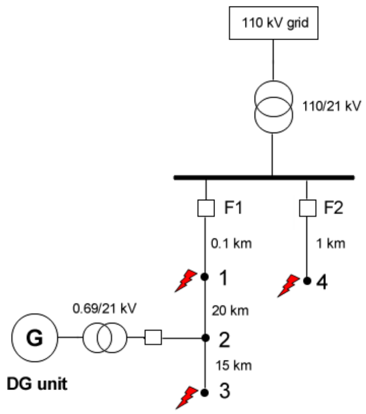

Figure 1. The example network used in the simulations

The case presented was studied in a dynamic simulation environment with PSCAD simulation software. The DG unit applied in the studies is a typical wind power unit with a 2.3 MW induction generator. The generator is connected to the network through a standard delta-wye distribution transformer with an earthed star point on the LV side. The DG unit connection point is equipped with typical protection devices (overcurrent, voltage, frequency, df/dt and vector shift).

Before installing the DG unit to the network, the earth fault protection of the network has been adjusted to operate correctly in all faults. Zero voltage (U_0) measured at the substation's bus detects the faults and the zero sequence current measurement on feeders is used to identify the faulted feeder.

The situation after installing DG in point 2

As the DG unit is connected to point 2, certain questions arise regarding the operation of protection:

1. Is the earth fault protection of feeders affected by DG?
2. How the DG unit can detect the earth faults?
3. Will the DG unit be tripped by faults occurring elsewhere in the network?

These questions are discussed in the following one by one.

Impact on initial feeder protection

The earth fault occurring in point 1 is practically not affected at all by the presence of DG. Thereby the feeder protection operates as initially. For a fault occurring "downstream" from the DG unit (that is, in point 3), the measured zero sequence quantities become slightly modified. However, the differences are very minor. Thus impacts on feeder's earth fault protection are not observed. Similarly, during a fault occurring on feeder F2, no significant impacts on feeder protection can be found. Selectivity problems similar to the short-circuit protection [6] can neither be found during earth faults.

DG unit's possibility to detect earth faults

One aim of the studies performed was to clarify the possibilities of the DG unit to detect the earth faults occurring on the MV side. The LOM protection is intended mainly for islanding detection and it often operates during earth faults after the operation of feeder protection. The possibility of applying LOM methods for detecting the actual fault was also studied.

At first, a fault occurring in point 1 is considered. As expected, the zero sequence values measured at the LV side of the DG unit show no indication of the fault. Similarly, no overcurrent or undervoltage can be detected during the earth fault. LOM situation after the operation of feeder protection is clearly detectable. It must be noted that the production does not match the loading particularly well in the case studied; hence the islanding could be more difficult to detect during different load/generation -combinations.

Currents, frequency, df/dt and vector shift show similar characteristics. The earth fault is impossible to detect whereas the islanding can be detected. The maximum rate of change of frequency (df/dt) as the fault occurs is 0.6 Hz/s and the maximum frequency variation is about 0.1 Hz. A vector shift angle of maximum 0.1° can be seen. Measured values are below typical limits and, besides, signals do not remain long enough. None of these quantities is thereby suitable for detecting the fault before the feeder is tripped. This is shown in figure 2. The fault occurs at 2 seconds and the feeder protection operates after 0.5 seconds.

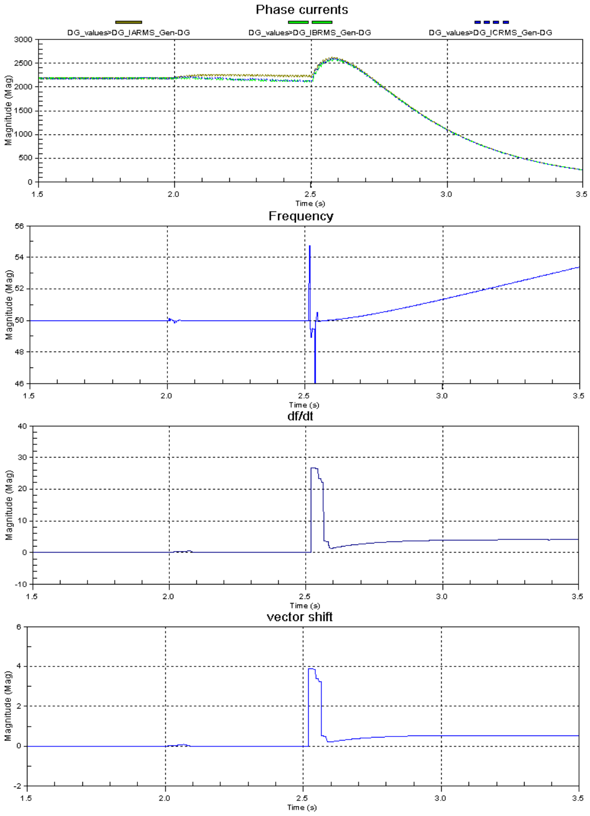

Figure 2. The variables of LOM protection during an earth fault. It is important to notice the amplitudes of the variables at 2 seconds, as the fault occurs. The greater values at 2.5 seconds are due to the operation of feeder protection.

The possibility of measuring the U_0 at the MV level of the connection point was also studied. As expected, the U_0 measured on the MV level can be used to detect the earth fault immediately when it occurs.

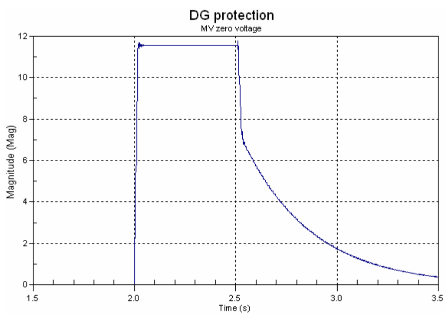

Figure 3. The U_0 measured at the DG connection point for a fault in point 1.

As a second case, an earth fault at the tail part of the feeder (in point 3) is studied. Now the DG unit is located "upstream" from the fault and the behavior might thereby differ in comparison to the first case.
The results show, that both frequency and rate of change of frequency are slightly increased in comparison to the fault in point 1. However, the possibility of detecting the fault according to these quantities is unsure. The maximum df/dt is about 4 Hz/s for a period of 0.05 seconds. This could be detected by the interconnection relay, but the signal duration is an uncertain factor. The frequency variation at maximum is about 0.3 Hz and could thus not be applied for protection. The vector shift of 0.5° can be seen for about 0.05 seconds, but could probably not be used for protection. As in the previous case, U_0 measurement on the MV level can be used to detect the fault. The measured U_0 level is similar to previous fault.

Faults on the adjacent feeder
Another typical case to be considered is a fault occuring on the adjacent feeder fed from the same substation. In the following studies this means an earth fault located in point 4 of figure 1. As it was observed earlier, the DG unit does not impact the operation of feeder protection when located on another feeder. The most important issue is the possibility of disconnecting the DG unit unnecessarily during such a fault. The DG unit should not become tripped when the fault is located elsewhere in the network. Coordination of protection devices may be needed to assure this.
The possibility of applying LOM protection for detecting earth faults was already obstructed by sensitivity in the previous studies. Simulations for earth faults on the adjacent feeder show that the LOM protection variables get even higher values in comparison to the ones on the feeder 1. Thus selectivity could also become serious problem in the case studied. It must also be noted that LOM selectivity during other network disturbances was not analyzed in this study.

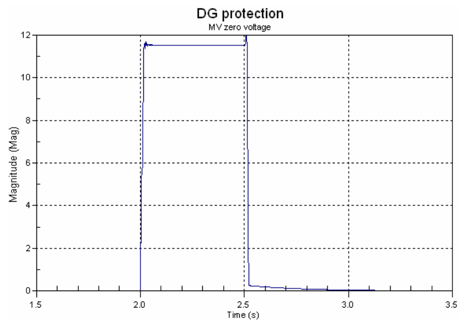

Figure 4. The U_0 measurement during fault on adjacent feeder shows problematic aspects.

The U_0 measurement on MV side shows a behavior similar to the earlier cases. This is presented in figure 4. This is problematic as the U_0 measurement was earlier observed to be a suitable solution for earth fault detection. Hence it seems that the essential problem is in coordinating the U_0 protection for selective operation during all possible faults in the network.

Zero voltage protection coordination

In the optimal solution, the DG unit becomes always disconnected faster than or at least simultaneously with the

DG feeder. On the other hand, it should be disconnected slower than the adjacent feeder. This can be simply expressed as:

$$t_{Adjacent\text{-}feeder} < t_{DG\text{-}unit} \leq t_{DG\text{-}feeder} \quad ,$$

where $t_{Adjacent\text{-}feeder}$ and $t_{DG\text{-}feeder}$ equal to the operation times of feeders' directional earth fault protection and $t_{DG\text{-}unit}$ equals to operation time of DG unit's U_0 protection.

The rule presented above can be used as a simple planning rule when only one of the substation's feeders includes DG. It leads to an optimized situation in which the DG unit causes no additional safety risks during earth faults. It is also possible to apply less restrictive principles as long as the prolonged earth fault voltages are taken into account.

Cases with multiple DG units located on two or more feeders are more problematic. It is impossible to meet the criteria proposed for earth faults occurring on each DG feeder. Thus the optimal solution can not be applied, but a safe operation can still be assured with suitable actions.

Figure 5 presents the measured U_0s for earth faults on the DG feeder and on the adjacent feeder. It can be seen, that a fault on DG feeder (which requires action from the DG protection) results in sustained zero voltage after the operation of feeder protection. In contrast to this, the zero voltage will not sustain when the fault is located on the adjacent feeder. Thereby it is possible to adjust the operation time of DG unit's U_0 protection a bit longer than the operation of feeder protection and use the decaying component for detection. The margin of operation times must be optimized between selectivity and safety.

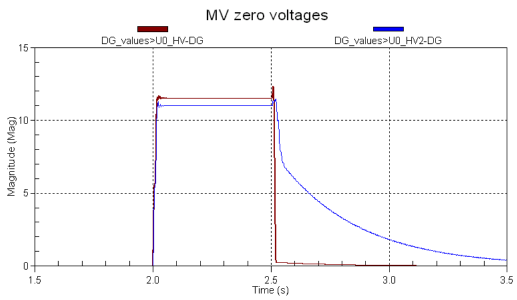

Figure 5. U_0 for fault on the DG feeder decays slower than U_0 for fault on the adjacent feeder.

It is quite common, that substation's feeders have equal operation times during earth faults. In these cases, the approach presented can be useful. DG is simply adjusted to trip little slower than the feeders. However, if any of the feeders applies slower operation than the others, the DG unit needs to be adjusted according to this feeder. Thereby the presence of DG may maintain the voltages significantly longer on the feeder the safety issue may arise again.

CONCLUSIONS

The earth fault protection of distribution network with DG units installed may become problematic under suitable circumstances. The operation of feeder protection is not harmed in systems with isolated neutral. A major concern is the safety of the network during earth faults, which may become jeopardized by DG maintaining voltages in the network after the operation of feeder protection. This may result in touch and step voltages that are not meeting the safety regulations. Thereby a rapid disconnection of DG is needed during earth faults.

The possibilities for detecting earth faults in the DG connection point were observed to be scarce. The zero quantities as well as LOM procedures measured from the LV side of the unit transformer can not be applied for detecting earth faults. LOM protection may even result in nuisance trippings during faults elsewhere in the network. U_0 protection was observed to be workable method, but it has to be applied on the MV level and is thereby not viable for DG units located further in the LV network. Coordination is required for the U_0 protection to assure correct operation during all faults.

Studies performed were based on systems with isolated neutral. The impact of DG can be assumed to be quite similar in the case of resonant earthed system when the block transformer is same type as in these studies. However, more studies on the impacts of grounding method on the subject must be conducted in the future.

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