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# Impact of Distributed Generation on Italian Distribution Network Protection

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*Abstract:* - The presence of a significant DG capacity in distribution networks will result in some conflicts with the operation of the system, mainly because, unlike the meshed transmission system, the distribution system is usually designed as a "passive" radial system. In general, the impact of DG depends on its penetration level in distribution network as well as on DG technology (e.g. synchronous generators, asynchronous generators, static converter interfaced generation systems). In order to maintain correct distribution operating conditions and provide a high quality service to customers, various issues such as voltage control, power quality, short circuit currents, system protection have to be taken into consideration. In particular, the present paper deals with the analysis of protection issues arising in distribution networks in the presence of DG, and examines some practical cases with reference to Italian networks.

*Key-Words:* - Power Distribution, Distributed Generation, Distribution Protection, Power distribution control.

## 1 Introduction

Deregulation of electric utilities and the emerging power markets (introduced in Europe by Directive 96/92/EC and supported by Directive 2003/54/CE) have created a renewed interest in operating generators in parallel with the utility system, especially with distribution networks, where the penetration of distributed generation (DG) is expected to grow. DG can be defined as electric power generation which is not centrally planned and dispatched, connected to the distribution network or on the customer side of the network.

On the other hand the presence of a significant DG capacity in distribution networks would result in some conflicts with the operation of the system, mainly because, unlike the meshed transmission system, the distribution system is usually designed as a "passive" radial system.

In general, the impact of DG depends on the penetration level of DG in distribution network as well as on DG technology (e.g. synchronous generators, asynchronous generators, static converter interfaced generation systems).

In order to maintain correct distribution operating conditions and provide a high quality service to customers, various issues such as voltage control, power quality, short circuit currents, system protection have to be taken into consideration [1].

In particular, the present paper deals with the analysis of protection issues arising in distribution networks in the presence of DG and examines some practical cases with reference to Italian networks.

Firstly, in Section 2, the Italian regulatory framework is briefly described. In Section 3 the structure of typical Italian distribution networks and protection schemes are described. In Section 4 the most relevant and common conflicts arising between DG and protection schemes are summarised and, then, described in the remaining Sections.

## 2 The Italian distribution regulation scenario

Italian MV distribution networks are undergoing significant changes, driven by the Italian Electricity Regulator (AEEG, *Autorità per l'Energia Elettrica ed il Gas*), in the following referred to as the Authority.

Within the statutory objectives of enhancing the quality and performances of the Italian distribution network, the Authority published in 2004 an integrated quality regulation [2].

In this scenario Enel Distribuzione, the major Italian distribution utility, is pursuing an extended program of connecting to ground the MV neutral point of all its MV networks within 2007, to achieve substantial reduction of supply interruptions due to faults and, consequently, to meet the Authority quality targets. According to this trend, Enel issued a new version of his DK5600 and DK5740, respectively, in March 2004 and in February 2005, stating the technical requirements of the customer's and producers' interconnection plants and protection systems to match the new network neutral management [3], [4].
However, the possibility to install DG units in distribution network is fundamentally subject to the conditions provided by CEI 11-20 [5] and CEI 11-35 [6].

## 3 Italian distribution protection

In Italy, MV distribution networks are radial or operated according to radial schemes: the radial structure is maintained during normal operating conditions by keeping opened the switches of emergency ties, that can provide alternative paths to power flows in case of outages or programmed interruptions.
A typical scheme of a distribution network, in which some dispersed generators are connected, is represented in Fig. 1.
MV distribution networks are supplied by primary substations, **PS** (HV/MV), typically equipped with two transformers, each supplying a section of the MV bars. The two sections can be put in parallel by closing a tie switch (see Fig. 1).
The radial circuits are formed by main feeders and laterals. Typically, the main feeders can be back-fed by a neighbouring PS by closing normally open switches.
A main feeder is supplied by a PS and connects various switching substations or satellite centres (**SC**), characterized by the absence of power transformers, and secondary substations (**SS**), with MV/LV transformers.
Fault protection is obtained by means of overcurrent relays for overload and short-circuit, earth-fault directional relays (directional varmetric relay in earth-isolated systems and directional wattmetric relay in resonant earthed systems), and zero-sequence voltage and current relays.
In the PS an Automatic Reclosing Device (ARD) is also installed. It is used to reclose the line circuit breaker after its intervention to avoid long outages in case of self-healing faults.

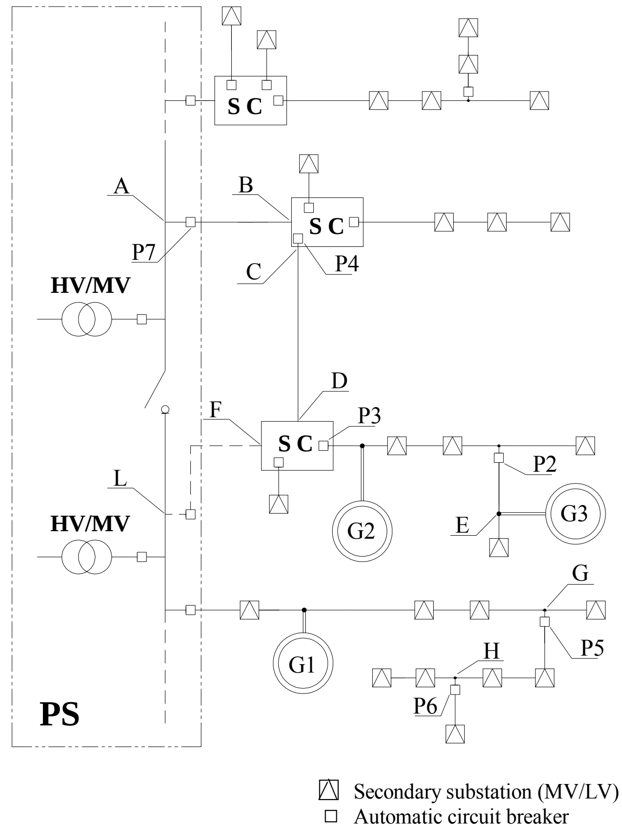


Fig. 1. Typical scheme of a distribution network with dispersed generators.

In Italy, according to specific operating conditions, the distribution operator may need to change the connection mode of the neutral to ground, from isolated to compensated or *vice versa*. For this reason, the MV customers and producers have to install both directional varmetric and wattmetric relays, as well as zero-sequence current relay.
Enel requires the DG units to be equipped with additional protective devices (in the following called "*generator's interface protection*") such as maximum zero-sequence voltage relay, maximum and minimum voltage relays, maximum and minimum frequency relays. These protections are required to avoid islanded operation of generators.
Undesired islanding can occur, for example, if, in a given feeder, the power produced by DG equals the load demand and the current drawn by the feeder is almost zero; intervention of line protection may be not felt by generator's interface protection preventing it from disconnecting from the network. Of course the islanding operation is technically possible only if the generator is able to control voltage and frequency. However this is not allowed since, with the present

network configuration and protection schemes it would cause safety and reliability problems.

# 4 Protection operating conflicts with DG

Generally speaking, the presence of DG can cause various problems related to incorrect operation of system protection. Conflicts between DG and protection schemes are usually due to:

- increase in short circuit currents;
- protection system coordination;
- effectiveness of line reclosing after a fault using the ARD;
- line back-feeding to improve reliability;
- phase-to-ground protection in islanded operation of DG;
- undesired islanding.

# 5 Overcurrent protection

Theoretical studies [7] of the impact of DG on the current seen by protective devices indicate that DG may invalidate overcurrent protection, as summarised in the following Sections with reference to some cases drawn from the Italian scenario.

## 5.1 Change in short circuit currents

DG may affect the operation of existing distribution networks by providing flows of fault currents which were not expected when the protection was originally designed. In practice, the presence of DG may result in increased fault currents.

For example, considering the scheme in Fig. 1, the fault current through circuit breaker *P5* caused by a fault located downstream from position *H*, could assume an increased value due to the presence of *DG1*.

Since this increase largely depends on a number of factors, such as capacity, penetration, technology, interface of the DG, system voltage prior to the fault, etc., detailed assessment of the impact that DG may have on the fault currents is, in general, very challenging [8].

## 5.2 Protective device coordination

Normally, protection of power systems is tuned in such a way that only the faulted part of the system is isolated at a fault. This tuning is called *protection coordination*, which can be negatively affected by the presence of DG. Some typical cases will be analysed in the following.

With reference to Fig. 1, suppose to have a fault in section *A-B*: coordination between protections *P3* and *P4* can be lost due to continued operation of generators *G2* and *G3* after that *P7* has disconnected the feeder from the PS; in this situation, which can be caused either by malfunctioning of generators' interface devices or, instead, desired islanding operation to improve reliability, we would want *P4* to operate before *P3*, in order to isolate the faulted section.

Actually, since the two protections see the same fault current, it is likely that *P3* operates before *P4*.

In the considered case the operation of *P3* would make useless the possibility to supply the disconnected SC through section *L-F*.

Another interesting case is represented by a fault in section *C-D*. It is essential to understand how the generators *G2* and *G3* contribute to the fault current. In fact, if the contribution of *G2* is lower than the one of *G3* (e.g. *G2* has a static interface with the network, while *G3* is a synchronous generators), coordination problems between *P2* and *P3* would arise similarly to the case of a fault in section *A-B*.

On the other hand, if the contribution of *G2* is greater than the one of *G3*, coordination between *P2* and *P3* depends on their characteristics (see Fig. 2).

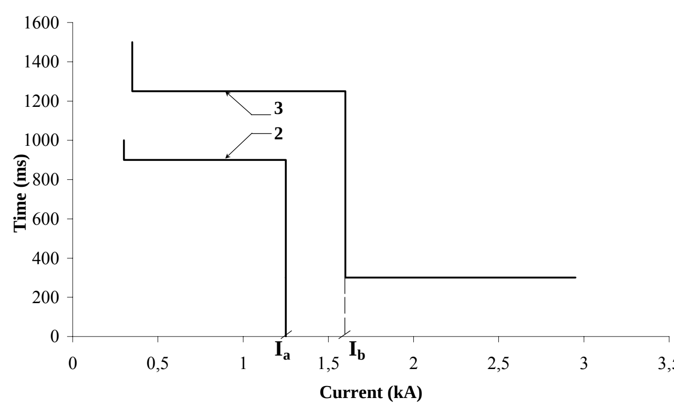


Fig. 2. Typical coordination between the characteristics of P2 and P3.

With reference to Fig. 2 it can be outlined that if the current through *P2* is lower than $I_a$ and the current through *P3* is lower than $I_b$, *P2* is expected to operate faster than *P3*. This means that the desired coordination is not achieved.

Instead, if the current through *P2* is lower than $I_a$ but the current through *P3* is greater than $I_b$, *P3* is expected to operate faster than *P2*, allowing for a correct coordination.

### 5.3 Conclusive considerations

From the above considerations we can conclude that protective devices installed downstream from the last generator do not see fault current for an upstream fault; for a downstream fault, if these devices can bear the increased fault current due to penetration of DG, there will not be any problem with their coordination.

In case of upstream faults with the protective devices that see fault currents, two possibilities exist:

- if they see the same fault current for a fault downstream as well as for a fault upstream, coordination will be lost;
- if they see different currents for a downstream or upstream fault, there is the possibility to keep a valid coordination depending on the value of the fault currents through each protection. From this point of view, we could say that it is preferable to install the generators that provide a greater contribution to fault currents upstream from the ones with a lower contribution.

## 6 Temporary faults and reliability: line reclosing after a fault

In MV networks most systems have a large number of overhead lines and most faults on overhead lines are temporary. Automatic reclosing is a very common and effective method of temporary fault clearing. That is, if the fault arc is interrupted, the fault will heal itself without outside intervention and power can be restored immediately by reclosing the interrupting device (a breaker or recloser).

On a radial system, fault clearing requires the opening of only one device because there is only one source contributing current to the fault. In contrast, meshed transmission systems require breakers at both ends of a faulted line to open. When DG is present, there are multiple sources and opening only the utility breaker does not guarantee that the fault will clear promptly.

Therefore, DG will be required to disconnect from the system when a fault is suspected so that the system reverts to a true radial system and the normal fault clearing process may proceed.

Generally speaking, there is the possibility that the DG will disconnect either too quickly or too slowly to avoid detrimental impacts on the distribution system.

This creates numerous potential operating conflicts with respect to overcurrent protection and voltage restrictions.

In this perspective DG seems to be rather incompatible especially with high-speed reclosing. This procedure may not leave to the DG units enough time to disconnect from the network. In this case DG units may sustain the voltage and fault arc, preventing successful reclosing in case of temporary faults.

Further, 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 [9].

On the other hand, if the load has increased to the point where the feeder is actually dependent on the DG to support the load, there can be significant operational difficulties when the fault occurs.

In order for the utility system fault protection scheme to operate, as said before, the DG must disconnect.

If the DG unit succeeds in disconnecting itself between the first opening of the interrupting device and its reclosure, it will remain disconnected until it can be determined that the utility voltage has stabilized (usually a few minutes).

However, if the load is too great, the utility will not be able to successfully serve the load upon reclosure.

Changes in operating procedure will be required to restore power and it will take longer to restore power to some customers. In that sense, the reliability of the power delivery system might appear to have worsened slightly, although, in a different perspective, the DG could somehow be regarded as a good means for mitigating a voltage regulation problem or providing alternative source of supply in case of system failure (reliability improvement).

## 7 Phase-to-ground protection in islanded operation of DG

As said before, intentional islanding operation of aggregated loads and generators is not allowed in Italy, so far, but in the future it is possible that distribution operators will consider this possibility in order to improve the continuity of power supply.

At present protection schemes of MV producers and customers connected to ENEL's distribution networks are based on directives DK5740 e DK5600, respectively, and are not suitable to this kind of operation. This is due to the fact that the possible islanded portion of network is typically characterised by:

1. a single feeder supplied by each DG unit without SCs;
2. a DG unit supplying a SC with few outgoing short overhead lines.

If a phase-to-ground fault occurs, in both the above cases the zero-sequence current relays are likely to fail since the zero-sequence current is extremely small and below their sensitivity.
This condition implies that only the zero-sequence voltage relays are able to operate; this means that the all the DG units will be disconnected without any possibility of selectivity.

## 8 Conclusion

At present, it can be foreseen that there will be a substantial increase in the amount of DG connected to utility distribution systems over the next years. On the other hand, the systems have been designed for unidirectional power flow and, consequently, as the penetration of DG increases, it should not be surprising that operating conflicts would arise.
As far as the protection system is concerned, several conflicts between DG and distribution operation have been identified in this paper, providing examples referred to Italian distribution networks.
The simplest solution to the problems cited above is, of course, to require all DG units to be disconnected when a fault occurs on the network. If DG units are able to detect the fault and rapidly disconnect from the network, DG will not interfere with the normal operation of the protection system. In fact, most interconnection standards, included the Italian ones, require the disconnection of DG when a fault occurs. However, this may not always possible or desired, in particular when DG penetration is high in a distribution network.
To find a solution to these problems, research goes in the direction of providing the distribution network with protection devices managed by a Remote Control System (RCS) which might allow the coordinated control of the protection system by analyzing the network relevant data (system voltages, level of loading, DG production, etc.) and the management of operation of various protective devices. Therefore, RCS could isolate the fault without much disturbance to other customers or unnecessary disconnection of DG. Of course, there may be some cost involved in additional equipment or some compromises made with respect to long-established utility operating practices.
In order to thoroughly analyse the effects of distributed generation on the requirements for the protection of distribution networks, detailed simulation studies are necessary.

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