SOLUTION OF OPERATION CONFLICTS BETWEEN PROTECTIONS AND DISTRIBUTED GENERATION IN MV DISTRIBUTION NETWORKS

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ABSTRACT

Present planning and operation criteria used for MV distribution networks are, in general, not suitable to cope with the presence of a significant distributed generation (DG) capacity. In fact, many technical problems are still to be solved in order to increase DG penetration and to provide, at the same time, high service quality levels to customers. The paper deals with the problem of incorrect operation of traditional protection systems in MV networks in presence of DG, and describes a new method to solve the problem of lack of coordination between overcurrent protection devices to improve service continuity.

The present work is part of a research project conducted by the authors in collaboration with ENEL Distribuzione S.p.A. (Italy).

INTRODUCTION

The general view is that Distributed Generation (DG) is expected to play an important role in future electrical energy systems, as recognized by the developers of the European Technology Platform "Smart Grids" [1], which is also supported by *Enel Distribuzione S.p.A.* (the major Italian distribution operator). Two major reasons for an increased utilization of DG are liberalized markets [2] and the global trend of reducing greenhouse gas emissions [3], which leads to the diffusion of small-scaled renewable energy sources. Besides a number of benefits, there are still some technical, economical and regulatory issues with DG. From the technical point of view, 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, which is conceived with neither generators operating in parallel nor power flow control.

In general, the impact of DG depends on its the penetration level in distribution network as well as on its technology (e.g. synchronous generators, asynchronous generators, static converter interfaced generation systems). As known, in order to maintain correct distribution operation and provide a high quality service to customers, various issues such as voltage control, power quality, short circuit currents, system protections have to be taken into consideration. In particular, the present paper deals with incorrect operation of traditional protection systems in presence of DG. In practice, connection of generators usually causes ineffectiveness of traditional protection criteria due to: unforeseen increase in short circuit currents, lack of coordination between protective devices, ineffectiveness of line reclosing after a fault using automatic reclosing devices, difficult line back-feeding (often used to reconfigure networks to improve reliability) and undesired islanding [4]-[8].

The paper presents some results of a research project, conducted by the authors in collaboration with *ENEL Distribuzione S.p.A.* In the following sections a new method will be presented to solve the problem of lack of coordination between overcurrent protection devices to improve service continuity and, consequently, increase DG penetration. Thanks to new control algorithms, the proposed method allows to rapidly establish which devices are concerned by fault location procedures when DG is connected to the network and how these devices have to operate.

MULTI-PHASE FAULTS AND PROTECTION COORDINATION

Commonly, protection of power systems is tuned in such a way that only the faulted part of the system is isolated when a fault occurs. This tuning is called *protection coordination*, which can be negatively affected by the presence of DG. To explain the reasons for loss of coordination in overcurrent protections and in order to propose practical examples, some typical cases will be analysed with reference to the network shown in Fig. 1[1]. This system is a typical Italian MV distribution network, but, of course, the issues discussed are of general validity. For the sake of completeness, the configuration chosen includes also the so called *satellite centres* (SCs), whose purpose is to increase network reliability thanks to installation of line protections at the sending-end of each feeder supplied by the SC itself. Further, it is typically possible to ensure emergency supply to SCs by means of energy alternative paths.

With reference to Fig.1, suppose to have a multi-phase fault (**F1**) in feeder section *e1*. In order to isolate the minimum faulted area, protections in *e1* and in d-e would be required to trip. Operation of device e1 would ensure the fault to be unsupplied by the primary substation (PS), while operation of d-e would ensure the fault to be unsupplied by generators G1 and G2.

[1] Protection devices are indicated by means of squares: the black ones indicate the closed circuit breakers, the white ones indicate the open devices. The black circles indicate secondary substations (SSs). In order to avoid a confusing representation, the switching breakers commonly installed upstream and downstream from each SS on the MV feeder have not been represented in the scheme.

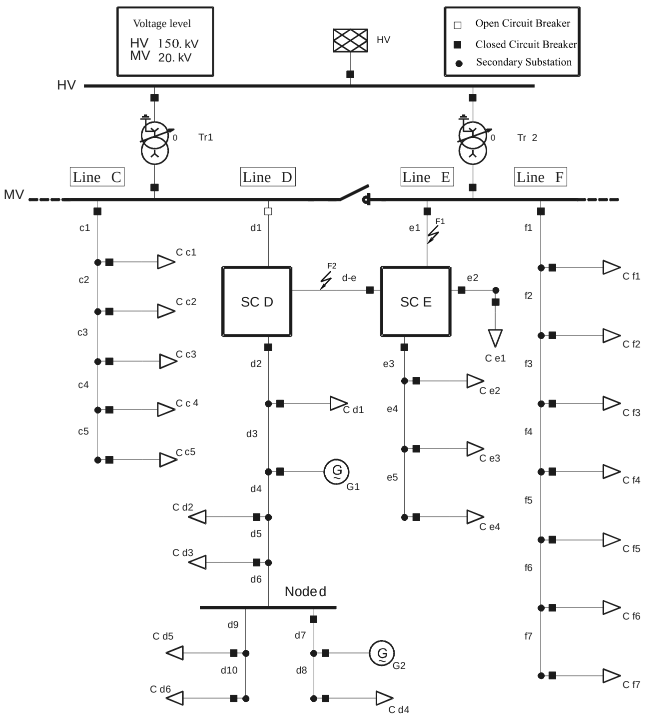

Fig. 1. Test MV distribution network with dispersed generators.

Actually, due to the characteristics assigned to the concerned devices (see Fig. 2), designed for a network without DG, protection in *d2* will trip faster than the one in *d-e* since they see almost the same fault current. Due to this wrong coordination, the procedures for fault detection and healthy lines reconfiguration could be ineffective. In the considered case, for example, it would be impossible to supply *line D* through *SC D* by automatically reclosing *d1*. Further, if *d-e* was still closed, closure of *d1* would supply the fault through the PS causing protection tripping in *d-e*.

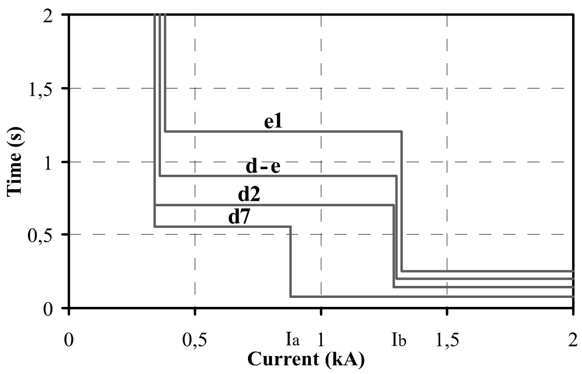

Fig. 2. Typical circuit breakers characteristics referred to the devices installed in sections *e1*, *d-e*, *d2* and *d7*.

Another interesting case is represented by a multi-phase fault in **F2**. It is necessary to consider how the generators contribute to the fault current increase. In fact, if the contribution of G1 is lower than the one of G2 (e.g. G1 has a static interface with the network, while G2 is a synchronous generator), coordination problems between protections in *d7* and in *d2* will arise, similarly to the case of fault F1. On the other hand, if the contribution of G1 is greater than the one of G2, coordination between *d7* and *d2* will depends on the fault current seen by the two devices and on their characteristics, which show different tripping thresholds, called, respectively, I_a and I_b in Fig. 2. In particular, if the current through *d7* is lower than I_a and the current through *d2* is lower than I_b, protection in *d7* will trip faster than the one in *d2*. This means that the desired coordination is not achieved. On the contrary, if the current through *d7* is lower than I_a, but the current through *d2* is greater than I_b, protection in *d2* will trip faster than the one in *d7*. A correct coordination is thus obtained.

From the above considerations we can conclude that protective devices installed downstream from the last generator do not see fault current for a fault upstream from the devices themselves; however, in case of fault downstream from the protective devices, there will not be any problem with their coordination, provided they can withstand the increased fault current due to DG. On the other hand, protective devices installed upstream from generators see fault currents notwithstanding the position of the fault itself with respect to protections. In particular, if the faulted section is upstream from the protections, two possibilities exist:

- protective devices see the same fault current and, then, coordination can be lost;
- protective devices see different currents, so that there is the possibility to keep coordination. This depends on the value of the fault currents through each protection. As a consequence, from the planning point of view, we can say that it is preferable to have the generators that provide a greater contribution to fault currents installed upstream from the ones with a lower contribution.

THE METHOD PROPOSED TO AVOID LACK OF SELECTIVITY IN PRESENCE OF DG

According to the method proposed, the control actions are performed after the involved line protective devices have tripped. In fact, the aim of the procedure is to correct the operation of the devices that have lost the capacity to be selective due to the presence of DG.

The proposed method can be applied in case of both multi-phase and phase-to-ground faults by implementing the same algorithms (described in the following sections) and relying on the appropriate sensing devices installed in the network. However, as for phase-to-ground faults, it to be noted that the presence of earth-isolated generators connected in parallel to the network does not prevent installed protections from correctly operating.

Preliminary procedure

When a fault occurs on a feeder, firstly, a *numbering procedure* is performed involving the fault sensing devices installed on the feeder. The control system, which knows the current network configuration, automatically starts assigning an *identification code* (*i.c.*) to the feeder devices immediately after a protective device has tripped and the devices sensing the fault have sent a signal to the control system. The numbering procedure is schematically described by the flow chart in Fig.3.

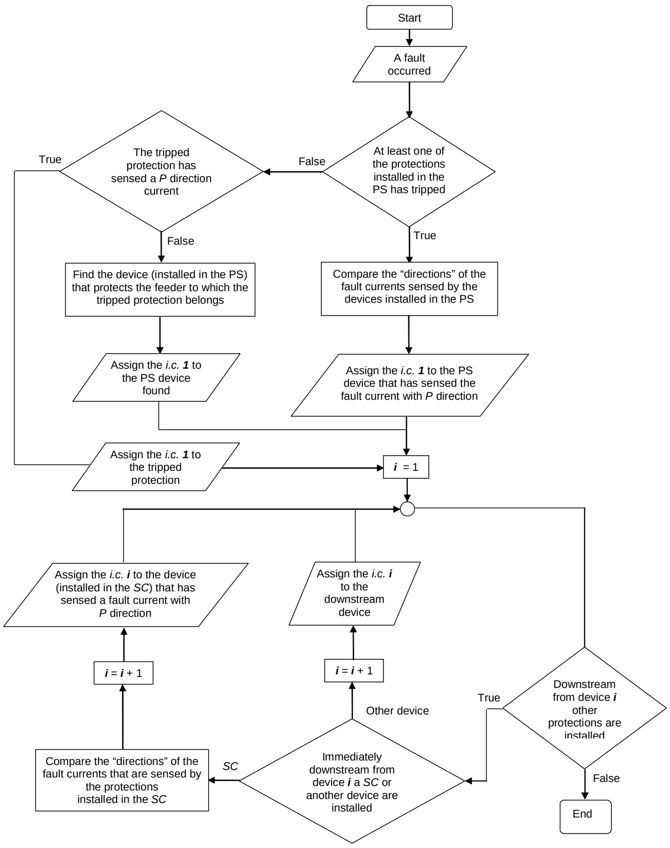

Fig. 3. Flow chart describing the numbering procedure.

It is important to know the "direction" of the fault current that has been sensed by each protective device in order to assess whether the fault is upstream or downstream from it. Commonly, in case of multi-phase fault, the current flowing from the PS to the feeder receiving-end is considered "positive". For the sake of concision, in the flow chart of Fig.3 we will use the conventional definitions of "*P* direction" and "*N* direction" in order to indicate the "behaviour" of the fault current sensed by protections in both multi-phase faults and phase-to-ground faults.

Note that, today, in Italian MV distribution networks, isolated and resonant grounding schemes are both present, even though the situation is evolving towards the use of Petersen coils.

We will say that the sensed current has *P* direction if:

- there is a multi-phase fault and the current has positive direction;
- there is a phase-to-ground fault in an earth-isolated system and the zero-sequence current lags the zero-sequence voltage;
- there is a phase-to-ground fault in a resonant earthing network and the zero-sequence current has a resistive component.

We will say that the sensed current has *N* direction if:

- there is a multi-phase fault and the current has negative direction;
- there is a phase-to-ground fault in an earth-isolated system and the zero-sequence current leads the zero-sequence voltage;
- there is a phase-to-ground fault in a resonant earthing network and the zero-sequence current has not a resistive component.

Fault location

As described in the previous section, the method proposed for fault location is based on appropriate numbering of the devices installed in the faulted feeder and on the acquirement of fault current direction. Then, the sequence of operations that are required for fault location is reported in the flow chart of Fig. 4.

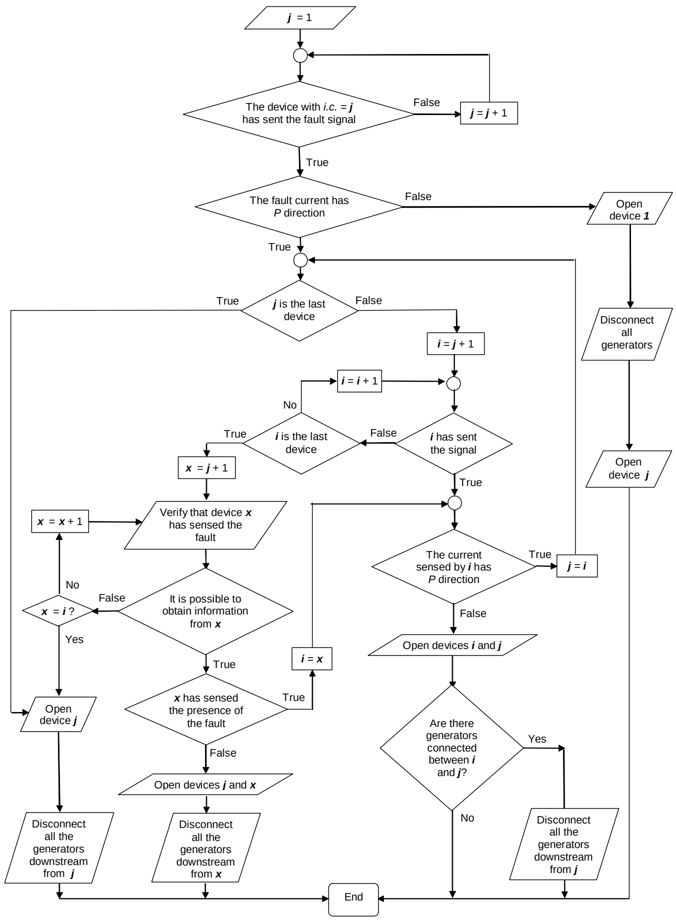

Fig. 4. Flow chart of the fault location procedure.

It is to be noted that the algorithm allows to obtain the best result in terms of isolating the minimum part of the faulted feeder when all the SSs have fault sensing devices and telecontrolled switching breakers.

The proposed algorithm considers the possibility that some devices might not send the required information to the control system after a fault event. However, based on the available information, the fault location procedure is able to find the minimum part of the network that it is possible to isolate.

IMPLEMENTATION ISSUES IN PRESENT DISTRIBUTION NETWORKS

The implementation of the proposed procedures is based on the availability of an efficient monitoring system and a bidirectional communication between control centres and fault sensing devices. The procedures can be easily implemented thanks to the technology nowadays available. During the last years, for example, Italian distribution system has yet undergone a wide restructuring process that has been essentially characterized by the introduction of telecontrol and automation technologies, along with new management policies, to cope with the need for higher service quality levels. Consequently, in order to realize the proposed protection scheme, it would only be necessary to update the software running on the MV network Telecontrol System (MV-TS) and the software of the field devices installed in the peripheral units (PUs). These devices (called RGDAT, which is the Italian acronym for *directional fault and lack of voltage detectors*) are currently used by ENEL for phase-to-ground fault detection in both earth-isolated and resonant networks.

According to what was previously described, the MV-TS would perform the fault location procedure on the ground of the information provided by the field sensing devices.

Further, it would be necessary to adapt the connection plant of the independent producers by adding telecontrolled switching breakers on the utility side of the producer's SS.

As for the telecommunication system, it would be possible to use the present system, where communications between MV-TS and PS, as well as between CTS and SCs take place using ISDN technology on dedicated lines (that, in future, will be probably replaced by a LAN network). Communications between CTS and PUs are currently performed by means of GSM technology.

Obviously, exploitation of the GSM network has the advantage of using an existing/well-established communication infrastructure, which, however, has the typical limitations of a public utility (possible unavailability, overload, presence of uncovered areas and fault events linked to electrical supply unavailability). At present, ENEL is considering the possibility to use private lines to implement Power Line Communications.

CONCLUSIONS

The paper presented an innovative protection scheme to allow increased DG penetration in MV distribution systems without causing lack of selectivity between overcurrent protection devices due to the presence of generators.

From the economical viewpoint the benefits deriving from the implementation of the method proposed would be significant for the distribution operator. In fact, the procedure would allow to drastically reduce the time required by fault location, since the isolation of the faulted feeder section would be done by means of a single action instead of using the present mixed procedure (telecontrol + manual action). In most cases it would be possible to isolate the fault in less than 180 seconds, which is the limit over which the interruptions are considered "long" and, consequently, recorded in order to calculate the amount that the distribution operator must pay when the maximum allowed number of interruptions is reached during a year.

Further the proposed solution would allow to overcome the present limit in the number of protective devices that can be connected in series in order to obtain a selective intervention.

The greater service continuity level that the distribution operator would achieve thanks to the implementation of the proposed procedures would be awarded by the Italian Authority.

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