PERFORMANCE AND REFURBISHMENT STRATEGIES FOR PROTECTION SYSTEMS ACCORDING TO NEW QUALITY REQUIREMENTS FROM ENERGY AUTHORITY, ENEL

DK5600 CONNECTION REQUIREMENTS AND CHANGE OF NEUTRAL EARTHING OF MV DISTRIBUTION NETWORKS IN ITALY

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INTRODUCTION

The Italian MV distribution networks are undergoing a significant transformation, driven by the Electrical Energy Authority (AEEG).

Within his statutory objectives of enhancing the quality and performances of the Italian distribution network, the Authority published in 2004 an integrated quality regulation. It defines a quality of supply regulatory mechanism based on penalties to the utilities underperforming and on automatic reimbursements to worst quality affected customers. It promotes through customer’s reimbursements/penalties the renewal process of the customer’s interconnection plants and protection systems to ensure higher protection selectivity levels for customer site faults and therefore to limit not localised interruptions affecting the distribution networks.

In this scenario Enel Distribuzione, the major Italian utility with over 92,000 MV customers, is pursuing an extended program of connecting to ground the MV neutral point to all his MV networks within 2007, to achieve substantial reduction of supply interruptions due to faults and, consequently, to meet the Authority quality targets.

In March 2004 Enel issued a new version of his DK5600 MV network interconnection rules, stating the technical requirements of the customer’s interconnection plants and protection systems to match the new network neutral management.

In the paper the new scenario is briefly described, analysing the technical and economical aspects driving the utility requirements on one side and the impact and needs of customers on the other side.

The focus will be major novelty items of DK5600 requirements, i.e. on the connection switchgear and protection system, on the impact on new plants and refurbishment of existing ones. The extended dynamic range and the accuracy required under normal and fault conditions according to DK5600, both for current and voltage transducers, for the protection device and the whole protection system are analysed and commented together with the operational condition they arise from.

The adoption of non-conventional current and voltage transducers now accepted by Enel and some experimental characteristics of the linearity, accuracy and saturation behaviour of such transducers are then described, comparing the performances with conventional protection current transformers. In conclusion the impact on existing customer plants of the new regulations and the protection system refurbishment options are highlighted.

BACKGROUND

The Italian MV distribution system is historically affected by poor performances of the quality of supply indicators, ranking low in Western Europe countries for Customer Minutes Loss (CML) and long interruption frequency in events/customer/year [1].

To enhance the quality of supply The Italian Electricity Regulator AEEG (Authority) was instituted by law in 1995 with the statutory objectives of regulating the tariff system; of enhancing the quality and driving the minimal technical requirements of the Italian distribution network.

In its’ first 4 years regulatory period the Authority imposed ambitious targets to the distributors for the reduction of low voltage customers CML’s and has effectively driven the improvement of Power Quality thought a premiums/penalties mechanism based on utilities performances.

In year 2004 the Authority published an integrated quality regulation [2] targeting the reduction of long (> 3min) interruption frequency for HV and MV customers, effective from 2006.

The regulation introduces penalties for the distributors and automatic reimbursements mechanism towards worst quality affected customers, exceeding the maximum-targeted number of long un-forecasted interruption. Those targets are ranging from 1 interruption/year for customers connected on HV networks to 3 – 4 - 5 interruptions/year for customers connected on MV networks in high, medium and low concentration areas respectively.

A second explicit regulation’s target is promoting the renewal process of the customer’s interconnection plants and protection systems to ensure higher protection selectivity levels for customer site faults’, limiting not localised interruptions affecting the distribution networks, today estimated up to 40% of long interruptions.

The Authority has recently issued a consultation document [3] that shall become a regulation in 2005, proposing how to regulate the reimbursements/penalties. The foreseen mechanism is based on:

- benefits through the automatic reimbursement to customers who already fulfil or will update their plants to the technical requirements defined by the Authority, starting from 2006;
- penalties to customers not fulfilling the requirements starting from 2007 for major ones, above 500 kVA, and extending in 2008 to all.

The minimum technical requirements for the customer’s interconnection plants and protection systems are defined in order to ensure the operation of the customer breaker before the distributor breaker at the head of the MV radial line and,
in any case, to be open at the line automatic reclosure sequence.
It is therefore defined that all MV customers shall have a MV breaker as interconnection switch towards the distributor network and a protection system providing phase overcurrent 50, 51, earthfault overcurrent 51N and, depending on customer plant complexity, directional earthfault 67N protection functions driving the breaker.

In this scenario Enel distribuzione, owner of over 300,000 km MV network and 270,000 MV/LV substations, starting from first successful installations and operational results in year 2000, has undergone a wide program of change of the MV neutral management from insulated to connected to the earth through an impedance (Petersen coil + resistor), to achieve a substantial reduction of supply interruption due to faults (15% … 30% reduction on long interruption, up to 50% on short and transients ones) and, consequently, to meet the Authority quality targets [4].

By 2004 a significant part, ranging between 30% to 50%, of Enel primary (HV/MV) substation has been upgraded, thus affecting an increasing number of the over 92,000 MV customers. In March 2004 Enel issued a new version of his DK5600 MV network interconnection rules [5], stating the technical requirements of the customer’s interconnection plants and protection systems to match the new network neutral management.

### ENEL DK5600 CONNECTION REQUIREMENTS

DK5600 rules scope is to define criteria and process for the customer’s connection to Enel Distribuzione MV networks. Those rules now apply to all new MV connections or substantial rebuilding of existing ones, while for existing installations the new requirements are communicated to customers when Enel locally changes the network management to compensated grounding. Modification of existing plants where a breaker is already used, about 22,000, introducing the new protection functions, is suggested but not enforced while waiting for the Authority regulation.
The case of existing plants where the an on-load break switch with fuses is used as interconnection to the network is still open: the requirement of upgrading the protection functions cannot be meet, in particular for earthfault protection, and it is necessary to install a breaker and a new protection system.

### DK5600 main novelty items

The main novelty items in the new version of DK5600 are due to a number of constrains to ensure that the interconnection switch (DG or General Device) clears any fault originating in a customer’s plant, thus avoiding the intervention of the line breaker in the distributor’s main substation.
The DK5600 criteria therefore prescribe:
- The installation of a MV breaker (24kV, 12.5kA) in the customer’s plant as interconnection switch DG. The use of on-load break switch, previously accepted up to 400 kVA is no more possible to ensure selectivity for ground fault.
- The installation of a General Protection (PG) controlling the DG to provide selectivity towards the line breaker. The PG shall provide providing phase overcurrent 50, 51 for overload and short circuit protection, earthfault overcurrent 51N and, depending on customer plant complexity, directional earthfault 67N protection functions driving the breaker.
- The limitation of maximum size of customer’s MV/LV power transformers to limit the LV short circuit value and to avoid the line protection trip.
- The adoption of a protection system, including the protection relays PG and current and voltage transducers, globally capable of properly working in all the current and voltage range expected under normal and fault conditions, specified in 10kA for phase to phase faults and 2kA for phase to ground or cross-country faults.
- The prescription of 10P30 and 5P20 accuracy class for phase and ground current transformers respectively, to ensure that the transducer can supply, within its accuracy limit, the protection device PG in the extreme fault conditions of MV short circuit and double phase fault to ground.
- The possibility to adopt unconventional current and voltage transducers when providing protection system’s performances equivalent to those obtained using traditional voltage and current transformers.
- Finally DK5600 introduces the requirements to manufactures to type test the protection system with laboratories recognized by the European cooperation for Accreditation and to provide a Conformity declaration by UNI-CEI-EN45011 certification body, to ensure the quality of the material installed.

In the following an example of the selectivity between protection curves of the Enel line breaker and customer’s PG is reported in figure 1:

![Selectivity between Enel’s line CB and customer’s DG](image)

**Fig. 1: Selectivity between Enel’s line CB and customer’s DG**
Selectivity for phase-to-phase faults is ensured by maximum MV/LV power transformer limits, only faults on the MV side of the customer plant can provide a fault current higher of the 1400A high set 51 protection in the distributor substation at the head of the radial line.

In this case both the customer’s DG and Enel CB open to clear the fault. After 0.4s Enel starts a reclosure cycle to supply again the line, usually with tens of MV customers and thousands of LV ones in high concentration areas.

If the fault had a transient origin or was located in a customer’s plant the system is reenergized successfully and all the line users experience only a transient interruption, shorter than 1s.

Selectivity for phase-to-ground faults is based on the prescription of omopolar overcurrent protection 51N with high sensitivity for simple plants, with MV cable extension lower than 500 m and a single MV/LV transformation busbar (case A). More complex customer’s plants (case B) require the adoption of earthfault directional protections 67N, with a double setting to ensure operation both with neutral compensated and insulated network operation, and a higher 51N protection set for double fault to ground.

PROTECTION OPERATIONAL CONDITIONS AND CURRENT TRANSDUCER REQUIREMENTS

The focus of DK5600 rules is to provide the customer’s plants with a protection system effective to clear internal faults in all the expected operating conditions; i.e. in all the expected current (and voltage) range and in the different network neutral grounding conditions.

Regarding the overcurrent protection for phase-to-phase faults the major concern it to ensure proper operation of the protection system up to the maximum expected short circuit level.

Therefore Enel suggests 300/1 phase CTs with 10P30 class, calling for a transducer’s almost linear behaviour slightly over Limit Factor, up to the maximum current expected of 10kA.

The same concern drives the suggested choice of 100/1 omopolar CT with 5P20 class, to properly behave at the maximum expected earthfault current of 2kA in cross-country fault conditions; i.e. when a double earthfault is located within customer’s plant and on an other phase in a different network location.

The required accuracy of protection class CTs is in line with + - 3% accuracy of the protection relays.

In practice the PG earthfault protection operational settings are extremely low to be selective towards the directional protection settings of the distributor line breaker. For 51N protection those range at 2, 3 and 4 A depending from the customer’s connection voltage level, 10, 15 and 20 kV respectively.

When the PG earthfault directional protection 67N is required the current settings are the same of the line breaker, typically 1 to 2 A, and chronometric selectivity is used.

The earthfault current is limited below 50A with compensated network operation and the high sensitivity directional protections are required in the Enel substation to identify the faulty line. The use of earthfault directional protections to drive the customer’s interconnection DG provides higher selectivity for complex plants; in particular it avoids the possibility of untimely tripping for the internal capacitive contribution to the external earthfault when long cable networks are present in the customer’s premises.

Unconventional current and voltage transducers

DK5600 introduces the possibility to adopt unconventional current and voltage transducers when providing the required protection system’s performances.

ABB has therefore chosen to push the use of unconventional transducer as an effective alternative to traditional CTs and VTs.

Current sensors are based on the Rogowski coil principle; the sensor consists of a toroidal coil without an iron core placed around the primary conductor.

It is immune to any risk of saturation, as it has no ferromagnetic core. It is linear over the whole measuring and protection range for primary current up to and over 10000A.

Current sensors have rated accuracy in class 1 (3 without calibration).

Voltage sensor is based on the use of a resistive voltage divider. It is immune to any risk of saturation, as it has no ferromagnetic core. It is linear over the whole measuring and protection range for primary voltage.

In all cases, the transmitted signal reproduces the actual primary voltage waveform. Voltage sensors have rated accuracy in class 1/3P and rated voltage factor 1.9 / 8h.

Fig. 2: Rogowski coil principle current sensor type KEKA
Current sensors and combined current/voltage sensors can work properly in all the current and voltage range expected under normal and fault conditions according to DK5600 and supply to the protection device a correct signal, within their accuracy limits in the whole operational range.

When used in combination with protection and control unit REF542plus voltage and current sensors provide accuracy and linearity characteristics equivalent or better than traditional voltage and current transformers. Current and combined current/voltage sensors are designed, manufactured and tested according to the latest international standards [6, 7].

Figure 3 compares typical sensor accuracy with accuracy requirements for measuring CTs Class 1, on the left, and accuracy requirements for protection CTs Class 10P on the right. It is worthwhile to underline that protection class CTs have no accuracy requirements below the rated currents. This is in particular important for the omopolar CT, which supplies the earthfault current signal to the PG earthfault directional protection. The typical primary current setting, lower than 2 A, is in a range where ratio and phase accuracy is not prescribed for protection CTs and below the minimum, 5% In, for measuring CTs.

**PROTECTION SYSTEMS COMPLY WITH DK5600**

ABB, as a global supplier of protection relays, circuit breakers and MV switchgear, has designed its offer to comply with the new DK5600 rules. Two devices are targeted to support the protection functions required:
- A basic overcurrent protection relay version to cover case A, PR521/DK, that can be integrated in MV breakers together with phase current sensors, figure 4.
- A more performing protection relay version, REF542plus/DK, providing earthfault directional overcurrent protections, and optionally, communication to a control system based on industrial standards, to cover case B requirements, figure 5.

Those devices are installed in MV switchgear and as loose components for OEM for all new installations that are already required to comply with DK5600. They are available as loose components in kit with the sensors for the application in existing plants where the PG has to be upgraded following the network neutral change to grounded through impedance. In those cases, supplying the whole protection system, ABB certifies the performances of the sensors in combination with the relays over the required current range.

For retrofitting/refurbishing application the use of sensor technology enables easy installation of toroidal phase sensors on incoming cables, figure 6.

For case B application combined current and voltage sensors enable to substitute existing DIN form CTs in the MV switchgear without the need additional space for VTs. Furthermore a shielded twin BNC terminated standard cable connects sensors to REF542plus PG, enabling a fast and polarized wiring and avoiding phase shift errors, critical in directional protections.
The application of DK5600 rules in the Italian MV distribution network is a powerful drive for a better selectivity of faults and therefore to achieve higher continuity of supply levels for all the customers over radial operated lines. The coming Authority regulation and reimbursements/penalty mechanism will provide the economical leverage to enforce the application of the new network connection standard to the 100,000 existing MV users in the next regulatory period.

REFERENCES

[4] E. Di Marino et al., 2003, "Change of neutral earthing of MV networks from isolated to ground through impedance: operation results and transition management", Proceedings 17a CIRED

CONCLUSIONS