CONTINUITY OF SUPPLY IMPROVEMENT BY MEANS OF CIRCUIT BREAKERS ALONG MV LINES

Giovanni VALTORTA
ENEL Distribuzione – Italy
giovanni.valtorta@enel.com

Roberto CALONE
ENEL Distribuzione - Italy
roberto.calone@enel.com

Luigi D’ORAZIO
ENEL Distribuzione – Italy
luigi.d’orazio@enel.com

Vincenzo Giulio SALUSEST
ENEL Distribuzione – Italy
vincenzogiulio.salusest@enel.com

ABSTRACT
This paper proposes a method to find the most effective point where to install a MV circuit breaker along the lines to improve the continuity of supply measured by means of the following indicators:

a) cumulative duration of long interruption per LV customer;
b) number of long and short interruptions per LV customer.

The following pages describe a method to localize the phase to phase short-circuits faults knowing the intervention threshold of the maximum current relay associated to the circuit breaker installed at beginning of MV feeders. The phase-to-phase faults percentage for each MV line and the probability for one fault to occur in a determined distance from the MV bus-bar are evaluated as well. Finally a way to obtain the maximum advantage for the continuity of supply with the use of all mentioned data and information is determined.

INTRODUCTION
Since 1999 the Italian Electric Energy and Gas Regulator (AEEG) actions aimed to improve the continuity of supply. For this purpose Enel Distribuzione during the last ten years made various infrastructural investments, to address the Regulator targets. In particular the following interventions have been made:

a) remote control of MV/LV substation to reduce the fault selection time;
b) installation of Petersen coil in HV/MV substation to reduce the number of interruptions.

By means of both the two solutions above mentioned it was possible to realize also the automation on the MV network to reduce even more the time to select the faulted section and increase the continuity of supply. The following figure 1 shows how the Enel Distribuzione SAIDI was reduced in the last eight years:

Figure 1 – Enel Distribuzione SAIDI in the last 8 years.

From the beginning of 2008 AEEG has foreseen a new indicator: the average number of long plus short interruptions per LV customer, and changed the calculation rules (interruptions within one hour are aggregated).

The continuity of supply indicators are directly connected to the number of customers affected by the interruption. The following types of interruptions are taken into account to evaluate the indicators:

Long interruption for the duration indicator;
Long and short interruptions for the number indicator.

In general, the mathematical equation to calculate each indicator’s value is:

\[ Ind_{QdS} = \sum_{k=1}^{N} \frac{NCI_{k} \cdot Val_{Ind_{k}}}{NCI_{Linea_{i}}} \]

where \( NC1_{k} \) is the number of customers with the same history during the event, \( Val_{Ind_{k}} \) is the value of the indicator (minute for the duration and pure number for the number), \( NC1_{Linea_{i}} \) is the total number of customers per line.

1 AEEG defines three kinds of electric interruptions in function of the duration:
a) Long interruption, lasting more than three minutes;
b) Short interruption, lasting more than 1 second and up to three minutes;
c) Transitory interruption, lasting up to 1 second.
the i line 2 and the result $N_{Cl \cdot Ind_{k}}$ is the “customer moment”.

![Number of interruptions of Enel Distribuzione LV customers](image)

**Figure 2 – Number of the long and short interruption per LV customer in the last 8 years.**

In order to obtain the foreseen improvements one possible solution is to improve the network automation to optimize the time and the way to select the phase-to-phase fault installing a circuit breakers along the MV lines.

A circuit breaker installed along the MV line allows to select rapidly a downstream faulted section of the feeder. This solution allows to reduce the number of customers interrupted and consequently, the relevant moment.

**Figure 3**

When a fault occurs in the second section of the line (see figure 3) and selectivity can be ensured, the circuit breaker installed along the line opens with a determined delay time. In this way, the first circuit breaker doesn’t open, and all the customers connected to the first section of the line are not interrupted.

Immediately after the opening, the circuit breaker along the line closes and supplies the second section. If the fault is not permanent, the customers on the second section of the line will be affected by only one transient interruption (not longer than 1 s), otherwise the circuit breaker operates with the typical re-closing cycle: O – 0.4s – CO – 30 s. However the maneuvers, to select the fault’s section, will interest only the ending part of the line. The first section of the MV line doesn’t suffer any interruption and it does not contribute to increase the continuity of supply indicators.

**SHORT CIRCUIT LOCALIZATION ON MV LINES**

This chapter describes a method to estimate with a good accuracy the intervals of the line length where fault location determine the intervention the various thresholds of maximum current relays installed at feeder sending end. This allows to identify the section of the MV line where it is better to install the MV switch in order to improve the continuity of supply, reducing as much as possible the duration and number of interruptions. To save the MV line against multiphase faults, relays with definite time characteristic are usually installed, i.e. these systems intervene with a fixed delay time into various ranges of the current.

Maximum current protection systems are identified with ANSI code 51. Typically, they have three operation thresholds. Knowing the feeder MV line length $L_{MT}$ (km), it is possible to identify the distance $D_{51-3}$ (km) from MV bus bar within which protection 51 certainly intervenes on the third threshold, and the distance $D_{51-2} > D_{51-3}$ where protection 51 operates certainly on the second threshold. Beyond $D_{51-2}$ up to the end of the feeder end $L_{MT}$ ($D_{f-L}$), the protection 51 operates on the first threshold.

It is possible to identify three lengths on the line: $L_{51-3}, L_{51-2}$ and $L_{51-1}$. All mentioned distances are evaluated with an accuracy margin; in fact, it is not possible to know the exact the fault resistance (usually negligible for multiphase faults), the equivalent impedance of the considered electric system.

The choice to install one MV circuit breaker along the line depends on the length within which the protection system operates. $D_{51-3}, D_{51-2}$ are calculated for each MV line knowing the short circuit current decay function $FD(I_{CTO-CTO-3})$. The decay function depends on the maximum 3-phase short circuit current on primary substation MV bus bar and electric parameters of the feeder.

**Figure 4 – Theoretical curve of the $FD(I_{CTO-CTO-3})$**

The reference value of the short circuit current is calculated with the same method used by the software applications of Enel Distribuzione (network simulation system) to evaluate the typical phenomena on the network during a dissymmetric regime. The method takes into consideration two hypothesis:

a) HV network with infinitive short circuit power;
b) HV/MV transformers with a percentage short circuit voltage relative to the minimum ratio of transformation (taking care of transformer Tap Changer).

**Figure 5 – General scheme of the Primary substation.**

**FD(I_{CTO-CTO-3}) CONSTRUCTION**

The decay function for each electric line depends on its P.U. impedance. The function is calculated knowing (o on the basis of) the 3-phase short circuit current on the feeder nodes of the considered MV line.

In this way, the short circuit current value depends on the distance from the source node (MV bus bar). Decay function is built by linear approximation. The following picture shows a Hypothetic graph of FD (I_{CTO-CTO-3}) function.

**Figure 6 – Typical curve of FD(I_{CTO-CTO-3}) for line nominal voltage of 10 and 20 kV.**

Now, it is possible to determine L_{51-3}, L_{51-2} and L_{51-1} through the comparison between the short circuit current value along the feeder and the 3rd and 2nd intervention threshold of the 51 protection system: 1400 A and 800 A.

In many real cases, where the MV lines are not very long and are mainly in cable, the short circuit current is higher than 1400 A at any distance from MV bus bar. In these case, it’s necessary to adopt a coordination among two circuit breakers installed on the MV line. In fact the second circuit breaker will be positioned necessary on the L_{51-3} sector and it operates with the same delay times of the first circuit breaker. So it will be necessary to foresee the inhibition of the re-closing cycle for the circuit breaker along the line.

**NUMBER AND PROBABILITY OF FAULT ON MV LINES**

The log file of distribution network SCADA allows to determine the number of maximum current protection system interventions on the first, second and third threshold for each MV line: N_{int-51-1_i}, N_{int-51-2_i}, N_{int-51-3_i}.

Taking into consideration these kinds of protection interventions relevant to the last two operation years, the MV lines with a major fault risk can be determined. Knowing for each line the total number of interruptions for 51-2 and 51-3 interventions, the fault rate (N_{int} per 100 km of line) can be calculated as follows:

\[
T_{\text{Guasto}_i\_n} = \frac{N_{\text{int}_{-51-2\_i\_n}} + N_{\text{int}_{-51-3\_i\_n}}}{L_{\text{tot}\_\text{Linea}_i}} \times 100
\]

\[N_{\text{int}_{-51-2\_i\_n}}\] and \[N_{\text{int}_{-51-3\_i\_n}}\] represents the number of interruptions per 51-2 and 51-3 protection system intervention on the line i over the years n and the \[L_{\text{tot}\_\text{Linea}_i}\] is the total length of the i line.

Among the MV lines analyzed, the ones where the installation of the MV circuit breaker along the line is more effective are those with highest number of interventions of the protection on the second and third threshold over the last two years.

**MV CIRCUIT BREAKER INSTALLATION**

When all the variables are determined, the length \[L_{51-3}, L_{51-2}\] and \[L_{51-1}\] the number of interventions \[N_{\text{int}_{-51-2\_i\_n}}, N_{\text{int}_{-51-3\_i\_n}}\], the fault rate per 100 km \[T_{\text{Guasto}_i\_n}\] and \[T_{\text{Guasto}_i\_n-1}\] referred to the last two operation years, it is possible to define where to install the MV circuit breaker along the line in order to improve the continuity of supply.

Only the MV lines, for which the following logical condition is true, are selected:

\[
T_{\text{Guasto}_i\_n} > 0 \oplus T_{\text{Guasto}_i\_n-1} > 0 = \text{true}
\]

In this group, we have to consider the line with a large number of customers and a high number of interventions of the protection on the second threshold over the last two operation years:

\[
\max_{i\_n}(N_{\text{CT}_i\_\text{Linea}_i})
\]

The optimal location for the circuit breaker depends on the customer moment (generated in case of interruptions). The maximum advantage is obtained where the value of following equation is 0.5:

\[
F_{\text{inst}_i} = \frac{N_{\text{ct}(51-2)}}{N_{\text{CT}_i\_\text{Linea}_i}}
\]
\( N_{cl(51-2)} \) is the number of customers affected by the interruptions into the sector of certain intervention of the protection system on the second threshold. Assuming a uniform distribution of customers along the MV lines it is valid:

\[
N'_{Cl\_Linea\_i} = \frac{N_{Cl\_Linea\_i}}{L_{MT\_i}}
\]

Along the feeder the number of customer is equal to:

\[
\int N'_{Cl\_Linea\_i} dl = N'_{Cl\_Linea\_i} l + K
\]

Since at the end line \( L_{MT\_i} \), the total number of customers is \( N_{Cl\_Linea\_i} \), the value of \( K \) is 0.

Calculating the maximum of the function \( F_{ins\_i} \) it is possible to evaluate the distance from MV bus bars where to install the switch.

\[
F_{ins\_i} = N'_{Cl\_Linea\_i} l \cdot (L_{MT\_i} - l) \Rightarrow l = \frac{L_{MT\_i}}{2}
\]

The function \( F_{ins\_i} \) is the obtained combining “Customer distribution” and the “fault probabilities”. In the real case the \( F_{ins\_i} \) is a discrete mathematical function and the optimal point is:

\[
\frac{N_{cl(51-2)}}{N_{Cl\_Linea\_i}} \sum_{k=1}^{m} \frac{N_{cl\_CS\_i\_k}}{N_{Cl\_Linea\_i}} = 0.5
\]

It is better if the point of installation corresponds to \( L_{51-3\_i} \).

**CONCLUSIONS**

The installation of one circuit breaker along the MV line allows to obtain substantial continuity of supply improvement for various aspects:

a) technical, with one circuit breaker along the MV line can be selected rapidly the section affected by multi-phases fault;

b) economical, reducing the **customer moment** corresponding to one event will reduce the penalties or increase the awards relative to the geographical areas where the line is considered.

The introduction of the circuit breakers along the MV lines allows to review the typical strategy for the planning distribution network. In other words the effect of a circuit breaker installed along the line, is similar to the one obtained building a new primary substation i.e. reducing the equivalent length of the electric lines. This is another important economical aspect to control the investment costs.

To increase the advantages of the introduction of the circuit breakers along the MV lines it possible to foresee the installation of two or more circuit breaker along the line. This solution is possible on the MV network with an optical fiber system as support to transmit the communications and information between the protections system.