NEUTRAL CONNECTION TO EARTH IN MEDIUM VOLTAGE NETWORKS: OPERATION EXPERIENCE IN ENEL

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Summary

In general, the way of neutral connection to earth in MV networks is chosen on the basis of legal and technical issues, related to safety and operation of electrical networks; therefore different solutions can be adopted.

The Italian choice has been to operate the MV networks isolated in almost all the cases. This solution was adopted forty years ago since it assured simple operation together with earth fault currents reduced to acceptable values, even if some drawbacks like greater stress for insulation and intermittent arc phenomena were expected.

Recently, the issue of neutral to earth connection has been reconsidered, taking into account the raising requirements for power quality. Following that, Enel Distribution has begun the experimentation of connecting neutral to earth through impedance in MV networks.

This experimentation involved different aspect related to

- the connection schemes
- the choice of fixed or mobile coil
- the protection system adaptation to the new network
- the automation to manage different connection to earth during the experimentation
- the monitoring of the operation of three pilot plants.

In particular, the adoption of neutral connection to earth through impedance in the MV network requires the adjusting of the protection system to the new situation: to detect single phase fault in MV compensated network protections based on wattmetric principle have been chosen, that means able to detect the resistive component of the fault current.

Moreover, the “neutral compensation” of the MV busbars involves the adoption of a set of devices and apparatus whose characteristics are mutually related and depend on the position of the MV busbars connector. In fact, it must be taken in account that the neutral compensation is a permanent condition but the operator, depending on the situation of the MV network, should be able to come back to isolated condition. Since it seems not convenient to charge the operator of the task of performing the procedures for the selection of the neutral conditions (also considering that the HV/MV substations are operated without permanent staff) such activity has been implemented in an automatic device. This device must respond to instruction imposed by the remote control center and to electrical events that may produce variations of the electric network configuration.

Finally, to assess the improvement in the supply quality following the introduction of the Petersen coil a statistical analysis of the events has been carried out. Following these experimental experiences, a method for the choice of the plants to install the compensation coil has been developed. This method is essentially based on

- the power quality registered in the network,
- the single phase fault current,
- the earth resistivity in the area of the MW network considered.

and defines simplified criteria in order to decide the optimal configuration for the plant relevant to the best cost/benefit ratio.
In general, the way of neutral connection to earth in MV networks is chosen on the basis of legal and technical issues, related to safety and operation of electrical networks; therefore different solutions can be adopted. The Italian choice, up to now, has been to operate the MV networks isolated in almost all the cases. This solution was adopted forty years ago since it assured simple operation together with earth fault currents reduced to acceptable values, even if some drawbacks like greater stress for insulation and intermittent arc phenomena were expected.

Recently, the issue of neutral to earth connection has been reconsidered, taking into account the raising requirements for power quality and the environmental constraints (cables instead of overhead lines). Following that, Enel Distribution has begun the experimentation of connecting neutral to earth through impedance in MV networks (Petersen coil).

This experimentation involved different aspect related to:
- the connection schemes
- the choice of fixed or mobile coil
- the protection system adaptation to the new network
- the automation to manage different connection to earth during the experimentation
- the monitoring of the operation of three pilot plants.

In most cases, the Italian distribution networks are nowadays operated isolated. Nevertheless, some years ago (1950-1960), various interesting experiences were carried out on either compensated and connected to earth through resistance networks.

In particular, very significant experiences were carried out on a 15 kV MV network in the Milan area by ENEL during sixties. In fact, a comparative study was performed among the operation of the same network isolated, compensated and earthed through a resistance. In that network the operation were changed weekly adjusting the protection system.

In the Donada plant, near to the Adriatic Sea with a mixed – cable and overhead - 20 kV network. The Petersen coil was installed for the first time in 1995 and had some initial problems due to the protection system. In fact, the ground resistivity is very low; therefore, the earth fault is characterised by unidirectional components that can cause incorrect reproduction of the primary currents (CT saturation). In this condition, the protection devices, used at that time, had sometimes incorrect behaviours.

Subsequently, the above mentioned problems were solved and now the Donada plant is operated with the Petersen coil and the two busbars joined. This leads to a total fault current of about 270 A, compensated with a mobile coil of max 300 A connected to the star point of the HV/MV transformer.

The new protection system has showed a very satisfactory behaviour because no incorrect trip has been recorded.

The Corvara plant, operated with a Petersen coil starting from 1995, supplies the namesake skiing area, with a very high harmonic distortion caused by the ski lifts plants. The MV star-point of one busbar is connected to earth through a fixed (off-load adjustable) coil, whereas the other one through mobile (on-load adjustable) plus fixed coils.

Starting from 1995 to now quality of service has become excellent, especially for the busbar equipped with the mobile coil.

The Reana plant, located north of Udine, supplies a MV network with different kind of loads: residential, industrial, commercial centres. It’s worth noting that the
Petersen coil used was directly connected to the star-point of the HV/MV transformer.

Therefore, on load motor driven sectionalizers (IMSs) have been used to have a flexible system:
- when both HV/MV transformer are operated, the on load motor driven sectionalizers are so arranged that each coil and each resistance are connected to a single transformer;
- when the two busbars are joined, the same on load motor driven sectionalizers are so arranged in such a way to have two coils and only one resistance connected to the same transformer.

The substation control system was realised by a computer logic that allows to operate the plant automatically. This logic also assures the monitoring of the plant.

Figures 1 and 2 illustrate some recordings relevant to earth fault in case of isolated or compensated network. Examining these figures, big differences can be noticed:
- in the case of isolated network (fig. 1) the electric quantities reach very quickly their permanent fault values. Moreover, the homopolar current flowing in the faulted line is opposite to the others and higher;
- in the case of compensated network (fig. 2) the steady condition of the homopolar currents is quite similar, therefore the faulted line is not so easily detectable. Nevertheless, some spikes in the first milliseconds after the fault can be observed and, once more, the faulted line has spike opposite to the others. Moreover, when the fault self-extinguishes, a transient with a near 50 Hz oscillation starts: this transient caused many problems to the first protections installed before 1998.

OPERATION RESULTS

To evaluate the quality of supply improvement due to Petersen coil, a statistic analysis of the events realised by means of a fault recorder occurred in Donada, Reana and Corvara primary sub-station was carried out. Tables 1, 2 and 3 summarise the results and refer to data available in August 2000.

To read the above mentioned tables, it has to be taken into account that:
- the column “data with Petersen system operation” contains data referring to all earth fault recorded,
- the number of extinguished faults corresponds to events with current flowing into the Petersen coil associated with no trip protection system. It’s worth noting that in the future ENEL will have an automatic system able to categorise such events.

Looking at the results, the Petersen coil operation has been very satisfactory. In particular the fault self-extinction occurred in more than 95% of events in case of mobile coils and in more than 60% of events with fixed coil and compensation of about 50% of busbar capacitive current.

Also the analysis referred to long interruptions shows a significant reduction: for example, the exam of Donada network data points out a long interruptions reduction from 36% to 46% considering only those possibly affected by the Petersen coil.

As regards Reana network, the corresponding values are 5% and 31% but it has to be taken into account that this network has been connected to lines with a poor quality of service.

As a consequence of the above-mentioned results and taking into account
- the use of cables with the corresponding growth of the earth fault current,
- the need for a better quality of service,
ENEL decided in 1999 to extend the installation of Petersen coils in the Italian MV networks.
**CONNECTION SCHEMES**

Generally, the Petersen coil can be connected

- directly to the HV/MV transformer star-point,
- to the MV busbar by means of zig-zag transformer.

ENEL prefers the first solution because is less expensive of the other one and doesn’t need a line-breaker.

This solution is very flexible and allows to use 1 or 2 coils connected to the HV/MV transformer. Of course, if the HV/MV transformer is not able to withstand the current flowing through the coil, it is necessary to use the second solution with the zig-zag transformer. As regards the Petersen system, with reference to the compensation coil, two solution are possible:

- fixed coil tunable off-load by means of fixed steps,
- mobile coil tunable continuously

The Petersen system also consists of

- a parallel resistance to allow the protection system operation. In the case the two busbars are connected, one resistance will be excluded;
- a series resistance to limit the time constant independently from the fault resistance and from the primary sub-station earthing resistance.

Solutions adopted by ENEL will be different according to the earth fault current and to the quality of service needs summarised in table 4.

<table>
<thead>
<tr>
<th>Transients interruptions caused by earth fault [n/\text{year/line}]</th>
<th>Earth fault current in isolated operation over rated voltage [\text{[A/kV]}]</th>
<th>Mean earth resistivity multiplied by earth fault current [\Omega\text{mA}]</th>
<th>Solution adopted</th>
</tr>
</thead>
<tbody>
<tr>
<td>high [ (&gt; 3 \pm 4) ]</td>
<td>&gt; 13</td>
<td>any</td>
<td>mobile + fixed</td>
</tr>
<tr>
<td>high [ (&gt; 3 \pm 4) ]</td>
<td>4\pm13</td>
<td>any</td>
<td>mobile</td>
</tr>
<tr>
<td>high [ (&gt; 3 \pm 4) ]</td>
<td>&lt; 4</td>
<td>any</td>
<td>shunt</td>
</tr>
<tr>
<td>low [ (&lt; 3 \pm 4) ]</td>
<td>&gt; 13</td>
<td>any</td>
<td>fixed</td>
</tr>
<tr>
<td>low [ (&lt; 3 \pm 4) ]</td>
<td>4\pm13</td>
<td>&gt; 50000</td>
<td>fixed</td>
</tr>
<tr>
<td>low [ (&lt; 3 \pm 4) ]</td>
<td>4\pm13</td>
<td>&lt; 50000</td>
<td>nothing</td>
</tr>
<tr>
<td>low [ (&lt; 3 \pm 4) ]</td>
<td>&lt; 4</td>
<td>any</td>
<td>nothing</td>
</tr>
</tbody>
</table>

Table 4 – Solution adopted versus network conditions

**PROTECTION AND CONTROL SYSTEM**

The adaptation of the protection and control system in HV/MV substation equipped with compensation coil is mainly represented by the introduction of:

- earth fault directional relay, with varmetric and wattmetric intervention characteristic
- a new automatism based on a PLC logic for the automatic control of the neutral point of the busbars which represent also the interface to the remote control, with system supervision functions.

Concerning the first point, a strong constraint in the P&C design has been represented by the need of switching in automatic or manual mode the varmetric-wattmetric intervention sector of the protection device depending on:

- the availability of the coil compensation system on both busbars;
- the possibility, that has to be taken into account in this first phase of experimentation, of a single busbar resupplying from a isolated neutral busbar of another primary substation.

So, a new enhanced protection generation has been designed and installed in ENEL plants after severe laboratory and field type tests. Their performance covers all fault types typical of network operation with isolated or compensated neutral such as single earth fault (low and high resistance), cross-country fault, intermittent arc, to provide always a fairly dependability level.

The new automatism is the hinge of the automation system, and provides for:

- the functional interface between the operator at the control centre and the plant. It normally operates in automatic mode; the operator’s commands for the coils connection are enabled only in case of right check of the correct position, status and availability of single apparatus and protection system setting on the busbars. In any case the manual operation of the plant is allowed;
- the control of the busbars status also in system first failure conditions, in order to provide a steady state operation in isolated or compensated neutral operation through the proper selection of the protection system setting. In double fault condition, when the automatic control of the plant is no longer possible, the PLC sets itself in a block manual mode, giving back the commands to the operator;
- the monitoring and the supervision of the apparatus and the handling of alarm information (e.g. sectionalizer position incongruency).

**SYSTEM MONITORING**

To monitor plants when incorrect operations occur during the initial period of experimentation, it is necessary to use fault recording systems with high performances. ENEL decided to use devices with 32 analogue channels and 128 digital ones. These devices will be integrated with the control system of the primary sub-station.

To verify the Petersen system effectiveness in case of earth fault, a special device has been introduced, based on digital signals coming from both the protection system and the network analyser. The device can

- produce synthetic information about the Petersen system behaviour (e.g. number of fault extinguished by the coil),
transmit these information through the SCADA system,
detect possible critical conditions of the single network feeders. This function, together with the feeder loss of insulation one, allows personnel to make focused maintenance operations.

**INSTALLATION PLAN**

During 2000 the installation plan makes provision for

- 37 Petersen systems with fixed coil in 19 primary sub-station;
- 61 Petersen systems with mobile coil in 31 primary sub-station.

In the following five years the Petersen system will be installed in about 400 primary sub-stations so that almost 30% of plants will be equipped with such a system. On the other hand, it must be noticed that, up to now, at least 30% of plants are equipped with shunt circuit breakers.

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**Table 1: DONADA Primary station - Analysis of Petersen system operation**

17.06.99 ÷ 31.08.00

<table>
<thead>
<tr>
<th>Network length</th>
<th>Fault current</th>
<th>Busbar</th>
<th>Total</th>
<th>Plant data</th>
<th>Data with Petersen system in operation</th>
<th>Interruptions [1]</th>
<th>Operation analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Self-extinguished</td>
<td>No self- extinguished</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td>Total</td>
<td>Total</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Transient</td>
<td>Short</td>
<td>Long</td>
</tr>
<tr>
<td>[km]</td>
<td>[km]</td>
<td>[A]</td>
<td></td>
<td></td>
<td>%</td>
<td>%</td>
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</tr>
<tr>
<td>3.3</td>
<td>8.0</td>
<td>33.2</td>
<td>R</td>
<td>DONADA</td>
<td>7</td>
<td>5</td>
<td>71%</td>
</tr>
<tr>
<td>4.1</td>
<td>5.4</td>
<td>21.8</td>
<td>R</td>
<td>LOREO</td>
<td>13</td>
<td>12</td>
<td>92%</td>
</tr>
<tr>
<td>11.9</td>
<td>1.9</td>
<td>8.3</td>
<td>R</td>
<td>MOGENGA</td>
<td>10</td>
<td>10</td>
<td>100%</td>
</tr>
<tr>
<td>4.6</td>
<td>0.7</td>
<td>3.1</td>
<td>R</td>
<td>SIBERALE</td>
<td>12</td>
<td>11</td>
<td>92%</td>
</tr>
<tr>
<td>24.4</td>
<td>12.6</td>
<td>51.9</td>
<td>R</td>
<td>TAGLIO PO</td>
<td>88</td>
<td>80</td>
<td>91%</td>
</tr>
<tr>
<td>39.3</td>
<td>20.6</td>
<td>117.3</td>
<td>R</td>
<td>Total</td>
<td>130</td>
<td>118</td>
<td>91%</td>
</tr>
<tr>
<td>25.0</td>
<td>1.1</td>
<td>5.9</td>
<td>V</td>
<td>CA PISANI</td>
<td>58</td>
<td>55</td>
<td>95%</td>
</tr>
<tr>
<td>16.7</td>
<td>1.4</td>
<td>8.6</td>
<td>V</td>
<td>CAVANELA</td>
<td>50</td>
<td>47</td>
<td>94%</td>
</tr>
<tr>
<td>2.7</td>
<td>13.7</td>
<td>54.8</td>
<td>V</td>
<td>CONTARINA</td>
<td>2</td>
<td>1</td>
<td>50%</td>
</tr>
<tr>
<td>15.1</td>
<td>4.6</td>
<td>19.3</td>
<td>V</td>
<td>GRIMANA</td>
<td>22</td>
<td>22</td>
<td>100%</td>
</tr>
<tr>
<td>14.8</td>
<td>12.9</td>
<td>52.1</td>
<td>V</td>
<td>VALLESINA</td>
<td>34</td>
<td>30</td>
<td>88%</td>
</tr>
<tr>
<td>16.6</td>
<td>1.2</td>
<td>5.0</td>
<td>V</td>
<td>VILLAREGIA</td>
<td>32</td>
<td>29</td>
<td>91%</td>
</tr>
<tr>
<td>39.3</td>
<td>34.8</td>
<td>144.9</td>
<td>V</td>
<td>Total</td>
<td>196</td>
<td>184</td>
<td>93%</td>
</tr>
<tr>
<td>137.2</td>
<td>63.5</td>
<td>262.2</td>
<td>V</td>
<td>Total</td>
<td>328</td>
<td>302</td>
<td>92%</td>
</tr>
</tbody>
</table>

[1] Reduction supposing that a fault extinguished by Petersen system would have caused a transient interruption
[2] Total interruptions (with or without Petersen coil in operation)
### Table 2: REANA Primary station - Analysis of Petersen system operation

<table>
<thead>
<tr>
<th>Network length</th>
<th>Plant data</th>
<th>Data with Petersen system in operation</th>
<th>Interruptions [1]</th>
<th>Operation analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Earth fault</td>
<td>Transient</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Single phase</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Short</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Long</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

#### Notes:

[1]: Reduction supposing that a fault extinguished by Petersen system would have caused a transient interruption

[2]: Total interruptions (with or without Petersen coil in operation)

### Table 3: CORVARA Primary station - Analysis of Petersen system operation

<table>
<thead>
<tr>
<th>Network length</th>
<th>Plant data</th>
<th>Data with Petersen system in operation</th>
<th>Interruptions [1]</th>
<th>Operation analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Earth fault</td>
<td>Transient</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>Single phase</td>
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<td></td>
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<td>Short</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Long</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

#### Notes:

[1]: Reduction supposing that a fault extinguished by Petersen system would have caused a transient interruption

[2]: Total interruptions (with or without Petersen coil in operation)