SHUNT CIRCUIT-BREAKER INSTALLED IN UNGROUNDED MEDIUM VOLTAGE SYSTEMS

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SUMMARY

The "Entreprises Electriques Fribourgeoises" (EEF), a Swiss utility, operate their medium voltage system with isolated neutral. In order to comply with the legal requirements for the security of people, the protection relays trip the lines also in the event of an earth fault. This kind of operation is not appreciated by our customers who have to accept too frequent interruptions of supply, mainly due to faults on the overhead lines.

A recent study suggests using a shunt circuit-breaker in the HV/MV substations combined with the existing isolated neutral system. The improvement aimed at is to operate continuously our electrical network in case of an earth fault. Our studies show a potential reduction of supply interruptions of over 50%.

The solution with isolated neutral and a shunt circuit-breaker, consisting in grounding the earth-faulted phase to the ground at the HV/MV substation, seems to have all the advantages of a compensated neutral point (Petersen coil) as well as a lower cost (approx. ratio 1:4).

MEDIUM VOLTAGE NETWORK FEATURES

Our network is operated with isolated neutral. Its operating voltage is 18 kV. It comprises 24 HV/MV substations, 157 MV radial feeders. The overall length of the network is 1900 km, overhead lines accounting for 46% of the MV network.

ACTUAL OPERATING MODE

Each line departure is equipped with a directional earth fault protection relay, which as soon as a ground fault appears trips the line. With the exception of those feeders exclusively composed of underground cables, an automatic reclosure function carries out a fast and slow shot reclosure sequence. In the event of a persistent fault, the line is definitively disconnected after the last cycle.

BASIC PROBLEMS

In MV networks with isolated neutral such as we currently operate, quality of supply and safety are contradictory. Consequently, is it necessary to place quality of supply before safety of people, or rather the opposite? The ideal solution obviously consists in finding an acceptable compromise or to stress both aspects. Even if the power quality of our network is in conformity with the EN 50160 standard, we receive more and more frequent complaints from customers, subjected to interruptions caused by reclosure cycles, due to faults mainly located on the overhead lines.

Taking into account the very probable opening of the electricity market in Switzerland, we are convinced that the distribution utilities will have to make efforts to improve the reliability and the continuity of their supply.

IMPROVEMENT POTENTIAL OF OUR NETWORK

Obviously, the targeted objective consists in maintaining the continuity of supply during a single line-to-ground fault. In this case, if one admits a continuous operation even in the event of permanent faults, the global potential of reduction in supply interruptions, based on the statistics of the events 2001 to 2003, is 56% (Figure1).
SAFETY AND PERMANENT SUPPLY DURING SINGLE LINE-TO-GROUND FAULTS.

To preserve the safety of people and material, the following rules were established, to authorise further supply of electricity:

- Admissible continuous earth fault current < 40 A
- Earthing electrodes < 5 ohms
- Supply cut in the event of intermittent ground faults lasting longer than two seconds.
- Supply cut if earthing electrode voltages higher than 200V last more than two seconds.

In the large majority of the cases encountered in our network, the capacitive current of the lines exceeds 40 A. Maintaining supply is not possible without preliminary measures.

SOLUTIONS CONSIDERED FOR IMPROVEMENT

Among the solutions studied, we selected two principles of operation, capable of improving the continuity of supply:

- Resonant-grounded network with arc suppression coil.
- Shunt circuit-breaker at the MV distribution substation.

Both have their advantages and disadvantages.

Resonant-grounded networks

The arc suppression coil solution is interesting; it is efficient in cases of fugitive auto-extinguishing and metallic faults. On the other hand, it remains without effect in case of intermittent ground fault, reason for which, we would have abandon sustaining supply during permanent ground faults.

Despite this restriction, its application in our networks would still lead to a reduction in supply interruptions of up to 48%. This restrictive operation measure is justified by the following reasons:

- dangerous touch voltage
- strong MV and LV voltage constraints due to transient phenomena
- liberation of large destructive energies, possibly degenerating rapidly into a short-circuit

The application of resonant-grounded networks is spreading through Europe. Even EDF adopted this solution in 2001, gradually introducing it in their networks with predominantly overhead lines. The reliability of this technique is largely demonstrated, unfortunately with high investment costs.

Since our HV/MV transformers are of the star-delta type, the arc suppression coil has to be connected to the MV busbars through an earthing transformer.

The selectivity of the fault is carried out by injection of an ohmic current of short duration in the network. Existing protections can be kept, if commuted in the active component measurement mode of the fault current and if their tripping is delayed to a second.

The protection operation being different in the two modes (isolated and compensated neutral), the simultaneous installation of two arc suppression coils per substation is essential in order to satisfy the operation redundancy.

Theoretically the arc suppression coil tunes itself automatically. It should be known that the operation of a conventional regulator could be problematic on highly-cabled networks whose capacitive loads are very balanced. More sophisticated and more expensive regulators have their own device for injecting measurement current, making it possible to guarantee the adjustment function in any circumstance, independently of the network topology.

As some very recent protection relays are provided with a function of detection of intermittent ground faults, one can consider operating on metallic faults. However, this advantage is not very significant in our network, since the overhead lines are mainly constituted of wooden poles, where this kind of fault is rather rare.

Another disadvantage of an operation on permanent fault is the necessity to improve the earthing electrodes exceeding 5 ohms, because a residual current of 20 to 30 A flows permanently through the earth electrodes.

The shunt circuit-breaker associated to networks with isolated neutral

To our knowledge, this solution is very little spread. It apparently presents the comparable advantages to those of compensated networks, at a much lower cost. Its application
in our networks could reduce the interruptions of supply by 53 %. Moreover, it does not require additional investments for the improvement of the earth electrodes, the selective detection of the ground faults is easy and the extinction of the faults is guaranteed in the large majority of insulation failures.

On the other hand, the efficiency of this new solution must still be evaluated and proven in our networks using a pilot installation to be implemented in two HV/MV substations.

The operation principle of operation is rather simple. It is a circuit-breaker with single phase closing and tripping mechanism, which solidly puts the faulted phase to the substation ground, approximately 300 ms after its occurrence. Hence in case of insulation faults on the line, the fault voltage is stabilised and limited to a low residual value, the capacitive current is drained back to the substation and the arc is quenched. Those faults represent the large majority of the cases (statistically more than 94 % of the earth faults). A few seconds later, an attempt to open the shunt circuit-breaker is made by the switchgear automatic control. If the fault restores itself, one can carry out a new cycle of closing-opening. If the insulation fault is permanent and extinguishes itself with the closing of the shunt circuit-breaker, the later is maintained closed until the defective section is isolated.

In case of conducting faults (statistically less than 6 % of the faults to the ground), a load current establishes itself through the shunt and the fault, whose magnitude depends on fault location along the line, line load, earth resistance at the fault location, longitudinal impedance of the line, and earth resistance at the injection substation. In some cases, this current can reach significant values and cause an inadmissible voltage at the fault location. In such a case, the protection relay associated with the shunt circuit-breaker, detects the establishment of the ohmic load current and give the final trip command to the shunt circuit-breaker. The earth protection function definitively trips the feeder after a time delay of 1 second (Figure 2).

When the fault is permanent and non metallic, and when the shunt circuit-breaker remains closed after the automatic extinction cycles, operating personnel activates a manual opening command of the shunt circuit-breaker, in order to endeavour restoring normal operation of the network after intervention and fault elimination. If the fault is still present, the shunt circuit-breaker is closed again. If the fault has disappeared, the shunt circuit-breaker remains open. This command can be carried out locally or remotely.

The permanent capacitive fault current running out to ground of HV/MV substation via the shunt circuit-breaker reaches 200 A maximum and does not generate dangerous touch voltage, since the earth impedances of the substations are low.

As the neutral arrangement does not change, current protections relays are entirely compatible with the introduction of the shunt circuit-breaker. The trip time will be set to 1 second. In fact, this compatibility leaves any freedom of choice to the deployment of the installation of the shunt circuit-breaker in the network, and to the more advantageous investment’s repartition. There is no need to simultaneously equip the HV/MV substations with two shunt circuit-breakers, as it is the case for the arc suppression coils. For example, the operation of a substation equipped with a single shunt-circuit breaker can take place indifferently with coupled or separated busbar sections. There is no need for redundancy even in the case of dysfunction of the shunt circuit-breaker. The MV line protection relays still work correctly.

Theoretically the shunt circuit breaker does not require any maintenance; it is reliable and of great availability.

Although theoretical, our study and its considerations confirm the adequacy of the shunt circuit-breaker to our MV network. Whereas EDF is on the point of dismounting its shunt circuit-breakers, to apply compensated networks, so widespread in Europe, this choice can seem paradoxical and we are well aware of it.

The comparative criteria, which distinguish the two solutions, are summarized in Table 1.
TABLE 1: COMPENSATED NETWORK COMPARED TO SHUNT CIRCUIT-BREAKER

<table>
<thead>
<tr>
<th></th>
<th>Compensated networks</th>
<th>Isolated networks + shunt breakers</th>
</tr>
</thead>
<tbody>
<tr>
<td>EFFICIENCY IN CASE OF SINGLE LINE-TO-GROUND FAULT:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extinguishing capacity of fugitive faults (87 % of earth faults)</td>
<td>☺</td>
<td>☺+</td>
</tr>
<tr>
<td>Extinguishing capacity of permanent restriking faults (~7 % of earth faults)</td>
<td>☺ trip</td>
<td>☺</td>
</tr>
<tr>
<td>Continuous supply in case of permanent conducting faults (~6 % of earth faults)</td>
<td>☺ trip</td>
<td>☺</td>
</tr>
<tr>
<td>Total reduction of supply interruptions (in % of short-circuits and earth faults)</td>
<td>☺(-48%)</td>
<td>☺+(−53%)</td>
</tr>
<tr>
<td>SAFETY (conformity with the legal requirements)</td>
<td>☺</td>
<td>☺</td>
</tr>
<tr>
<td>TOTAL MV NETWORK INVESTMENT COSTS (Tax free, in Swiss Francs)</td>
<td>☺ 16.5 millions</td>
<td>☺ 4.5 millions</td>
</tr>
<tr>
<td>MAINTENANCE COSTS</td>
<td>☺</td>
<td>☺+</td>
</tr>
<tr>
<td>RELIABILITY, COMPLEXITY OF THE COMPONENTS</td>
<td>☺</td>
<td>☺+</td>
</tr>
<tr>
<td>SELECTIVITY</td>
<td>☺</td>
<td>☺+</td>
</tr>
<tr>
<td>Fault detection reliability</td>
<td>☺</td>
<td>☺+</td>
</tr>
<tr>
<td>Is it compatible with the actual situation?</td>
<td>☺</td>
<td>☺+</td>
</tr>
<tr>
<td>IS IT NECESSARY TO IMPROVE THE SYSTEM GROUNDING?</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Not necessary if the fault current duration does not exceed 2 seconds</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>VOLTAGE CONTRAINTS AND INSULATION COORDINATION</td>
<td>☺</td>
<td>☺</td>
</tr>
<tr>
<td>Equal between the different types of neutral system, isolated, with or without shunt, and compensated.</td>
<td>☺</td>
<td>☺</td>
</tr>
<tr>
<td>RISK OF DOUBLE LINE-TO-GROUND FAULTS</td>
<td>☺</td>
<td>☺</td>
</tr>
<tr>
<td>OPERATIONAL CONSTRAINTS COMPARED TO THE ACTUAL ISOLATED NEUTRAL SYSTEM</td>
<td>☺</td>
<td>☺</td>
</tr>
</tbody>
</table>

CONCLUSIONS

Decision has been taken to commission in 2005 two pilot installations with shunt circuit-breakers in two distinct HV/MV substations. The financial risk is acceptable.

The first operation tests will be carried out by simulating rigid and intermittent earth faults, at various locations in the network, at the beginning and the end of predominantly overhead and underground lines. These tests will make it possible to optimize the protection settings and to check the automatic control of the shunt circuit-breaker.

If the results give satisfaction for operation, behaviour analyses will be carried out during two years. At the end of this experimental period and according to the global assessment (technical and financial), the choice of the final concept will be made, implemented and generalized in our MV network.

If the results are not satisfying, we will choose the neutral compensated technique with Petersen coils.

**PS:**

Another paper presented in session 1 (# 0044 CONCEPT AND PRACTICAL TESTING OF SINGLE POLE OPERATED EARTHING BREAKERS IN AN URBAN MV CABLE NETWORK) deals with the subject of earthing breakers. However, the approach is a little bit different, the main topic being the testing in an urban MV cable network.

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