OPERATIONAL STABILITY OF SHUNT CIRCUIT-BREAKER SYSTEMS IN UNGROUNDED MV NETWORKS WITH DISTRIBUTED GENERATION (DG)

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Summary

This document is a follow-up of the studies published for CIRED 2005 and 2009 (Shunt Circuit-Breaker in Ungrounded Medium Voltage Systems - Paper 0028 and 0875), ref. [1]
The Fribourg and Neuchâtel Electricity Company (Groupe E) is a Swiss utility company which currently operates its medium voltage networks in ungrounded mode. Any fugitive single line-to-earth faults are suppressed using a shunt circuit-breaker.

However, in recent years, new actors - distributed generation (DG) installations - have altered the normal operation of the distribution networks. When DG penetration level increases, various effects can be felt: voltage imbalances in the case of single-phase installations, overvoltages generated when photovoltaic installations are switched off, reverse energy flows, or even a reactive power increase.
In the case of a short circuit, DG installations also affect network impedance, power and current direction. Consequently, system protection may need to be reconsidered.

For all these reasons, it was necessary to ensure, with simulations, the reliability of our arc suppression systems when DG installations inject current into the networks.

IMPACT OF DISTRIBUTED GENERATION

Do distributed generation (DG) installations, especially when their penetration level is high, have an impact on protection measurement and selectivity in the case of single line-to-earth contacts on the MV network? To stress this concern, we have continued our previous studies on this subject in order to ensure not only the reliability of our earth fault suppression system based on the use of a shunt circuit-breaker, but also the selectivity of the shunt relay and the feeder earth protection, both analogical (with wattmetric characteristics) and digital.

The effectiveness of the technique used today for the suppression of single line-to-earth faults by using a shunt circuit-breaker is due mainly to the evolution of protection relay technology over recent years. These devices are now extremely effective for the analysis of all types of faults and for the speed with which they control how such faults evolve, for example when a single line-to-earth fault degenerates into a short-circuit, and all of this is done selectively, ref. [2].

However, the need remained for us to ensure the stability of the protection systems and in particular of the shunt circuit-breaker in the presence of DG infeed, especially when these installations produce considerable reactive energy or significant reverse flows thereby distorting the measurement of a protection relay.

STUDIED SYSTEM AND SIMULATION RESULTS

In order to verify these points, the effects of DG were analyzed on a typical MV network during fugitive, restriking or metallic single line-to-earth faults. For that purpose, various DG scenarios were considered:

- connected to LV nodes: photovoltaic (400 kW, 2 x 20 kW and 10 kW) and biogas (100 kW and 50 kW);

- connected to MV nodes: wind turbine (2 x 5 MVA).

The alternatives were studied in both steady and transient states:

- Case 0: without DG;
- Case 1: with maximum MV and LV DG, at cos φ = 1;
- Case 2: with maximum MV DG only, at cos φ = 0.7;
- Case 3: with LV DG only.

Modelling and considered earth fault studies:

- On the infeed sub-station 18 kV busbar;
- On the underground cabled network;
- On the overhead lines network.

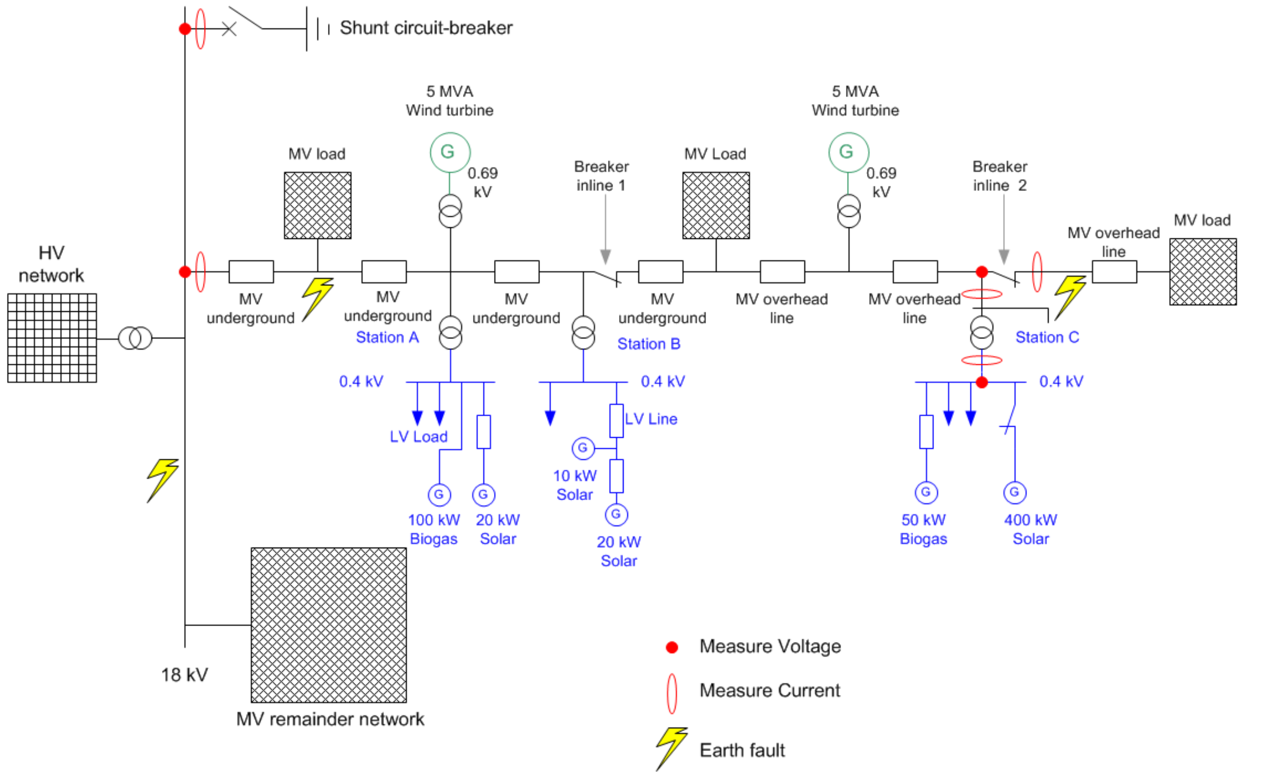


Figure 1: MV network with DG

SELECTIVITY OF PROTECTION SYSTEMS

In ungrounded networks, the zero-sequence current is usually large enough to allow a reliable measurement to be taken regardless of network topology. Without DG contribution, the measurement of reactive power direction is invariable, as reactive energy always moves in the direction of a fault. In this case, we have not evaluated any particular operating constraint.

The study also considered energy direction reversal and reactive power production in the case of high DG energy production levels. In all the cases analyzed and also during the tests conducted in 2005, the shunt circuit-breaker protection relay and the feeder directional digital relays correctly identified the magnitudes during a single line-to-earth fault, as the selective detection criteria are based on the measurement of the zero-sequence voltage U(0), the capacitive earth current (starting from 5 A) and its direction.

In networks equipped with earthing circuit-breakers, there are no particular constraints on selectivity, because the way in which the neutral is handled is the same as in a compensated system. It is sufficient to take into account the operation of the earthing circuit-breaker in the tripping time of the MV line protections, as faulted phase selection is dependent on network capacitance, ref. [3] and [4].

The operational simulations carried out by our company have identified the following operational limits:
About 350 ohms of earth fault resistance for a small network with 20 A capacitive current during a solid fault to earth.
About 60 ohms for a conventional network with 130 A capacitive current during a solid earth fault.

However, in real operating conditions, we have only been able to measure earth faults with maximum values below 30 ohms.
The selectivity of the protection systems is therefore reliable, fast and effective for resistive faults up to about 500 ohms. Beyond that limit, earth faults are no longer detected by MV feeder directional protection systems.
From a safety standpoint, there is however no risk of a contact voltage, as the fault current power factor remains rather low ($I0 < 30$ A).

The use of "Wischer" type relays, whose operating principle is based on the measurement of the capacitive energy flow direction during the earth fault entry transient phase, offers the advantage of being independent of DG penetration level in compensated or ungrounded networks. Detection is, of course, very fast, ref [5].

However, some uncertainty still remains in the selective analysis of the earlier analogical type relays that are still in use for some feeders in our networks. In this particular case, the detection and trip characteristic falls well beyond an angle of 90°, and the directional measurement of capacitive current is not guaranteed in the case of DG infeed power reversal. This problem arises only when the penetration levels of DG installations become sufficiently high, and it can easily be avoided by implementing a plan to renew the old protection relays.

RESULTS

Steady state simulations showed a satisfying voltage profile, with values remaining within the following ranges:
- In MV, from 99.4 % of Unom (reference case 0) to 102.4 % (case 2)
- In LV, 102.3 % of Unom (reference case 0) to 106.1 % (case 1)

The maximum values of three-phase fault currents ranged from:
- In MV, 7.283 A (reference case 0) to 8.496 A (case 1)
- In LV, 15.615 A (reference case 0) to 16.380 A (case 1)

In actual fact, DG, which is totally controlled by the power electronics (for ex. solar), is immediately stopped during a multi-phase fault and does not contribute to the increase of short-circuit currents.

In ungrounded networks, earth faults, possibly due to a network component insulation failure (damaged power cable or termination, dampness in sleeves, etc.), cause touch and step voltage increases at the fault location and submit the MV network components to electrical constraints: capacitive discharges at the fault location and very abrupt voltage variations to earth, in the order of kV/µs.

Cases of single-line-to-ground fault

In our ungrounded networks, the **permanent earth faults** are mostly of the **restriking** type.

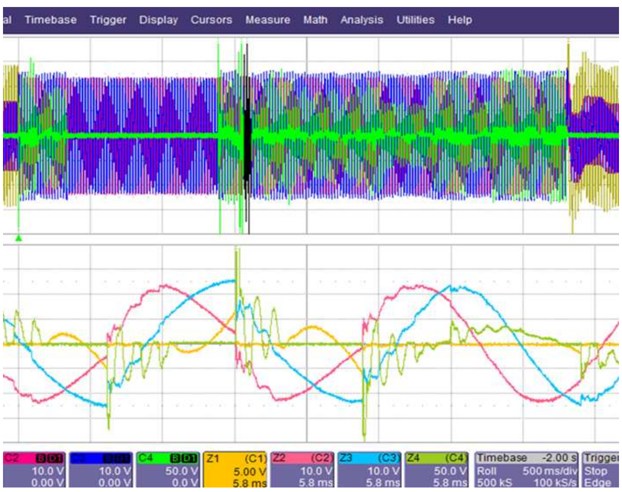


Figure 2: Restriking earth fault in ungrounded MV network, with capacitive current 20 A. Voltage waveform.

With permanent and restriking faults, the constraint is repeated on each half-alternation and is therefore more severe than in the steady state.

Considerable energy is produced at the fault location, and the fire risks are not negligible.

A particular feature of the shunt circuit-breaker is that it converts a restriking fault into a fault effectively grounded at the substation's busbar, thus avoiding the observed overvoltages and the resulting damage.

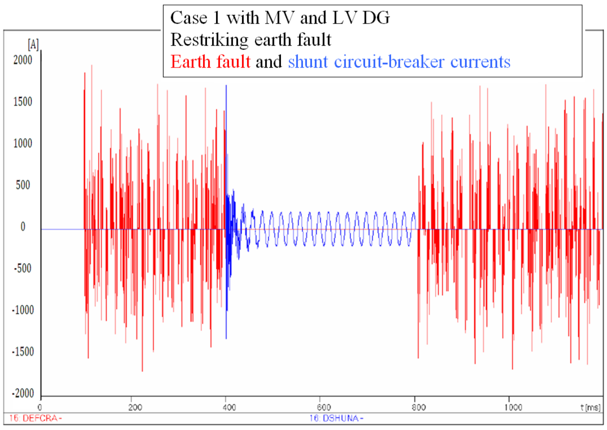


Figure 3 : Restriking power cable earth fault in ungrounded network, with earth fault and shunt circuit-breaker currents, and maximum DG energy

The simulations carried out have shown that the detection of this type of fault is not deteriorated by the presence of DG. Once the shunt is closed, there is practically no current at the fault location. As soon as the shunt opens, the electric arc is restarted once the flashover voltage is reached, and it resumes its restrike-extinction cycles. It should be noted that these voltage constraints are badly tolerated by the AC/DC converters of the DG installations.

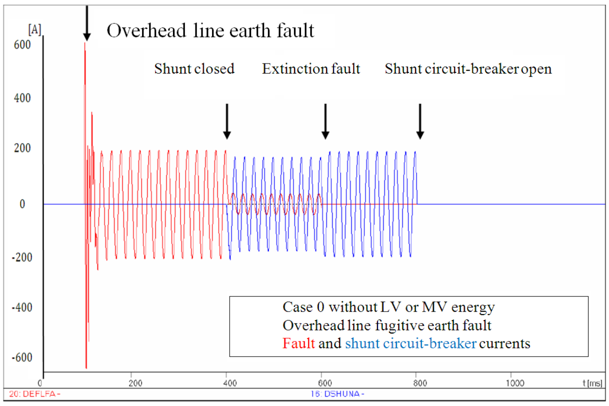
In the case of **fugitive faults** in the overhead lines network, the studied current values are theoretical, as the instability of the arc does not form a permanent path for loading and DG power evacuation. This type of fault, which lasts only a short time, does not interfere with the correct operation of the shunt circuit-breaker.

Lastly, a particular type of fault, referred to as a **permanent metallic** (or galvanic) earth fault, was also analyzed, ref: [20]. In this case, a part of the load and generated current is led in parallel through the ground between the shunt circuit-breaker and the earth fault location, depending on line and ground electrodes impedances. In the shunt circuit-breaker, which is closed during the fault, a part of the load current is thus added to the capacitive current.

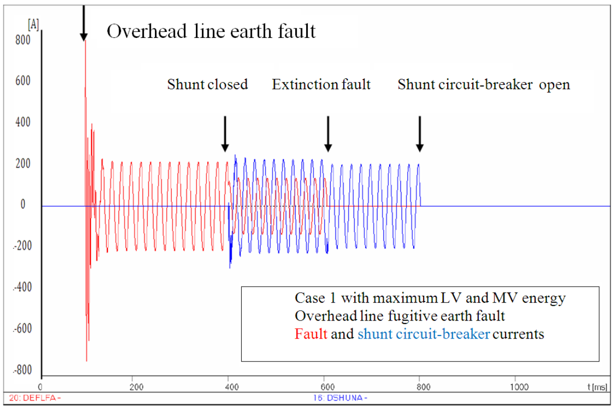
At the fault location, a part of the load current replaces the capacitive current. It may then reach values that are too large and dangerous. This load current may be reversed

depending on DG contribution. For safety reasons, the feeder must be switched off.
This particularity is also noted in simulations of other types of faults, and a fault current increase may be observed during DG energy production. This is not due to the increase of the capacitive current, which does not change (regardless of load and generation), but rather to the replacement of the capacitive current by a part of the loading or DG evacuation current, which also has a reactive component. The complex sum of the capacitive and the partial load currents is therefore present in the shunt circuit-breaker.
In itself, this creates no problem for the selectivity of the protection relays, but it must be taken into consideration in sizing the ground electrodes of installations.

The current increase can be observed in the following graphs:



Figures 4: Fugitive earth fault, current without DG production.



Figures 5: Fugitive earth fault, current increase with DG production.

CONCLUSION

Due to optimal network sizes, in normal operation and in the summary outline offered here, the LV and MV voltage profile is quite satisfactory in all the examined cases, with an increase of 3% of MV voltage and 3.8% of LV voltage in the presence of DG production. With this production, the increase of the max three-phase short-circuit currents is 16.7% in MV (18 kV bus bars) or 4.9% in LV (station C), respectively. The above values are not those specific to the LV power unit terminals. When DG infeed is completely controlled by the power electronics, the power units are immediately stopped during a multi-phase fault, and they do not contribute to the increase of the short-circuit currents.
In all the examined faults and in all the cases of generation and load, transient voltage behaviours are similar. Conversely, current values are strongly dependent on fault location as well as generation and load characteristics (line and fault impedance). Consequently, the use of phase detection criteria based on voltage to control the shunt circuit-breaker may be maintained unchanged, with or without DG production.
Lastly, the need for line and power unit protection in the event of permanent single line-to-earth faults or multi-phase faults must be stressed.

The simulations carried out have demonstrated that, in disturbed mode and for all kinds of faults, the voltage profile remains stable. The selectivity of the protection relays and earth fault detection has always been correct and is unaffected by DG.
The simulations results confirm that our installed systems are stable without subsequent modification.

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