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Energy Research and Cleantech Division

REEL Demo – Romande Energie ELectric network in local balance Demonstrator

Deliverable: 6a1 Preliminary study for soft-open point deployment into REEL Demonstrator

Demo site: Chapelle

Developed by

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1 Description of deliverable and goal

1.1 Executive summary

The soft-open point is a conceptual device with only few practical demonstration attempts know to date. Its intended use is to allow a loop topology of previously radially operated (MV) distribution networks with no harmful impact on other installed devices including protection devices. The advantages of its use include a higher hosting capability of renewable generation at potentially lower costs and impacts on the network than traditional approaches. The deployment of such a device is planned in the REEL demonstrator at Rolle – Les Buttes.

1.2 Research question

The objective of the activity covered by the work in this report is to answer the following questions:

- Is the use of a soft-open point with no change to the existing protection concept of the Romande Energie MV protection philosophy possible in the considered Rolle – Les Buttes network possible?
- What are the interdependencies between the ratings of the SOP and its positioning in the MV network?

1.3 Comparison with other demonstrator activities

In this activity, a modelling framework allowing combining network models and device models into time domain simulations has been developed. The platform selected is PowerFactory. The models have been used for time-domain short-circuit simulations which have shown that the selectivity and reliability of the protection system is in principle maintained after an SOP is added to the considered network.

1.4 Description

1.4.1 The soft-open point concept

The soft-open point (SOP) is a power electronic device that has been proposed and conceptually studied by various authors with the purpose to permit a meshed (or looped) operation of radially operated distribution networks, i.e. open loops (Bloemink & Green, 2010; Bloemink & Green, 2011). As shown in Figure 1, a normally closed SOP represents a way to decouple load flows and fault currents:

- It is closed in normal conditions, thus establishing a meshed/loop network topology for load flows
- It opens (faster than mechanical breakers that remain in the distribution system) in fault conditions, thus establishing a radial network topology for fault currents.

The normally closed SOP (as opposed to the normally open) SOP has been selected in this activity in coordination with the requirements of the DSOs sponsoring the study of the SOPS (SOP with storage) via the EOSH consortium.

This activity permitted to show that the SOP therefore increases the operational flexibility with minimal influence on existing protection and automation systems: the short-circuit levels are only marginally influenced and protection settings of already installed devices do not need to be adjusted (or at least the protection concept can be maintained as it is).

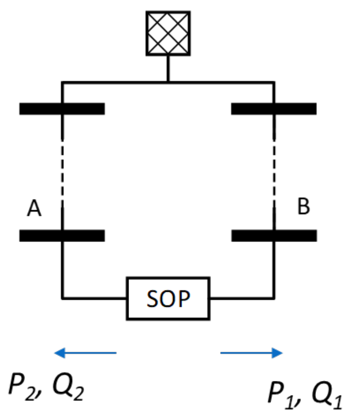

Figure 1: Illustration of the SOP inserted into a MV network

In order to achieve the functionality described above, especially fast opening times, the SOP is implemented as a power electronic device. The basic operation strategy of the normally closed SOP is as follows:

- In the "Closed" state, P2 = - P1 and Q2 = - Q1. This is the normal operation point, which permits a reduction of ohmic losses in typical load and generation situation as well as a reduction of voltage variation due to load and generation patterns.
- In the "Open" state: P2 = P1 = 0 and Q2 = Q1 = 0.
- The short-circuit contribution is controlled, i.e. the short-circuit current contribution is limited approximately to the rated current of the SOP and the SOP can disconnect fast, independently of the operation of the existing distribution system's protection system.

  The prerequisite for this is a fast fault detection system, which in the case of the Rolle – Les Buttes demonstration will be the PMU real-time monitoring system deployed by EPFL.

If implemented using full converters (e.g. back-to-back two level inverters or modular multi-level converters), the SOP can be extended with further control features including e.g.:

- Reactive power / voltage control
- Loss reduction / optimisation by controlling the power transit through the SOP
- Series compensation

A very limited numbers of demonstrations of the SOP has taken place in international demonstration projects: Some prototype normally open low voltage SOPs have been tested in the UK and Ireland (Caoa et al., 2016), and another SOP prototype has been demonstrated in conjunction with fast car chargers, also in the low voltage network (Alstom Grid, 2015). This activity targets a normally closed SOP.

1.4.2 The considered network: Rolle – Les Buttes

The site for the deployment of the SOP into Romande Energie's MV distribution network has been selected by Romande Energie during the preparation of the REEL project. Figure 2 shows the considered 20 kV system around the Rolle HV/MV substation.

The SOP location is close to the current sectioning point between feeders 51 and 60. When the SOP will be installed, the sectioning point will be removed.

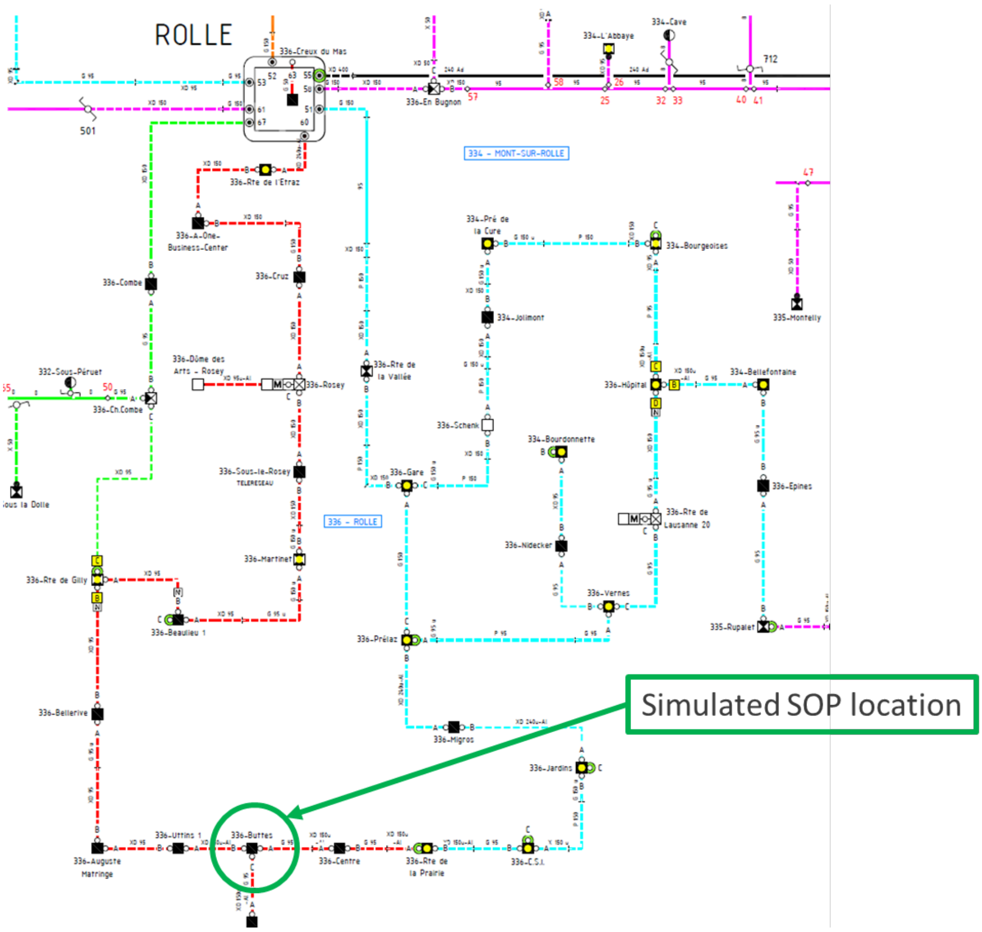

Figure 2: Considered network and SOP location for power flow and short-circuit studies.

1.4.3 Simplified modelling of the SOP and the network

In the following sections, only the "main loop" consisting of feeders 51 and 60 without the side branches will be modelled and discussed. The necessary impedances of the network elements have been gathered from various Romande Energie databases.

A full SOP model for has been established in PLECS for a two-level back-to-back converter structure. The PLECS environment permits precise and discrete calculations of the converter itself, but is inadequate for the representation of the relatively extensive distribution system. Hence a simplified network model is used in PLECS. In order to obtain results for short-circuits or load-flows, a co-simulation between Matlab-Simulink and PowerFactory is run, as described in Figure 3. The drawback of this method is the high computation time. For investigations requiring a high number of simulations, the SOP itself has been simplified such that it can be represented by transfer functions and implemented directly in PowerFactory by using the built-in scripting language DSL. The simplified model has been validated using the full model and subsequently used for the analyses discussed in the following paragraphs.

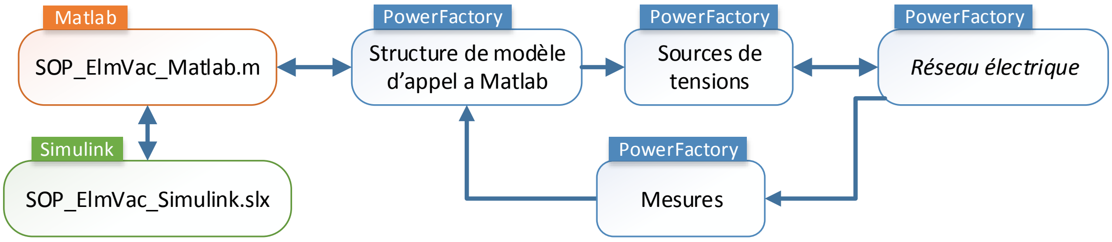

Figure 3: Principle of the co-simulation used for detailed converter simulations.

1.4.4 Power flow simulations: steady-state voltages and currents in the SOP and network

Based on these models, load flow calculations for different consumption and generation scenarios have been established. As an illustration, Figure 4 qualitatively shows the voltage distribution at different network nodes in the considered loop for a relatively high load on feeder 60 and a moderate load on feeder 50. Node 1 is the node closest to the HV/MV substation on feeder 60 and node 18 is Les Buttes, the location of the SOP. Node 37 is the node closest to the HV/MV substation on feeder 51. The voltages are shown for an open or closed state of the SOP. Closing the sectioning point reduces the voltage deviation from the nominal value thanks to a better sharing of the load currents on the two feeders.

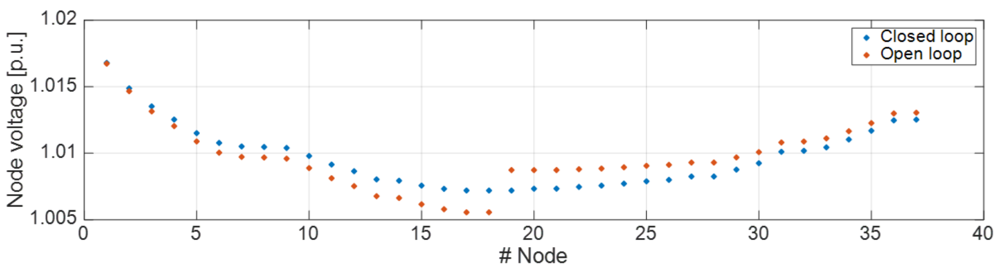

Figure 4: Voltage distribution at different network nodes in the open (no SOP) and closed (with SOP) MV loop.

The overall (yearly) variation of node voltages is determined by performing these calculations iteratively for several combinations of load and generation. For Rolle – Les Buttes the network consists of relatively short lines, close to a "stiff" network (Rolle is also an EHV substation). Consequently, the variation of node voltages is limited compared to more extreme situations in other Swiss distribution systems.

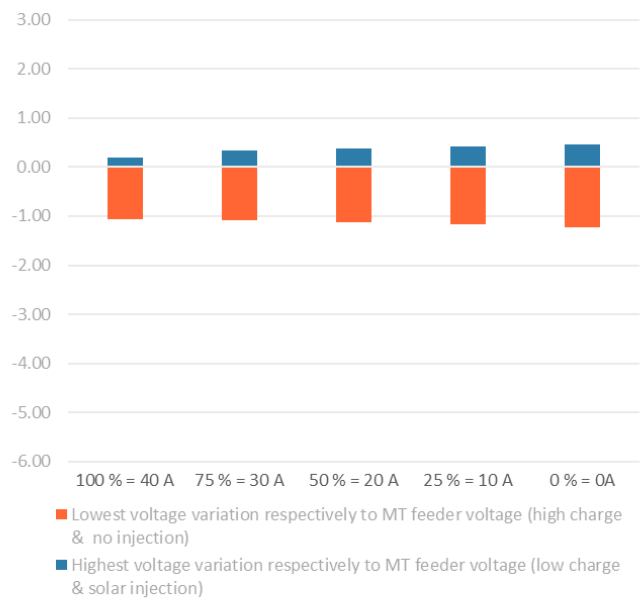

Figure 5: Influence of the SOP rating on the steady-state voltage for extreme load flow scenarios.

1.4.5 Short-circuit calculations: effect on protection

Figure 6 shows the results of short circuit (three-phase fault) calculations performed for an open and a closed soft-open point. The short-circuit current for both feeder 51 and 60 have been calculated for fault locations at each substation in the considered loop. For the open loop, each fault location results in a fault current only in one feeder, the other remaining unaffected (by the fault current). The fault current decreases as the distance between the fault and the HV/MV substation increases, but reliability and selectivity of the protection system is of course guaranteed, since the protection system has been designed for this situation.

For the closed loop, before the SOP opens, the situation is different: the fault will be fed from two sides and a fault current will flow in both feeders. In the case of three-phase ideal faults considered here, the contributions from both sides. As compared to the open loop case the maximum distance between the feeder and the fault can be longer and therefore the minimum short-circuit current decreases further.

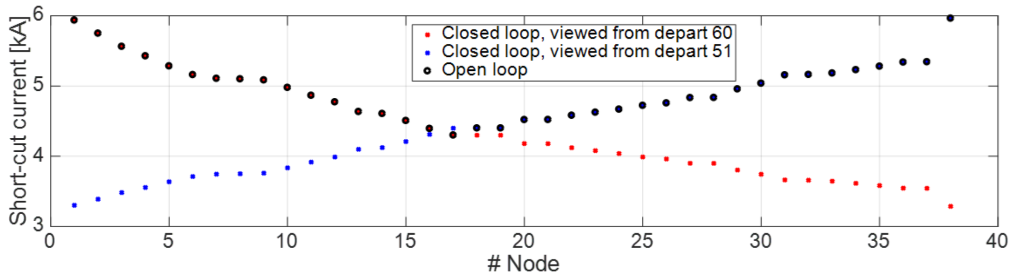

Figure 6: Simulated short-circuit currents for faults at each station in the considered MV loop.

Figure 7 shows three fault scenarios for the same fault location on feeder 60 (three phase fault with fault impedance). The plots show the currents as seen by the feeder overcurrent relays at the HV/MV substation, feeder 60 on the left side and feeder 51 on the right side:

- The first line shows the fault situation when the sectioning point is open, i.e. the current situation before the installation of the SOP. Obviously, the fault current is only present in feeder 60. The fault is detected correctly, the relay on feeder 61 trips and the relay on feeder 50 does not.
- The second line shows the fault situation for a closed MV loop without SOP. In addition, for fault locations at longer distance from feeder 61, the fault current can be too low to trip the relay on feeder 61, which corresponds to a malfunction of the protection system. Even if an overcurrent relay with reliable settings were used in this case, the total duration of the short-circuit would approach 1 second, which in turn would certainly be unacceptable.
- The third line shows the fault situation when an SOP is inserted at the sectioning point. Since the SOP operates much faster (within the first half-cycle), there is no visible difference to the case of the open sectioning point shown in the first line of Figure 7. For this reason, the protection system operated in a satisfactory manner without any need for adjustments of settings or modifications to the protection concept

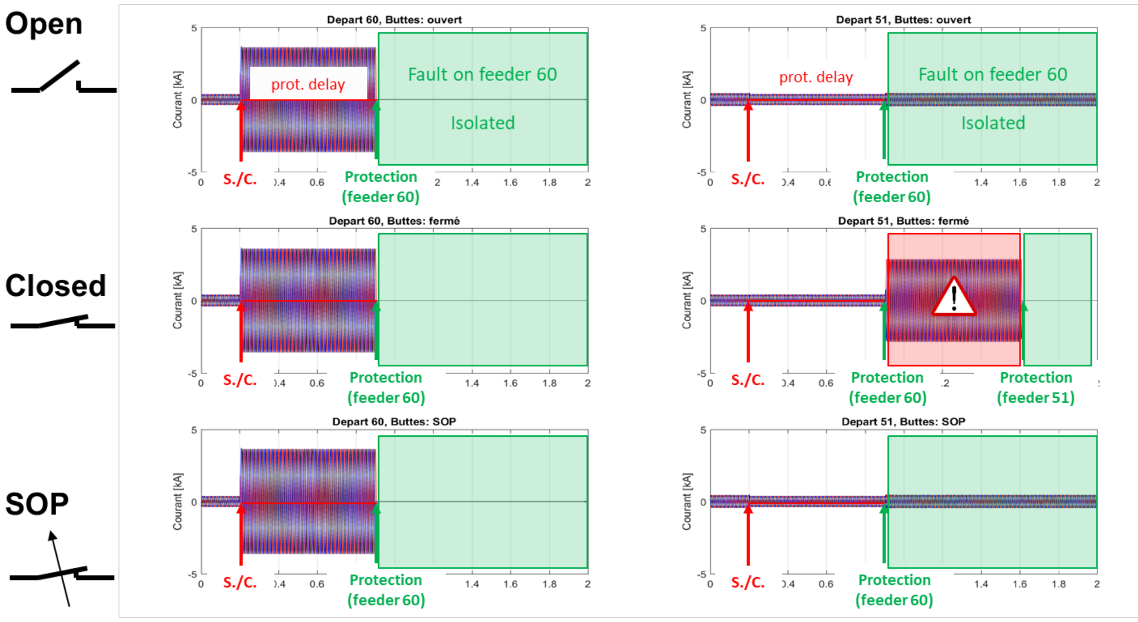

Figure 7: Illustration of the SOP operation as seen by overcurrent relays for a fault on feeder 60.

1.4.6 Concluding remarks

The results of the initial simulations and calculations confirm that the operation of the considered network at Rolle – Les Buttes is possible and that steady-state voltages are improved compared to the present situation. The considered network is relatively strong and conservatively designed, therefore the improvements are minor. The recently started investigation of the full-scale prototype has shown that the space requirements at the selected SOP location Les Buttes will be difficult to meet. Discussion have started with Romande Energie to find an alternative location.

1.4.7 References

Alstom Grid, "Hard facts about soft open points", http://www.think-grid.org/hard-facts-about-soft-open-points, 2015

J. M. Bloemink and T. C. Green, "Increasing distributed generation penetration using soft normally-open points," IEEE PES General Meeting, Minneapolis, MN, 2010, pp. 1-8.

J. M. Bloemink and T. C. Green, "Increasing photovoltaic penetration with local energy storage and soft normally-open points," 2011 IEEE Power and Energy Society General Meeting, San Diego, CA, 2011, pp. 1-8.

W. Caoa, J. Wua, N. Jenkins, C. Wang, T. Green, "Operating principle of Soft Open Points for electrical distribution network operation Applied Energy", Volume 164, 15 February 2016, Pages 245–257.

2 Achievement of deliverable:

2.1 Date

18.12.2017

2.2 Demonstration of the deliverable

The contents of this report has been discussed in several meetings with Romande Energie. The final meeting in this matter has be held as a teleconference on 18.12.2017.

3 Impact

The soft-open point and network models used in this activity are important in the preparation of the reduced-scale and full-scale demonstrator planned in the continuation of the project. A preliminary validation of the ratings of the SOP and the compatibility of the SOP concept with the existing protection philosophy of Romande Energie has been reached.

The contents of the report is now used for the discussions with potential industrial partners for the manufacturing of the full-scale SOP demonstrator.