FLEXIBLE NETWORK OPERATION

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ABSTRACT

This paper presents preliminary results from the research project "Flexibility in the future smart distribution network" (FlexNett). The project aims at contributing to increased flexibility in the distribution network through, among other measures, flexible operation of the distribution network. Flexibility is defined, in the project, as a situational and time limited response to an incentive, i.e. shortage of energy, interruption, or changes in energy prices. Flexible network operation can for example include using energy storage, remote control and automatization of network operation and voltage control, resulting in improved security of supply and voltage quality, and in some cases also postponement of reinvestments.

INTRODUCTION

A distribution network operator, like BKK Nett, holds a territorial concession and is obliged by the Energy Act [1] to deliver electrical energy to customers within the specified area. The level of continuity of supply is regulated through economic revenues regulation, and the voltage quality to be expected is specified by the Regulation on Quality of Supply in the Power System [2]. Both the public and industry is becoming more and more dependent on a high quality and reliable electricity supply. There is an increasing amount of available, and in some cases cost efficient, alternatives to fulfil the above-mentioned requirements. Examples treated in this paper are storage and automatic fault location, isolation and service restoration (FLISR) solutions.

The FlexNett-project have several demonstration activities for the participants to gain experience and increase knowledge about the different solutions available for increasing network flexibility. This paper reports on results from two demonstration activities at BKK Nett:

- Energy storage:
  - Installation of batteries to improve quality of supply and avoid costly reinvestment in an overhead line supplying a sports cafe.
  - Examination of voltage quality impact from a high power ferry charging station. The station has installed an onshore battery to prevent large voltage drops during the short charging periods.
- Testing of an automatic FLISR solution in a network exposed to harsh weather conditions during the winter (snow and wind) and weather-related failures. FLISR is expected to reduce System Average Interruption Duration Index (SAIDI). Personnel safety is also thought to be improved as automated switching will reduce the number of people and the time spent in the area for fault location and power restoration.

Relevant information, like cost of energy not supplied (CENS), will be recorded prior and after the different solutions have been installed and cost-benefit analysis will be performed for all of the cases and described in the paper. However, the sites selected for the battery package and FLISR solution are chosen due to R&D aspects for similar future deployments, other locations may have been chosen if cost-benefit were to be optimized.

ENERGY STORAGE

Today, batteries installed to smooth fluctuating production from distributed generation are the most common use of energy storage in the network. This can be small scale, i.e. at prosumers or in networks with large share of prosumers, or large scale, i.e. in relation with wind farms or large PV-plants. However, energy storage can also be beneficial for other purposes, and in FlexNett, two case studies that highlights some of these possibilities are examined.

Battery to improve power quality at Brushytten

Brushytten is a sports cafe that sells waffles, and a popular hiking destination located in the city mountains of Bergen. It is supplied by a 3 km low voltage line with small cross section area. Several measures have been performed to improve voltage quality: A 230/1000 V transformer at each end of the line has been installed, together with a voltage booster at the far end. In addition to voltage quality issues, the line often has faults. The faults are undetected until the weekend when the cafe is opened, when maintenance actions are expensive and impractical. Interruptions are also unpopular, as hikers must continue their trip without waffles.

A possible solution to the power quality issues is to build a HV line all the way to Brushytten, but at a very high cost. Another possibility is to install a battery system, both to even the load (increasing voltage quality) and to provide a backup during interruptions (increasing uptime).

To evaluate if a battery system is a better solution than extending the high voltage distribution network, a preliminary design of a battery system has been performed. Selecting availability requirements and mapping the load resulted in a requirement that the battery should be able to provide 12 kW over about 11 hours (130 kWh). The cost of this solution would be in the range of 150 k€, possibly making it a better measure than building HV-distribution network to the cafe, which would cost in the range of 200 k€. An investment decision will be made soon; if the investment is made the battery system will be operational in august 2017.

Mitigating voltage drops from challenging loads

In 2015, the world's first electric ferry, Ampere, was set in operation between Oppedal and Lavik in the western part of Norway. Ampere is powered by two 500 kWh batteries, that is charged on each side of the fjord between each trip. A trip takes about 20 minutes and consumes 200-240 kWh, which must be charged during the 10-minute docking period at each side. This results in a power requirement on over one MW in a weak network, and consequently voltage quality issues.

To cope with this issue, Siemens, the electric systems provider, installed a secondary battery onshore. This battery is charged for 50 minutes while the ferry is crossing, and discharges to complement the current from the network when the ferry is charging. Rather than providing over one MW in 10 minutes, the ferry dock is consuming roughly 250 kW continuously throughout the day, which does not result in too large voltage drops.

The topic of interest in FlexNett have been analysing the ferry chargers influence on voltage quality in the area. A high-powered battery system and a high power ferry charger are interfaced with power electronics, which potentially causes increased harmonic levels, flicker and other unwanted phenomena. It was therefore decided to perform voltage quality measurements at the ferry dock and nearby areas, to see if the ferry charger or battery system provided a negative influence on voltage quality.

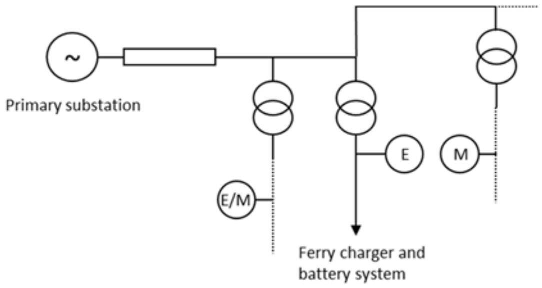

Figure 1 Network and measurement locations

A simplified sketch of the network supplying the ferry dock and other secondary substations in the area is shown in Figure 1. PQ-measurements were performed with a combination of Elspec G4500 (shown as E in the figure) which is capable of measurements up to the 500th harmonic, and Medcal N measurement instruments (shown as M in the figure) which are capable of measurements up to the 50th harmonic.

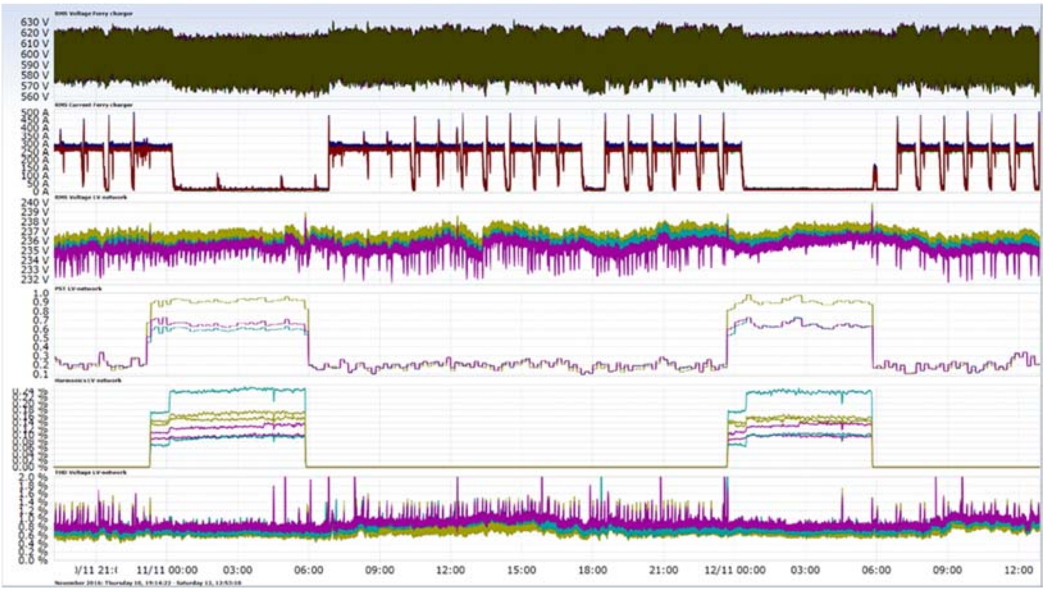

Figure 2 RMS voltage and current at the primary substation supplying the ferry charger, and RMS voltage, Pst-values, the 48th and 52th harmonics, and THD-values in the low voltage network

The measurements showed that the ferry charger and battery system did not cause a significant increase in harmonics. Although the harmonic levels were very high under the secondary substation that supplies the ferry charger and battery system (over 60 % line to earth, 4 % line to line), the transformer effectively damps these. Little noise is transmitted to the rest of the network; there was no visible increase in either of the two other measurement points when the ferry charger is consuming power. Figure 2 shows a summary of the most interesting parameters for the low voltage side of the transformer supplying the ferry charger and battery system, and for a measurement point in the low voltage network at the nearest secondary substation. Note that the large variation in voltage at the ferry charger is caused by measurement errors due to the high phase to earth THD, not actual variations.

Neither THD, flicker, nor the amount of rapid voltage changes were significantly affected by the ferry charger or battery system. Upon closer inspection it was found that at night when the primary substation supplying the ferry dock (battery bypassing) was not consuming any power, the flicker levels in the low voltage network increased significantly from 0,3 to 0,9. This is still within limits in the Norwegian power quality regulation. Upon analysing the times when the flicker levels increased and discussion with the ferry operator, it was found that the increase was caused by maintenance charging of the ferry. The maintenance charger was connected when the ferry was fully charged in the evening, and was supplied from a connection point below the 230 V substation supplying the nearby area, rather than the 600 V substation on the dock. Quite small values of the 48th and 52th harmonics were registered together with the increase, which was only registered by the Elspec instrument and not the Medcal instrument.

SELF-HEALING/FLISR

Self-healing is the capacity of electrical distribution systems to automatically restore themselves if a permanent fault occurs [3]. Self-healing can be achieved using automatic FLISR solutions. Figure 3 [3] illustrates the sequence of events from a permanent fault occurs until the fault is repaired. After a permanent fault occurs, localization is performed using fault indicators and relays. This can be done centralized or distributed depending on the ability of the indicators and relays to communicate with each other. Fault isolation and service restoration is performed either centralized/semi-centralized or distributed using a self-healing scheme. The self-healing scheme implies initiation of an automatic algorithm, among other things operation of switches, designed to isolate the fault and restore service for those not affected by the fault as fast as possible. A maintenance crew must repair the fault itself.

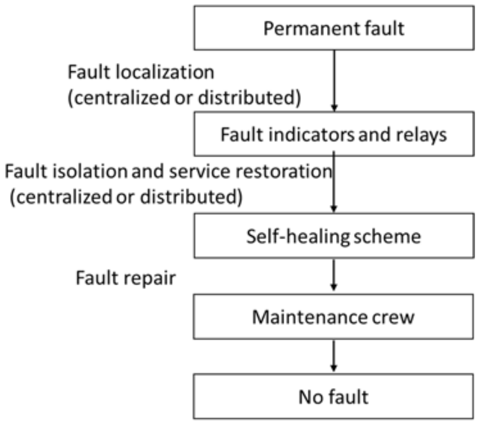

Figure 3 Sequence of events [3]

Compared to traditional manual methods the benefits of automatic FLISR can be:

- Reduction in interruption duration, SAIDI, and CENS which can defer reinvestments in the network; upgrading or cabling of existing overhead lines:
    - Reduction in the number of customers affected by the fault (rapid localization, isolation and restoration)
    - Reduction in the interruption duration (rapid localization) for those affected by the fault
- Improved personnel safety as there is no need for manual operation of switches and the location of the fault can be specified more precisely. Therefore, time spent outside in bad weather conditions are reduced and the risk of accidents and injuries is also reduced.
- Increase customer satisfaction and safety (faults are repaired more rapidly and third party access to i.e. faulty overhead lines is reduced).
- Reduced cost due to less working hours and travelling expenses related to fault localization and manual breaker operation.

Case: Eksingedalen

Eksingedalen is a 30 km long valley supplied from both sides. The valley is situated in a sparsely populated area, approx. two hours' drive from the main office of BKK Nett in Bergen. The 22 kV-network consists of overhead lines, which is exposed to harsh climatic conditions during wintertime.

Figure 4 is an illustration of the network in the area with the FLISR solution installed. Actual installation is planned in the spring of 2017. A to G are circuit breakers. After installation of a FLISR-solution, there will be eight different possible fault locations in the area and nine different points of division (including at the supplies). The area below point F in the figure has most faults today. Customer connected to point C has complained to the regulator about the number and durations of interruptions during the winter (the complainants did not get support from the regulator [4]. Table 1 provides

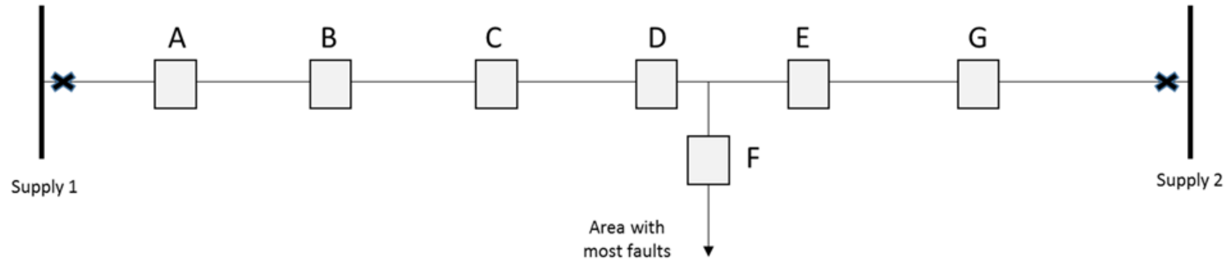

Figure 4 Network and location of circuit breakers (A to G)

information about the historical CENS, interruption duration and number of switching operations for the area shown in Figure 4.

Table 1 Historical CENS, interruption duration and number of manual switching operations

	2014	**2015**	**2016**
CENS, €	6900	9900	8300
Interruption duration, h	26	14,5	34
No of switching operations	6	9	6

The customers of Eksingedalen is experiencing long interruptions, especially in the wintertime. Travelling to the area for manual switching takes time and fault localization in bad weather conditions increases the probability of personnel injuries. All of this motivated BKK Nett to test a FLISR-solution in this area.

In Eksingedalen, a decentralized FLISR solution has been chosen. This solution is shown in Figure 5. In this type of FLISR solution the decision regarding isolation and (re) sectioning is made locally based on information exchanged between the FLISR units. The breaker status is sent to SCADA and DMS. Information is needed from the network information system (NIS).

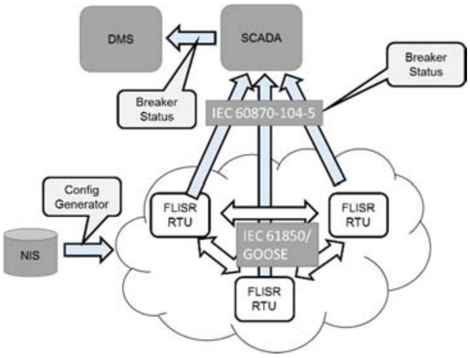

Figure 5 Decentralized FLISR solution

Cost/benefit of self-healing in Eksingedalen

The benefits of FLISR will be reduced interruption duration and CENS. The customers in the eight sections of Figure 4 will now only experience interruptions in the section they are connected. Previously, all customers experience all the interruptions no matter where the fault occurred. In addition, reduction in operational expenses (OPEX) is expected, as the need for manual switching operation is removed and fault location takes less time.

A conservative estimate can be a reduction of CENS by 7/8. In fact, the reduction can be higher, as the breakers are strategically placed where the probability of failure is highest (highest probability of trees falling over the lines). As finding the fault will be easier, the duration of interruption for the faulty section is reduced, estimated to 1/3. In addition, the OPEX is reduced as less time is spent searching for the fault and the time spent on manual switching is eliminated, from six to zero in Table 1 for 2016. This is summarized in Table 2.

Table 2 Costs and interruption duration before and after FLISR

Factor	**Before FLISR 2016**	**After FLISR Generally**	**After FLISR 2016 used as example**
CENS	8300€	7/8 reduction	1038 €
Interruption duration	34h	1/3 reduction for faulty section	11h
Cost of manual switching operations	2221€	0	0

In 2016 the savings would be 9 483€ and taking into consideration the increased customer satisfaction and the reduced need for the personnel of BKK Nett to be outside in harsh weather conditions to locate and repair faults, this is a good investment for the company. In addition, experiences is made with the equipment, both hardware and software. The equipment and installation of FLISR in Eksingedalen is estimated to 330 k€. Alternative solutions to reduce CENS could be to replace overhead lines with cable (impossible in practice due to topology), renew the overhead lines and pylons (the area has an ageing infrastructure), remove more trees (important root cause for faults), and increase emergency preparedness when the weather forecasts are bad.

CONCLUSIONS

Demo activities in FlexNett has shown that solutions enabling flexible network operations can provide good alternatives to traditional network reinforcements. BKK Nett considers it important to have experience with these solutions, so that they can be implemented when found beneficial.

Although still expensive, energy storage can be a good alternative to increase reliability in cases where power consumption is low and other mitigation measures costly. Gaining experience with using energy storage as backup power is also useful considering that battery prices are falling fast, and there are several cases where battery storage could be a feasible solution to mitigate challenges. Batteries can also be used mitigate voltage quality issues, and be used to postpone network reinforcements. Measurements performed after installation show that the negative voltage quality impact on nearby areas from the power electronics in battery chargers are small, but this is of course dependent on the power electronic design.

The case study also shows that self-healing solutions can be a good measure to reduce CENS, while providing other benefits such as increased personnel safety, freeing up personnel resources, increasing customer satisfaction, etc. Using Eksingedalen as a case study is a good way to build competence and expertise and make FLISR solutions easier to implement in other areas. It can be argued that utilities are becoming service providers rather than electricity providers, and it is therefore important that utilities are able to implement measures that increase quality of supply when desired.

MISCELLANEOUS

Acknowledgments

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