LVDC PILOT IMPLEMENTATION IN PUBLIC DISTRIBUTION NETWORK

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ABSTRACT

Reliability has become a more important issue nowadays and the demands of the new act will require major changes in the rural distribution network in Finland. Low voltage direct current (LVDC) distribution is a promising solution whose benefits are a large power transfer capacity with low voltage (LV), high cost saving potential and improvements to reliability and voltage quality. Previous studies have been showed that the LVDC distribution has a good utilization potential in rural distribution networks. The paper presents the unipolar point-to-point type of LVDC pilot implementation system, which has been implemented in co-operation with distribution system operator (DSO) Elenia Oy and ABB Oy Drives in March 2014. Purpose of the LVDC pilot is to gather long-term experiences of operation and maintenance and also specify life cycle costs of the system. The LVDC system has operated so far without any problems and experiences have been promising.

INTRODUCTION

In June 2013, a new Electricity Market Act was approved in Finland that will tighten the demands of reliability and customer compensation in case of long outages. The demands come into force in steps, but no later than after a period of 15 years the DSO's have to meet the demands that do not allow outages of over 6 hours in the urban planned area and of over 36 hours in other areas [1]. This concerns only outages caused by storm or snow load. In the last few years several major disturbances caused by natural phenomena have occurred. At the worst they have caused some customers to experience outages of several weeks. Therefore, the demands will require major changes in the distribution network, especially in rural areas.

During the next 15 years, investments in the rural medium voltage (MV) network focus on main lines due to the demands of the act [1]. Reliability of the main lines has the greatest impact on the duration of outages experienced by customers. After renovation of the main lines, mainly done by underground cables, the majority of branches, most of which have reached the end of their mechanical lifetimes, are still in their current state.

LVDC distribution is a promising solution for renewal work of the branch lines. Its main assets are high cost saving potential and improvements to overall reliability and voltage quality. In addition it provides an easy connecting point for the distributed generation and energy storages and develops distribution networks towards the smart grid. Moreover, the consumer based distortion and reactive current does not transmitted in the MV network. Thus, the LVDC decreases the stress of the MV network and releases capacity for active power transfer.

Due to a lack of long-term experiences of LVDC devices as part of a distribution network, a life cycle cost estimation of the system is challenging. Paper [2] presents one example of calculations for comparing life cycle costs of a traditional MV network branch to the costs of LVDC distribution. The paper concludes that LVDC distribution is an economical solution as a replacement of MV branch lines. In the last two decades, the price of power electronics has continuously reduced about 5% per year while the price of traditional passive components has increased significantly [2]. Thus, LVDC distribution offers a great cost saving potential for large-scale renovations of rural MV branches in the future.

This paper presents the unipolar point-to-point type of LVDC pilot implementation system, which has been planned in co-operation with Elenia Oy and ABB Oy Drives. In previous studies [3], [4] have been showed that the LVDC distribution has a good utilization potential in rural distribution networks. Elenia Oy and ABB Oy Drives implemented the first LVDC pilot in March 2010, which demonstrated the suitability of the LVDC technology as a part of the distribution network [5]. The second LVDC pilot, presented in this paper, is the next step in the research, the purpose of which is to gather long-term experiences of operation and maintenance and also specify life cycle costs of the system. Long-term experiences are essential when considering options for the large-scale renovation of the MV branches in the future. The point-to-point type of LVDC distribution, its utilization potential and advantages are described more detailed in the paper [4].

Elenia Oy is the second largest DSO in Finland with some 410,000 customers in a 50,000 km^2 geographical area. The market share of Elenia Oy is 12% and it has a distribution network of altogether over 65,000 km. Elenia Oy's distribution network consists mainly of sparsely populated areas, so the development of distribution technology is especially important in the rural area networks. Elenia Oy has decided to build all new network by cabling. The cabling rate of Elenia Oy is now 19% in

the MV network and 39% in the LV network, which means a total cabling rate of 32%. One of the main driver in distribution network development in Elenia Oy is to improve overall reliability of electricity supply. Elenia Oy has decided to raise its cabling rate to 70% during the next 15 years due to the demands of the act [1]. After this period of time, Elenia Oy has about 7,000 km of rural MV branch lines waiting for cost-efficient renovation.

STRUCTURE OF THE LVDC DISTRIBUTION

Power electronics enable several new network structures, of which a unipolar point-to-point LVDC system is the easiest option to replace a MV branch by LVDC from the perspective of the DSO. This is due to the fact that the present secondary transformer can be replaced by a centralized inverter when the LV network can be kept unchanged. This solution does not require changes at the customer's end like many other LVDC solutions as there is no need for an inverter for each customer. Fig. 1 illustrates the concept of the point-to-point LVDC distribution system, which is the main concept of research in Elenia Oy. [4]

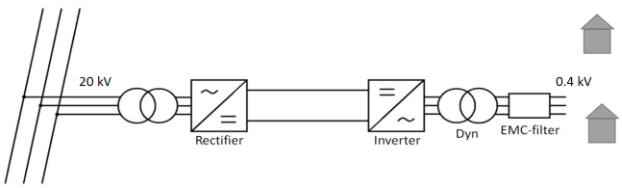

Figure 1. The point-to-point LVDC distribution system

PILOT IMPLEMENTATION SETUP

Pilot implementation is a point-to-point type of LVDC system, which was implemented in co-operation with Elenia Oy and ABB Oy Drives. It has been in operation since 05.03.2014 in Kylmäkoski, Finland. The system supplies two customers at the moment. The pilot implementation setup is presented in the Fig. 2.

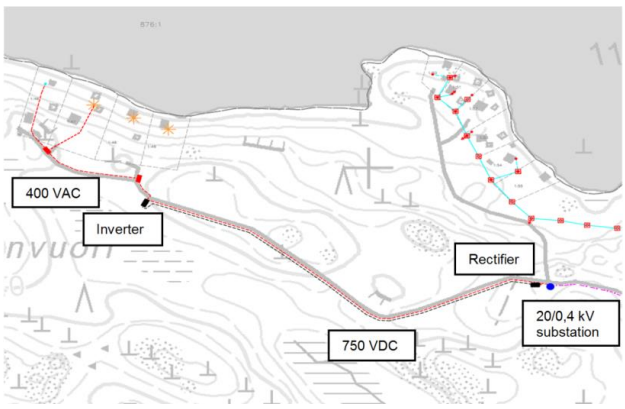

Figure 2. Field implementation setup of the pilot

Technical structure of the pilot setup

The pilot setup is implemented using the usual network components with the exception of a rectifier, an inverter and a DC-cable. Standard 20/0.4 kV distribution transformer supplies the rectifier and the inverter supplies a common low voltage alternating current (LVAC) distribution network with traditional fuse protection. Fig. 3 presents the structure of the pilot setup.

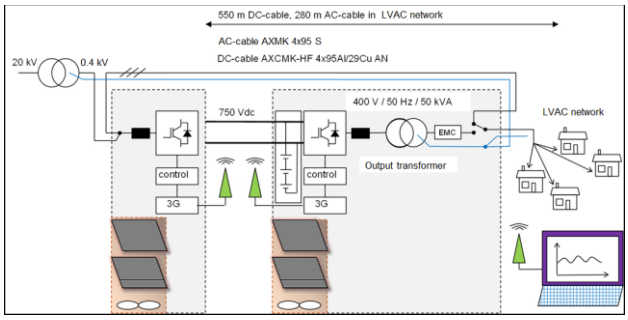

Figure 3. Schematics of the pilot setup.

Rectifier is a standard ACS800-11 module where only the bidirectional input power stage is used. The DC-voltage is boosted from normal 570VDC to 750VDC to minimize the DC-current and to maximize the available energy in DC-capacitor bank. Fig. 4 presents the cabinet of the rectifier and its contents.

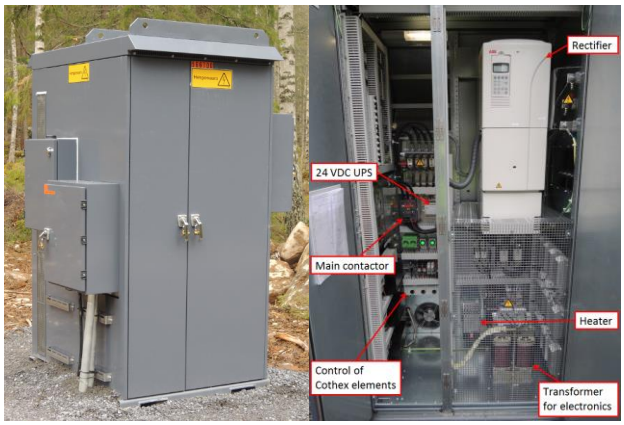

Figure 4. Cabinet of the rectifier and its contents

The cabinet of the inverter consists of a 150 kVA converter module, an output transformer and an additional DC-capacitor bank as energy storage. The output transformer is a normal dry Dyn distribution transformer with a static shield and 460/400V transformer ratio. The transformer prevents common mode disturbances from spreading to the LVAC network, decreases the conductive emission and makes an earthed star point for the single phase loads. High frequency conductive emission is limited with an EMC-filter in the output. The cabinet of the inverter is shown in the Fig. 5 and its contents in the Fig. 6.

Figure 5. Cabinet of the inverter

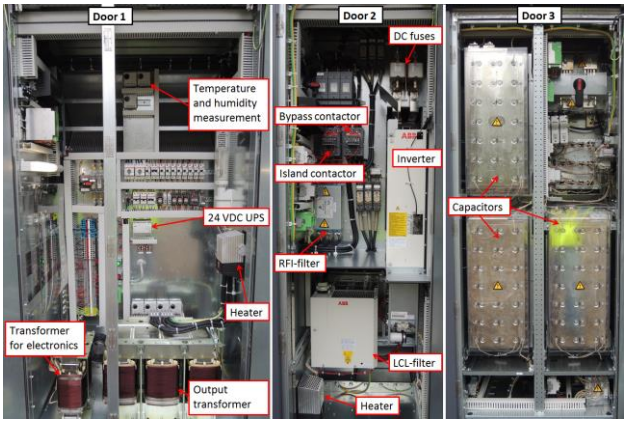

Figure 6. Contents of the inverter cabinet

Both the rectifier and the inverter cabinet are equipped with Cothex cooling elements. Cothex cooling uses closed air circulation and it is a new design of ABB for outdoor cabinets. The protection class is close to IP55. The air flow through the Cothex elements is controlled with fans and temperature sensors.

Both converters have 3G Phoenix modem and wireless communication to the service portal. The service provides access to measuring data, events and faults of the converters. Power supply for electronics is secured with +24V lithium-ion battery in both cabinets. The back-up time is about 15 minutes, during which the control boards are live and the 3G modem is sending data to the cloud service during outage.

The pilot setup includes also a bypass as a precautionary measure, which will automatically turn on during fault of DC devices ensuring electricity supply of customers. Bypass is implemented with a traditional AC cable. Table 1 summarizes the technical data of the pilot setup.

Table 1. Technical data of the pilot setup

20/0.4 kV input transformer, 50 kVA
ACS800-11 active rectifier, 60 kVA
Underground DC-cable, length 550 m, +750 VDC
ACS800 converter, 150 kVA
Additional energy storage, DC-capacitors 187 mF
Output transformer, Dyn, 50 kVA, 460/400V
Phoenix 3G modem and cloud service
ABB outdoor cabinets with Cothex cooling elements

Operation of the pilot system

The LVDC system starts automatically when MV network is connected to the supply side of the rectifier. The rectifier charges the DC-link, synchronizes to the network, starts modulation and boosts the DC-voltage to 750VDC. After the DC-voltage is charged, the inverter starts modulation automatically and ramps-up the AC-voltage to the reference value i.e. the start-up of the system is fully automatic and no human actions are needed.

During the outage of the supplying MV network, the rectifier is not tripping unless the voltage of the DC-link drops below tripping limit. The customers do not notice outage, as long as the voltage of the DC capacitors is high enough for inverter to maintain the island operation. Inverter starts limiting the AC-voltage when DC-voltage is not high enough for nominal voltage. Energy storage is supplying the customers until the voltage of the LVAC network drops 10% of the nominal value of 400V. The capacitance value of the energy storage is 187 mF and the inverter can maintain island operation about 10 seconds during outage of the supply network, when the load is 3 kW.

When outage of the supplying MV network is long enough that the inverter stops, supply turns automatically to bypass mode. Thus, the electricity supply to the customers start immediately when supply of the MV network recovers. After the converters have been started the inverter synchronizes to the bypass network and supply is switched automatically from the LVDC system. Normally, this takes a few seconds but it may be delayed due to frost or humidity. If during long time outage the inside temperature of the cabinet decreases below zero, the start-up of the converters is not allowed. In this case, heaters turn on and the converters start-up after the cabinet temperature rises higher than zero. The humidity sensor also prevents the start-up in case of condensing conditions inside the cabinet.

During short circuit in the LVAC network, the converter supplies only specified one-phase fault current of 250A, because the output voltage is limited to keep the current within safe limits of the power semiconductors. High

fault current supply capability allows normal operation of the fuse protection of LVAC network, but requires oversizing of the inverter compared to nominal power of the system.

Service portal

Both cabinets are equipped with Phoenix 3G modem, which sends data in one minute intervals in ABB service portal. At the moment the communication is only unidirectional, but it will be modified to bidirectional. Fig. 7 presents functionality of the service portal.

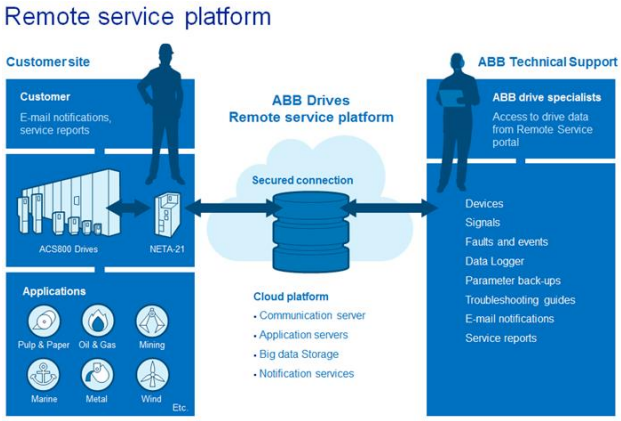

Figure 7. Functionality of the ABB service portal

Statistics of operation and the status of the converters are available through a web page. For example energy, current, voltage, power, reactive power and converter temperature can be monitored and plotted in a graph. Faults and alarms can also be monitored. Furthermore, the modem sends notice to the email in case of converter fault/alarm. The fault incident triggers converter data logger and signal data can be sent through the web service for analysis. Fig. 8 illustrates an example view of the graph of the portal service.

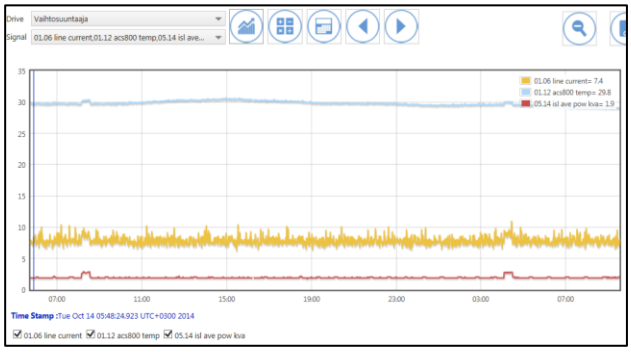

Figure 8. View of the signal page of the inverter on 14 – 15.10.2014. Current, temperature of the power stage and power are plotted on the graph.

MEASUREMENTS AND EXPERIENCES

Power quality

The software has specific features for power quality correction. It is possible to filter characteristic voltage harmonics and asymmetry generated by single-/two-phase loads and none-linear load. LCL-filter and DTC-modulation together with the output transformer and the EMC-filter in the secondary side guarantee low level of high frequency conductive emission.

According to measurements with 8 kVA load, the harmonic distortion THDU was 3% and individual voltage harmonics are within the limits of European standard EN50160. There is a clear difference between the supply trough bypass and the inverter. Natural frequency of the LCL-filter stands out from the harmonic voltage spectrum. Load characteristics of the LVAC network have a great effect on the voltage spectrum. Resistive load decreases the harmonics in the natural frequency range. Fig. 9 presents the harmonic voltages during measurements.

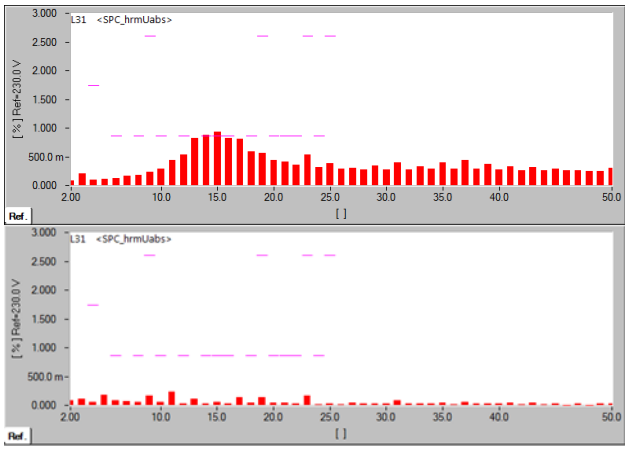

Figure 9. Harmonic voltages with 8kVA load. The top measurement is when the inverter is supplying the LVAC network and the bottom measurement is when the bypass is on.

Losses and efficiency

The losses and efficiency were not primary issue when developing this research platform. However, specific load, loss and efficiency measurements were completed in laboratory tests before the delivery. The LVAC network was loaded with 30 kW motor from idle to 35 kW. The losses and efficiency are calculated from the signals of the rectifier and the inverter. This laboratory test does not include the losses in long DC-cable. Fig. 10 presents the losses and efficiency calculated from the signals of the rectifier and the inverter.

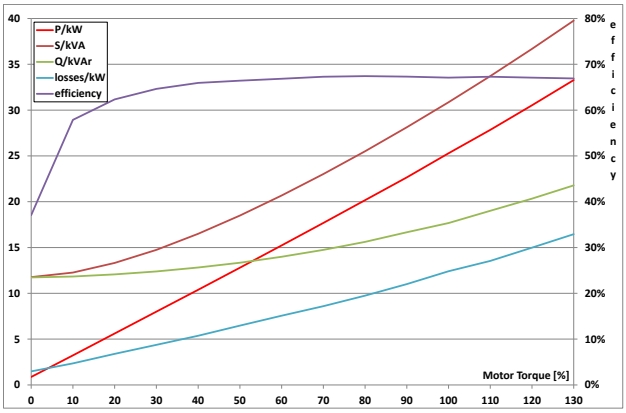

Figure 10. Losses and efficiency calculated from signals of the converters

User experiences

The LVDC devices have been in operation since installation and have supplied the customers faultlessly. There have not been any faults caused by the LVDC devices. Therefore, bypass has been in use only momentarily during start-up of the converters after outage of the supplying MV network.

During operating time, the LVDC system has experienced high-speed autoreclosings, time-delayed autoreclosings and a few longer interruptions of the supplying MV network. In all cases, the system has worked as planned and LVAC network has been supplied from the energy storage as long as the load situation of the time has allowed it. Customers have experienced not a single high-speed autoreclosing.

FURTHER WORK

The LVDC pilot system is designed as a research platform which allows versatile studying and testing of functionalities of the LVDC. It is also customizable if needed. During 2015 batteries will be added in the system, which allows much longer island operation in case of outage of the supplying MV network.

The main purpose of the LVDC pilot is to gather long-term user experiences of operation and maintenance, which will be collected and documented systematically. Based on experiences, the life cycle costs of the system will be specified and concept will be further developed in the future. In addition, the experiences will be utilized in optimization and simplification of the devices.

CONCLUSIONS

LVDC distribution is a promising solution for the renewal of MV branch lines. Its benefits are a large power transfer capacity with low voltage and improvements to reliability, voltage quality and cost-effectiveness. Pilot implementations have proved technical suitability of LVDC system as part of the distribution network.

Long-term user experiences will be gathered from the new pilot of Elenia Oy and ABB Oy Drives implemented in 2014, the basis of which the concept will be further developed in the future. The LVDC system has operated so far without any problems and experiences have been promising. According to measurements the voltage harmonics are within the limits of European standard EN50160. With DC-capacitor bank the customers' electricity supply is secured during high-speed reclosings of the MV network. In 2015 batteries will be added in the system, which allows much longer island operation.

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