POTENTIAL AND STRATEGIC ROLE OF POWER ELECTRONICS IN ELECTRICITY DISTRIBUTION SYSTEMS

Jukka LASSILA
Lappeenranta University of Technology (*)
Finland, jukka.lassila@lut.fi

Tero KAIPIA (*)
juha.haakana@lut.fi

Juha HAAKANA (*)
tero.kaipia@lut.fi

Kari Koivuranta
Fortum Distribution, Finland
kari.koivuranta@fortum.com

Jarmo PARTANEN (*)
jarmo.partanen@lut.fi

ABSTRACT

Electricity distribution technology is taking remarkable step by implementing the low-voltage DC-technology (LVDC) to the distribution networks. The first installations of this economical, transmission capacity and power quality increasing innovation in public electricity distribution will be done in coming years. Recent research results shows that there are remarkable potential and strategic role for LVDC technology in distribution networks, especially in rural areas.

INTRODUCTION

Reliable electricity distribution has become vital for the efficient functioning of modern society. The service reliability of electricity distribution in rural areas is most significantly influenced by the medium voltage (MV) network (10-20 kV), since more than 90 % of the outages experienced by customers are due to faults in the MV network. This network is mainly comprised of bare overhead lines, and it is exposed to weather effects. This is the situation especially in rural areas where the lines are radial fed (only few backup connections), feeder lengths are high and the lines are located in forests (Fig. 1).

Fig. 1. Traditional MV (20 kV) overhead line path (right of way) in rural area. Snow load is an acute when overhead lines are located in forests.

Since 90 % of the interruptions experienced by customers are caused by faults occurring in the MV network, the reliability of electricity distribution can be considerably improved by reducing the supply ranges, and thus also the ranges of influence of the faults. In Fig. 2 this problem in traditional medium voltage distribution network is presented. A fault in branch line affects whole feeder.

Fig. 2. One of the main problems in traditional medium voltage distribution network: A fault in branch line affects whole feeder.

LOW VOLTAGE DC SYSTEM

Present distribution network structure in rural area creates remarkable opportunities for power electronic applications in distribution systems. By utilizing low-voltage DC technology (LVDC), the low-power and fault-prone MV branches can cost-efficiently be turned to operate at DC low voltage (Fig. 3).

Fig. 3. A simplified structure of low-voltage DC system.

The number of faults and their range of influence are reduced significantly, since each branch implemented by DC technology forms a protection zone of its own, and consequently, in the occurrence of a fault does not affect the customers in the same MV supply range. While the maximum distance between the customer and the distribution substation in the traditional 400 VAC low voltage distribution remains below 1 km, the LVDC technology enables supply to the distances of several kilometres. According to the EU low voltage directive (LVD 72/23/EEC), any electrical equipment designed for use with a DC voltage rating between 75 and 1500 V DC is a low voltage instrument [1]. This includes also the
distribution systems. Technical limits for transmission capacities for different technologies are presented in Fig 4. It can be seen that the use of LVDC voltage in the same conductor magnify transmission capacity significantly.

Fig. 4. Transmission powers using 3x35+50 mm² low voltage cable in AC and DC distribution systems. Maximum voltage drop is 6 %. [2], [3]

POTENTIAL ANALYSES

Reliability and transmission capacity improvement described in previous chapter promise remarkable potential for LVDC-technology in electricity distribution. Before overall usability of the LVDC-technology can be estimated, there has to be economic potential analyses in actual networks. For this purpose, large distribution network was analysed. Target area of the analyses consists of six primary substation (110/20 kV) areas from Fortum Distribution Ltd. The company has distribution network activities in Finland, Sweden, Norway and Estonia as presented in Fig. 5. Information of target areas are also presented.

Fig. 5. Fortum networks and six primary substation case areas. All DC-case areas in this study are located in Finland.

Branch line classification

Number of potential places for LVDC system in traditional distribution network depends strongly on medium voltage network structure. LVDC-technology can be used especially when old MV branch lines has to be renovated because of aging and reliability. Amount of renovations because of the aging infrastructure is very common in coming years.

Instead of replacing old MV overhead line and pole-mounted distribution substations with traditional solutions, LVDC systems can be used in many cases. Example of MV network (20 kV) and branch lines is presented in Fig. 6. In the figure, those 20 kV MV branch lines are marked, where the transmission distances and loads are feasible for LVDC systems. It can be seen that the network structure and thus reliability will be changed radically if the network renovation can be carried out with LVDC systems.

Fig. 6. Potential of a DC system in a medium-voltage electricity distribution network and an example branch line.

There are several possibilities for analysing branch line structures. In this study, branch line types were divided for seven basic structures presented in Fig. 7. In previous picture presented branch line would be in this category no. 2 (two distribution substations in the same branch line). More complicated and extensive branch line structures did not taken into account in this analyse.

Fig. 7. Different types of 20 kV medium voltage branch lines and distribution substations.

Sorting of the branch line types was done using the special program created by researchers. The program goes through the network database separating medium voltage main lines from branch lines. Sorting was done for six primary substation area presented in Fig. 5. The results of this analyse are presented in Fig 8.

Fig. 8. Length of different types of MV branch lines in target area. Total length of MV network in target area is 1229 km.

It can be seen from the Fig. 8 that focus can be set on
branch line structure, where exists only one or two distribution substations. The target area consists of 1229 km of MV-lines of which 36 % (447 km) is branch lines. There are total 1132 distribution substations (20/0.4 kV) of which 65 % are located in branch lines. It this study focus has been on MV branch line type 1, 2 or 3 (see Fig. 8) which represents 46 % (= 205 km) of all MV branch lines.

Fig. 9. Medium voltage line structures in the target area.

ECONOMIC OR NOT?

Next, traditional overhead line, covered conductor (CC) and MV-underground cabling (UG) technologies are economically compared to LVDC-system. The case network is 1.0 km MV-branch line with one 20/0.4 kV distribution substation and five low-voltage customers (10 kW/customer) as presented in Fig. 10. Investment costs include line (MV and LV) and distribution substation investments. Outage costs are based on official nationwide Energy Market Authority (EMA) outage cost parameters.

Life-time costs of different network structures are presented in Fig. 11. It can be seen that outage costs are in remarkable role in traditional solution. On the other hand, power electronics investments are in huge role in LVDC-solution. It is assumed that DC/AC-inverter costs 2000 €/pcs. and they are installed to all five low-voltage customers. Price estimation of inverters is a little bit pessimistic. It is assumed that inverters are updated after 15 years.

Fig. 10. Comparison of network structures (LVAC vs. LVDC).

It can be seen that the traditional 20 kV OH-solution and LVDC-solution have similar lifetime costs when renovated medium voltage branch line is 1 km. Costs are strongly dependent on length of branch line. Sensitivity analysis is presented in Fig. 12. It can be seen that savings in total costs increase significantly when MV-branch line is longer than 1 km. For instance if renovated MV-branch line is 2 km, life time savings are approximately 10 k€/km with LVDC technology, which means 20 k€ savings for whole 2 km branch line. In the same figure lengths of actual 20 kV branch lines in target area are presented. Target area consists of six 110/20 kV primary substations (Fig. 1). Selected branch lines are type 1, 2 or 3 (Fig. 8), which means there are one or two 20/0.4 kV distribution substation in the same MV-branch line. Amount of this type of branch lines in target area is 205 km of all 447 km MV branch lines. Approximately 16 % of branch lines are in economical area when LVDC is compared to 20 kV OH-line and 24 % when LVDC is compared to 20 kV UG.

Fig. 11. Comparison of costs of network structures (Fig. 10).

Amount of potential targets are strongly dependant on price of power electronics (see Fig. 11). If DC/AC—inverters cost is halved to 1000 €/pcs, economic curves and number of potential targets are as presented in Fig. 13. Curves are presented now with relative (%) values. For instance if renovated branch line is 1 km long and alternative for 20 kV underground cable is LVDC, savings in total costs are around 25 %.

Fig. 12. Comparison of network structures (LVDC vs. OH-line, CC-line and UG-cable) and amount of actual targets [km] in case area (poles in figure). (DC/AC-inverter = 2 k€/pcs.)
CIRED 20th International Conference on Electricity Distribution
Prague, 8-11 June 2009
Paper 0682

RESULT AND CONCLUSION

The DC system provides an opportunity to low-voltage and high-capacity underground cabling of the distribution network at a reasonable cost which reduces the risk of wide black-outs. It is estimated that in this particular example network, the number of faults experienced by the customers (SAIFI) would be cut tens of per cents. In addition to that, a LVDC system improves the voltage quality experienced by customers and the filtering of voltage disturbances. There are economic incentives for the LVDC system because of smaller cross-sections of cables needed in the LVDC compared with the traditional 400 VAC low-voltage distribution. Also the higher transmission capacity in the low-voltage network would decrease the number of distribution transformers. Thus, a LVDC system not only gives a possibility to improve reliability and voltage quality but also to improve economy.

On the case area, from all MV-branch lines (447 km) - 16-30 % can be economically replaced with LVDC when alternative is MV-OH - 19-31 % can be economically replaced with LVDC when alternative is MV-CC - 24-34 % can be economically replaced with LVDC when alternative is MV-UG

A range is depending of the unit price of DC/AC-inverter (2 or 1 €/pcs.) and if the major storm cost component (2150 €/km) is included or not. From outage cost point of view, benefits are 0.7-1.3 M€ in the whole case area depending of total length of branch line renovation. Lifetime outage costs in whole case network are 12 M€ so saving is around 10 %. Same outage cost saving could be get with 20 kV medium voltage underground cabling but in that case investment costs would be significantly higher.

REFERENCES


BIOGRAPHIES

Jukka Lassila was born in Ilomantsi, Finland, February 1975. He received his M.Sc. degree from Lappeenranta University of Technology in 2000. Since then he has been a research engineer and a post-graduate student at Lappeenranta University of Technology. His main area of interest is long term developing of electricity distribution systems.

Jarmo Partanen was born in Ilomantsi, Finland, November 1956. He received his M.Sc. and Dr. of Engineering degrees in electrical engineering from Tampere University of Technology in 1980 and 1991, respectively. From 1984 to 1994 Jarmo Partanen was first an associate professor and then a professor of electric power engineering at Tampere University of Technology. Since 1994 he has been a professor of electric power engineering and the head of electrical engineering laboratory at Lappeenranta University of Technology. At present he is the vice rector responsible of reseach of University, too. His main areas of interest are
electricity distribution systems and open energy market.