POTENTIAL OF POWER ELECTRONICS IN ELECTRICITY DISTRIBUTION SYSTEMS

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ABSTRACT

Electricity distribution technology is taking remarkable step by implementing the low-voltage DC-technology 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 for low-voltage DC 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, such as windstorms and snow loads that cause faults and interruptions in the electricity distribution. This is the situation especially in rural areas where the lines are radial fed (only few backup connections), feeder lengths are high (10-100 km) 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.

In many cases, the only reasons for the use of MV level in rural area are the long distances between the primary substations and the end-customers, not the level of loads. 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.

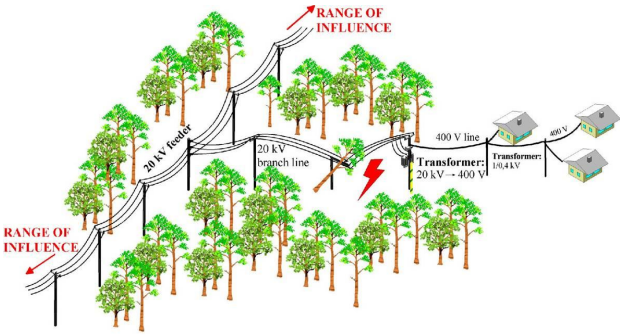

Fig. 2. One of the main problems in traditional medium voltage distribution network: A fault in branch line affects whole feeder.

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. A simplified idea of LVDC-system is presented in Fig.3.

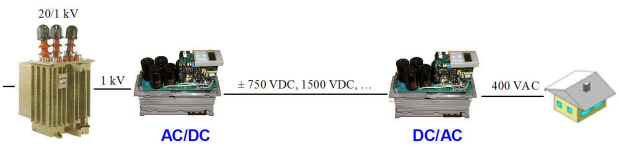

Fig. 3. A simplified structure of low-voltage DC system.

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.

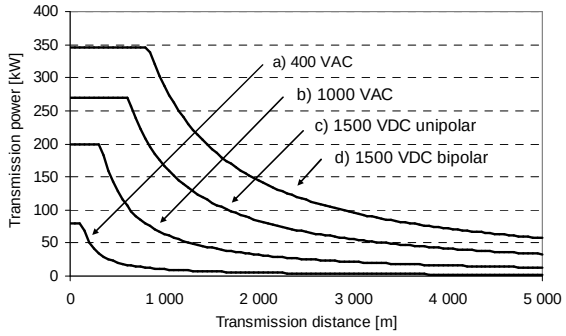

Fig. 4. Transmission powers using 3x35+50 mm^2 low voltage cable in AC and DC distribution systems. Maximum voltage drop is 6 %. [2], [3]

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.

	20 kV lines [km]	Customers	20/0.4 kV DS [pcs.]	20 kV Disconnectors [pcs.]	Peak load [kW]	400 V lines [km]
1 Isojoki	244	1 732	216	134	4 474	262
2 Isosyöte	255	1 485	188	41	5 819	291
3 Kyrö	184	2 104	197	216	216	356
4 Moisio	160	4 483	217	233	233	488
5 Taalintehdas	224	1 514	160	29	2 739	389
6 Virkkala	162	2 519	154	66	6 980	344
Total	**1 228**	**13 837**	**1 132**	**719**	**20 462**	**2 130**

PS = 110/20 kV primary substation
DS = 20/0.4 kV distribution substation

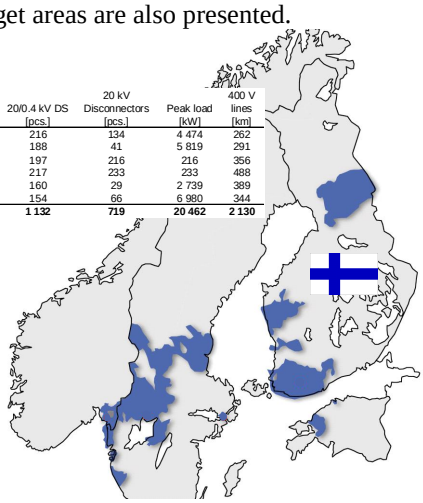

Fig. 5. Fortum networks and six primary substation case areas. All DC- case areas in this study are located in Finland.

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, can be done.

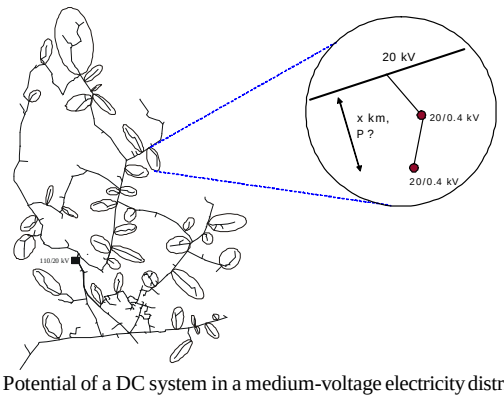

Fig. 6. Potential of a DC system in a medium-voltage electricity distribution network and an example branch line.

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.

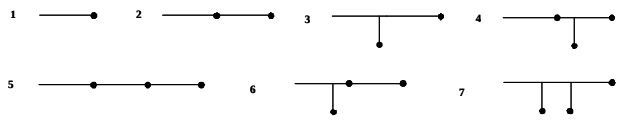

Fig. 7. Different types of 20 kV medium voltage branch lines and distribution substations.

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.

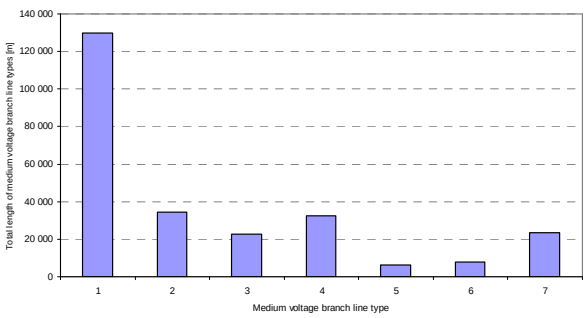

Fig. 8. Different types of medium voltage branch lines in target area. Total length of medium voltage network in target area is 1200 km.

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. This makes easier to estimate economicality of LVDC-system in distribution substation.

Structures of 400 V low voltage networks vary a lot in distribution districts. In Finland traditional low voltage network is three-phase system where main voltage is 400 V. In the target area low voltage network (total 2140 km) is mainly aerial bundled line (68 %) structure. The rest are underground cable (31 %) and bare overhead line networks (1 %). Typical maximum distance in planning in traditional 400 V three-phase low voltage network is 500 m. Example of customer locations in distribution districts is presented in Fig. 9.

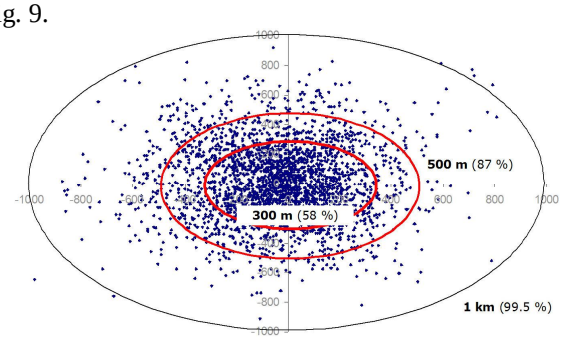

Fig. 9. Locations of 400 V low voltage customers in distribution substations. 20/0.4 kV transformer is located in the origin. Data includes 200 pcs. of 20/0.4 kV distribution substations and 2800 customers.

CASE DC-NETWORK

Economicality of LVDC-technology can be illustrated by following case (Fig. 10) [4]. Existing 20 kV bare overhead line network and 400 V aerial bundled cable network is presented. The network has to be renovated because of aging and weak reliability of 20 kV branch line. The question is what kind of technical solution should be used?

Distance from 20 kV main line to the 20/0.4 kV distribution transformer is 1.4 km and peak power is 35 kW. There are five low voltage customers in the network. Maximum distance from the distribution substation to the customer is 780 m.

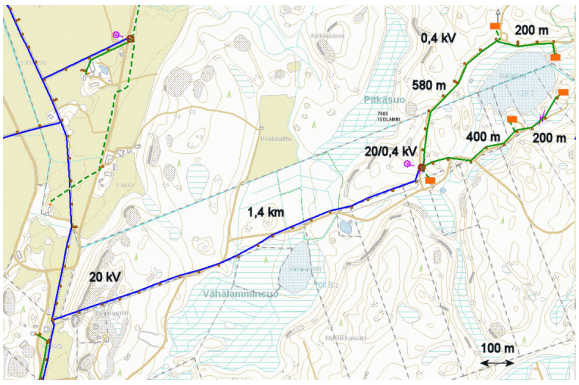

Fig.10. An example network: Existing 20 kV overhead line network and 400 V aerial bundled cable network. Distance from 20 kV main line to the 20/0.4 kV distribution transformer is 1.4 km.

LVDC technology could be utilized by following way. First, new 20/1 kV transformer is installed to the location where old MV branch line start. There 1 kV AC-voltage is converted to ±750 V DC-voltage. New LVDC line is built along the road by aerial bundled or underground cabling. Rest of the network, the old LV network, is underground cable. In this case all customers have their own inverter.

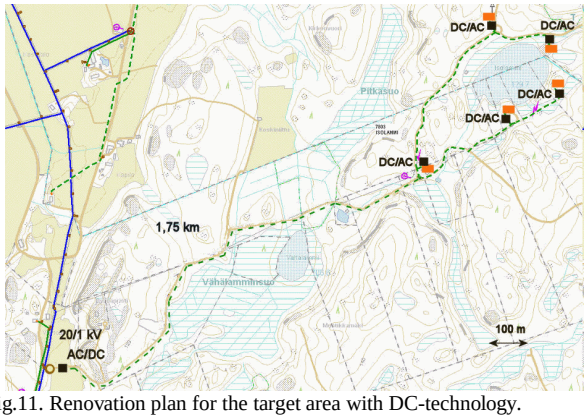

Fig.11. Renovation plan for the target area with DC-technology.

Investment comparison

Investment comparison is presented in Fig 12. Total cost of the LVDC system is lower compared to the situation where renovation is done using traditional methods. In the comparison investment costs, operational costs (losses, maintenance, fault repairing) and customer outage costs are taken into account. In LVDC solution life-time of the power electronics is used 15 years (40 years for traditional network components). In this case also costs of 1 kV AC-technology is presented. 1 kV technology is widely implemented in Finnish distribution companies [5].

Remarkable benefit of the LVDC and 1 kV AC-technologies are their capability to create own protection area. Faults in low voltage network do not affect MV network. This decrease outage costs in electricity

distribution. Also investment costs of the cables are significantly lower in low voltage level compared medium voltage. Because of the better power transmission capability in the DC systems, smaller and cheaper cross-sections can be used compared other low voltage systems.

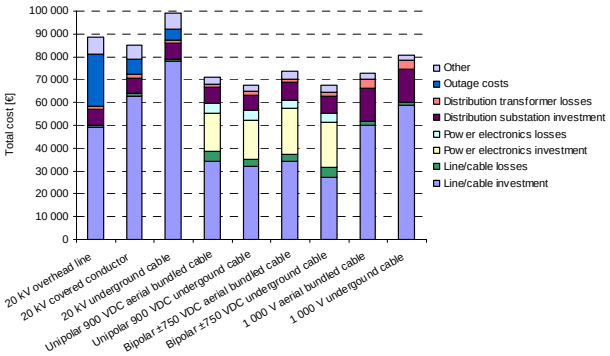

Fig. 12. Cost comparison of the case.

Cost analysis and economical limits for LVDC system is discussed in more detail in [3]. As in traditional long term network developing process, also in DC-network cost analyses are base on optimization between investment costs, operational costs (losses, maintenance, fault repairing) and customer's outage costs [6]. Economic curve for DC-system is presented in Fig. 13. In the same picture actual medium voltage branch lines (potential targets for DC-technology) are presented. It can be seen that many of the branch lines are suitable (length, power) for DC-technology from economic point of view.

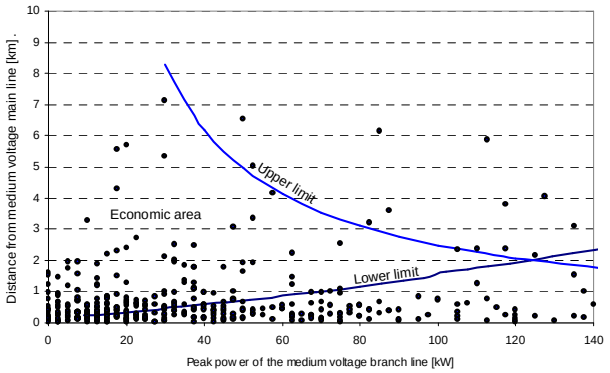

Fig. 13. Economical area for LVDC-technology and actual MV branch lines.

CONCLUSIONS

The latest research indicates that there is remarkable potential for the use of DC systems; in some cases even more than 50 % of the present MV systems could be replaced with LVDC systems (for instance ± 750 VDC).

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 blackouts. It is estimated that in this particular example network, the number of faults experienced by the customers (SAIFI) would be cut at least by half. 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 and energy efficiency.

REFERENCES

[1] European Commission. Low Voltage Directive LVD 2006/95/EC. European commission directive: Brussels 2006.

[2] Salonen P. *Exploitation possibilities of DC in electricity distribution.* Master's thesis. Lappeenranta University of Technology, Lappeenranta 2006. [In Finnish]

[3] Kaipia T., Salonen P., Lassila J., Partanen J. Possibilities of the Low Voltage DC Distribution Systems. *Nordac, Nordic Distribution and Asset Management Conference* 2006. Stockholm.

[4] Voutilainen V. *Determining the potential of DC distribution.* Master's thesis. Lappeenranta University of Technology, Lappeenranta 2007. [In Finnish]

[5] Lohjala J., Kaipia T., Lassila J., Partanen J. Lappeenranta University of Technology, Overview to Economical Efficiency of 1000 V Low Voltage Distribution Systems. *NORDAC, Nordic Distribution and Asset Management Conference* 2004, Finland.

[6] Lassila J., Kaipia T., Partanen J., Lohjala J. New Investment Strategies in the Modern Electricity Distribution Business - Reliability in the Long-Term Planning. *IEEE PES general meeting*, Tampa, Florida, USA 2007.

VI. 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 research of University, too. His main areas of interest are electricity distribution systems and open energy market.