DETERMINATION OF LVDC SYSTEM'S ECONOMIC PENETRATION RATE IN MV BRANCHES

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ABSTRACT

The demand for higher quality and reliability of power distribution system, role of distribution system in reducing losses and pollutions have increased requirement for utilization of power electronic devices in distribution systems. LVDC system is one of the newest technologies in the field of distribution networks. In this paper, LVDC system's economic penetration rate in MV branches is studied for different load densities, types and different influences of distributed generation units in multiple configurations. Simulation results are obtained by using MATLAB software on a hypothetical network.

INTRODUCTION

Proliferation of DC output type Distributed Energy Resource (DER) units in the utility power systems, mostly at the distribution voltage levels, and also recent advancements in the power electronics devices have motivated the integration of DC microgrids as an integral part of AC grids [1]. Technical and economical developments during last decades have established opportunity to create a new competitive distribution system based on modern power electronic technology. From technological point of view the LVDC system is a new concept in field of electricity distribution [2].

In this paper, LVDC system's economic penetration rate in MV branches has been studied for different load densities, types and different influences of distributed generation in multiple configurations. First, the number of costumers increases in each load point of the AC system. Then, the cost of this increased load is calculated according to criteria that are described blow. The same work is done for different distributed generation influences and also in unipolar and bipolar LVDC systems. In addition to calculating the LVDC system implementation cost, replacing these systems with MV feeder lines are also studied, and for each of this replacement, costs are calculated again.

By comparing the calculated cost with the cost of the AC system, we could find the rectifier economic location in beginning of the LVDC system, in other words, economic penetration rate of this system. Also this work is done for different kinds of customers.

LVDC SYSTEM'S CONFIGURATIONS

An LVDC distribution system constructs of power electronic converters and DC link between these converters [3]. Converters that are used in LVDC systems, form main structure of these systems and can provide customers voltage control and system management capabilities [4]. LVDC distribution system can be made with two basic implementations; unipolar 1500 VDC and bipolar ±750 VDC system. The differences between two connections are the number of voltage levels that costumers could connect to them. In unipolar system, only one voltage level is used for power transmission and all of customers are connected to system through this voltage level [5-6]. Unipolar LVDC system is shown in figure 1.

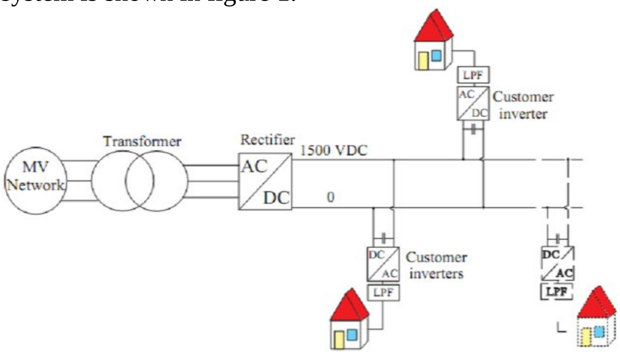

Fig. 1 Unipolar LVDC distribution system.

Bipolar LVDC system is formed by series connection of tow unipolar systems. In this system, customers can connect to network in different ways [7]. Bipolar DC system with various possible connections is shown in figure 2.

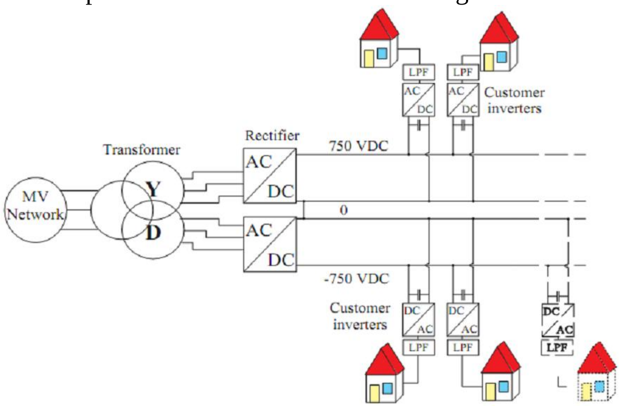

Fig. 2 Bipolar LVDC distribution system.

Recent researches [5-8] have shown that LVDC systems utilization increases power transmission capacity. This capability is result of higher voltage levels utilization and different LVDC system configurations. So, with regard to this increased power transmission capacity, MV branches substitution by LVDC system will be possible [8]. MV branches replacement will reduce distribution network cost and customers interruption number, and so network reliability will be improved. Also, this replacement causes simplicity of network topology, fault location detection and faster isolation of this area [4].

COST FUNCTION

In this study, cost function is composed of five terms, including costs related to system reliability, losses, equipments, power quality and equipments replacement costs over the life cycle and relevant economic factors. Mentioned cost function is constructed with converting fix and variable cost of loss and reliability to present value during study period.

$$C_{Total} = C_R + C_L + C_E + C_P + C_F \quad (1)$$

Reliability cost is calculated by contingency analysis method during study period and includes cost of no sale of electrical energy during network interruption and customers' damage due to this interruption. To calculate these costs, Energy Not Supplied (ENS) index and Customer Damage Function (CDF) is used. This can show impact of customers' type on LVDC system's economic penetration rate.

Losses include power losses in cables, network lines, transformers and rectifiers that system begin whit it and inverters. To calculate the power losses in the cables and network lines, first each costumers load is determined. Then considering systems type, its voltage level and KCL laws utilization, lines and cables currents are calculated. Finally, assuming constant voltage control strategy in rectifiers, retaining voltage and current ripple in very small values with capacitors and reactors that are used, losses can be calculated.

Equipment costs include the cost of LV cables, transformers, MV lines, and cost of required power electronics converters that are used in various system configurations, LVDC unipolar, bipolar and traditional AC system. With currents flow calculation, considering systems type, its voltage level and regarding of equipments thermal limit, we can select the cables and lines cross section and capacity of transformers, and converters.

Utilization of Power electronic device needs equipments to customer voltage filtering, power quality improvement and reducing losses due to produced harmonics [7-8]. Power quality costs include cost of filters that are used to reduce generated harmonics in different LVDC system configurations and cost of capacitors used to reduce the amount of current and voltage ripple and keeping them in allowed range. For calculating these equipments, a method that introduced in [7] is used.

In the end, replacement cost of devices that used with regard to their lifetimes, considering same interval for both systems, calculated and added to the previous costs. Also, reliability and loss costs must be converted to present value and then added to other costs.

CASE STUDY

Hypothetical network consists of one 20 kV MV main line and 50 MV branches that connected to 400 volt AC distribution systems through 20/0.4 kV transformers. This network is shown in figure 3. The length of each MV branch between two nodes is 5 km and length of each part of low voltage cables between two nodes in secondary system is 300 m. To protect the main MV line, one circuit breaker is used after 63/20 kV transformer. For faster recovery time during fault condition, disconnect switches are used between all MV branches.

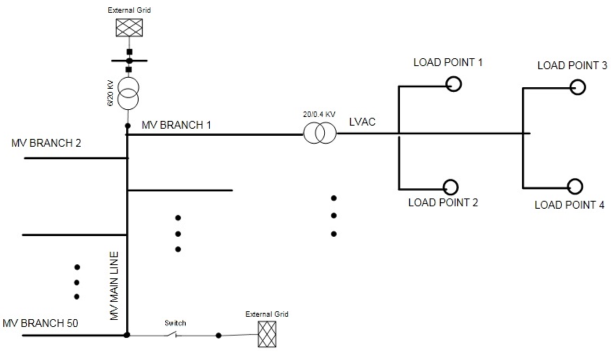

Fig. 3 Case study

Fault occurrence in a LV network hasn't any influence on other LV distribution systems. There are four load points in each LV network and each load point consists of some costumers. Overhead lines and cables are used in MV branches and LV network, respectively. Combination of 20/1 kV transformer and rectifier are used in DC system instead of 20/0.4 kV transformer. Also, single phase and three phase inverters are used in DC system as needed. In this paper hypothetical monetary unit, R, is used.

Cost of energy and loss assumed as 1810 and 200 R/kWh, respectively. Furthermore, customer interruption cost per kilowatt-hour is considered 1000 R/kWh and 10,000 R/kWh for residential and industrial respectively, but it could be calculated with CDF curves if it is necessary. MV lines and LV cables failure rates are considered 0.03 and 0.02 f/year.km respectively, and their repair times are considered 4 hour per fault. Rectifiers and inverters failure rates and repair times are considered 0.3 f/year and 1.5 hour. Also, load retrieval is done during one hour through neighbour network; each load point initial quantity is 50 kW, customers' power factor is 0.9 and study period is 10 years. Interest and inflation rate are assumed as 18% and 15%, respectively. Other parameters are similar to reference [4-8].

RESULTS

In this part, LVDC system implementation effects on system reliability, losses and equipment cost are investigated and then, LVDC system economic penetration rate in MV branches is obtained for residential and industrial loads.

Effect on system reliability

Number of equipments will increase with LVDC system implementation in distribution network and so system reliability not only will be improved with this work, but will decline. Reliability of system will improve by increasing LVDC network penetration in MV network and replacing MV branches with it. Because fault occurrence in MV network causes all loads interruption and with this replacement, both number of this interruptions and also number of affected customers will decline. During fault condition in bipolar LVDC system, only half of customers will have interruption and so bipolar LVDC system reliability will be greater than unipolar system. However, if the numbers of customers or their loads increase, cost of reliability will have more reduction and profit of reliability improvement will increase. These results can be seen in figure 4 and 5.

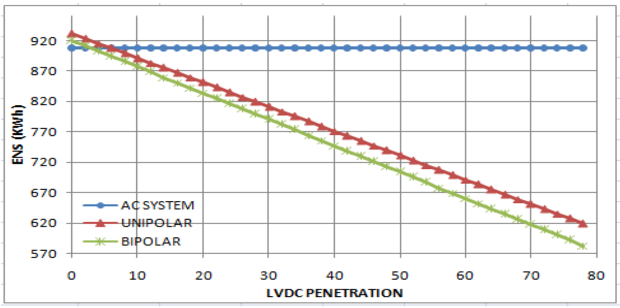

Fig. 4 LVDC effect on ENS with specified load density

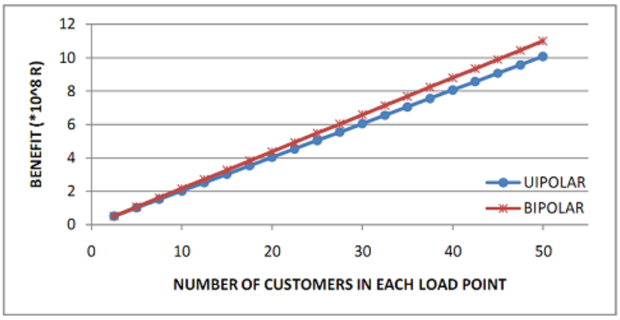

Fig. 5 Obtained profit, considering 20 percentage penetration of LVDC system.

Effect on system losses

There is no reactive current in LVDC network and so current magnitude reduces in this network. Also cables resistance will decrease due to elimination of skin and proximity effects of AC current. With utilization of same cables for both networks, losses will be reduced. With regard to higher voltage utilization in MV branches rather than LVDC systems, losses will be increased by MV branches replacement with LVDC network. Also, losses in bipolar LVDC system is greater than unipolar system because higher voltage utilization in unipolar LVDC system. This result is shown in figure 6.

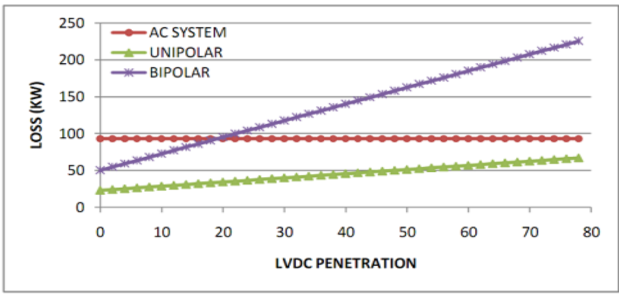

Fig. 6 Systems losses with considering specified load density.

Effect on equipment cost

With LVDC systems utilization and elimination of reactive current, current magnitude will decrease and so equipments with lower capacity are required. By increasing LVDC system penetration rate, expensive MV line is replaced with cheaper LV cables and so system equipment cost will decrease. In Bipolar LVDC system, expensive converters are required rather than unipolar system, so equipment cost in bipolar system is greater.

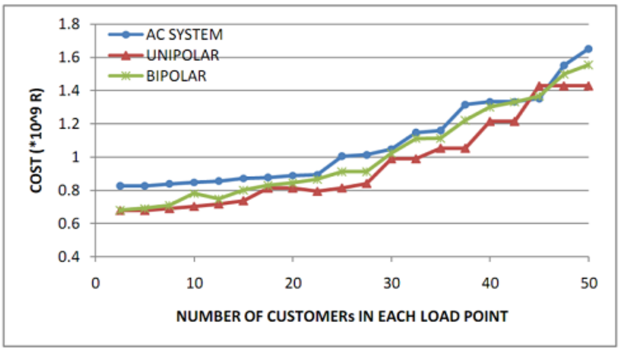

Fig. 7 Equipment cost considering 20 percentage LVDC penetration.

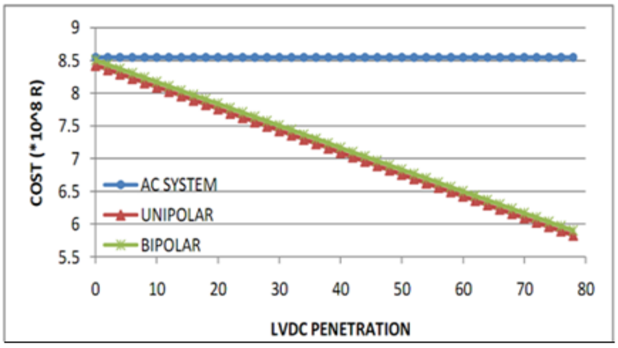

Fig. 8 Equipment cost considering specific load density.

ECONOMIC LVDC PENETRATION RATE

In this part, minimum LVDC penetration rate will determine until LVDC systems utilization will be economic considering different kinds of load. For low load densities, system losses and reliability cost are not so different in unipolar and bipolar LVDC systems, and so, minimum economic LVDC penetration rate is almost same for both configurations. In heavy loads, reliability cost differences between these configurations will be higher, considering previous results, minimum economic LVDC penetration rate in bipolar systems is lower than unipolar systems and utilization of bipolar system will be economic with lower penetration rate. For various kinds of loads, system reliability cost will be different and so profit of LVDC systems penetration will be greater for loads with higher CDF. In other words, LVDC systems utilization will be economic in lower penetration rate, for these loads. This issue is more obvious in bipolar system that has higher reliability. These results are shown in figure 9.

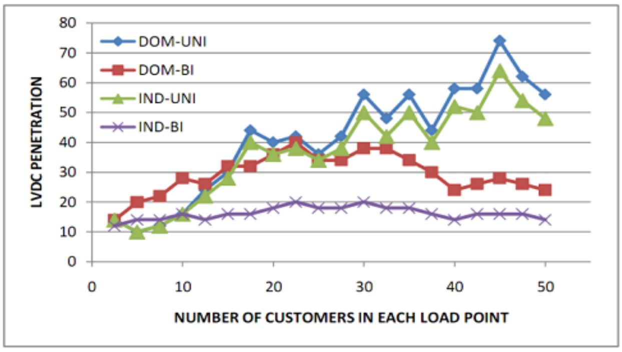

Fig. 9 Minimum economic LVDC penetration rate for domestic and industrial loads.

Now suppose there is one Distributed Generation (DG) in each low voltage network and suppose that their maximum capacities are lower than load capacity in each district. DGs penetration rate in low voltage network can impact on economic penetration rate of LVDC systems. This issue is shown in figure 10. As seen from this figure, if DGs penetration rate increase, minimum LVDC penetration rate will decrease. In other words, LVDC systems utilization will be economic in lower penetration with presence of DG units.

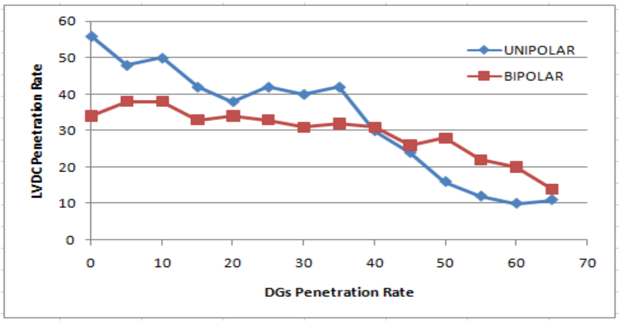

Fig. 10 Minimum economic LVDC penetration rate with presence of DG units

CONCLUSION

In this paper first, LVDC system and its different configurations were introduced. Then, LVDC system implementation and its penetration effects on system reliability and losses were investigated. It has been shown that using unipolar and bipolar LVDC systems and replacing MV branches with them, losses reduced and system reliability is also improved. Costs are calculated for each of this replacement and by comparing the calculated costs with the costs of the AC system, we could find the economic penetration rate of this system. The results indicate LVDC systems utilization would be economical with less replacement for loads that require higher reliability and for higher DGs penetration.

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