FACTORS AFFECTING THE EARTH FAULT CURRENT IN LARGE-SCALE RURAL MEDIUM VOLTAGE CABLE NETWORK

Juho JAAKKOLA
University of Vaasa – Finland
juho.jaakkola@uva.fi

Kimmo KAUHANIEMI
University of Vaasa – Finland
kimmo.kauhaniemi@uva.fi

ABSTRACT

This paper deals with the distributed compensation of earth fault current in large-scale rural area medium voltage cable network. First, the history and current state of the rural area medium voltage networks in Finland are reviewed. In considering the new requirements of customers and legislation, distribution network companies have decided to build weatherproof network, which increases the amount of cable network. PSCAD simulations have been used to verify how some factors such as the density of compensation coils, the share of decentralized compensation, the background network and the parallel resistance affect the earth fault current and how the earth fault current can be minimized during a fault condition. Also the effects of above mentioned factors to quantities measured by protection relays were investigated.

INTRODUCTION

Finland has typically overhead line medium voltage (MV) network in the rural areas. This network was built around 1960-70’s and therefore it has to be renewed. At that time, the overhead lines were mainly built along the most direct routes through forests from the substation to the place of consumption. It was also more important to get electricity to customers and build lines cost-effectively than to care about the quality of electricity and the reliability of distribution network.

In the last few decades, the distribution network operators (DNOs) have tried to install new lines or move the old overhead lines from the forests to the side of roads so that faults can be located and repaired faster. Also consumers have begun to require better quality of electricity supply with less outages and voltage fluctuations. Further, the government of Finland made an amendment to the Electricity market law in 2008 [1], which stipulates customer compensation in case of power outages. In addition to these, recent storms in Finland have also shown that the MV network is very vulnerable for accidents due to trees falling on feeders during storms or heavy snow falls. One such incident was during the Tapani storm in December 2011, which caused several days power outage for several thousands of households. Due to the facts mentioned above, DNOs have started to increasingly use cables in new and renovated rural feeders to prepare for storms and in order to ensure more higher-quality power supply and thus responding to increase in customer needs. For examples, Elenia Network Oy, previously called Vattenfall Network Oy, has made the promise that they will build all new and renovated parts of the network using underground cable.

However, the growing use of underground cables in MV network causes some problems. One of them is the increased capacitive earth fault current causing the step and touch voltages to increase. Thus the fault current has to be compensated by a Petersen coil, in order to avoid danger to people or animals. In this study the focus is on different compensation techniques. Further, the second safety point of view is the secure indication of an earth fault and therefore the new and promising admittance based earth fault protection is briefly investigated in this study.

DIFFERENT EARTH FAULT COMPENSATION METHODS

The earth fault compensation coils can be placed in the network centrally, mixed (partly centrally) or decentrally (also called distributed or locally). Fig. 1 presents the distribution network containing central and local compensation coils, and therefore it can be said that the system has mixed compensation. If local compensation units are removed then the network is centrally compensated and if central compensation unit is removed from HV to MV transformer then the network is decentrally compensated. This study was carried out by simulating networks applying all three different compensation methods mentioned above.

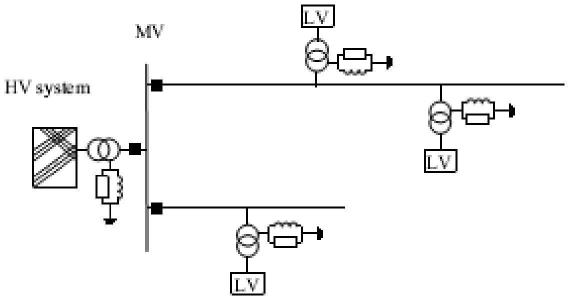

Fig. 1 The distribution network with central and local compensation [3].

Fig. 2 and Fig. 3 illustrate the difference between centralized and decentralized compensation. The decentralized compensation decreases the zero sequence current and hence the neutral point voltage. The question is, how big this difference is and what is the optimum amount of compensation coils.

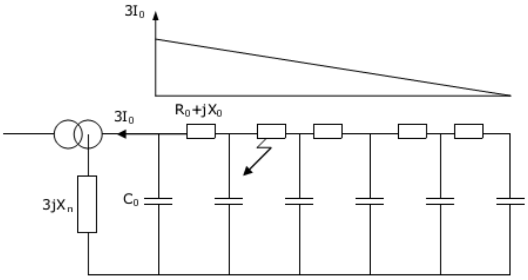

Fig. 2 The zero sequence current with a central coil [2].

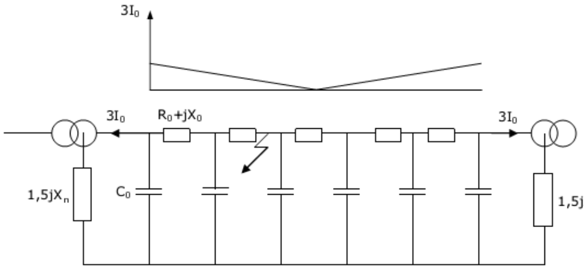

Fig. 3 The zero sequence current with two compensation coils in different places of feeder [2].

MODELLING AND SIMULATION

The simulation models described in this paper have been designed specifically for the typical Finnish MV distribution network. The research presented is also characterized by the fact that all the different simulation cases with the variety of network configurations can be performed with the same PSCAD simulation model. Furthermore, the study has specially taken into account the transition from the overhead line to the cabled network in Finland. Therefore the PSCAD models used in this study have both cable and overhead line feeders.

The model includes 110/20 kV main transformer, a busbar system with the studied feeder and background network consisting of other feeders. Main features of the model are:

- Controlled parallel resistance at the neutral point, which is adjustable so that the current through it is 5 A
- Compensation degree, distance between compensation coils (5, 10, 20, 40 km) and the number of coils can be changed; compensation degree in this study is 80, 90 or 101 %
- Length of the network can be changed from 100 km to 220 km
- Length of the studied feeder can be 20 km (width 1), 40 km (width 2) or 60 km (width 3)
- Background network: two cables (AHXAMK-W 3x185+35) and two overhead lines (Raven 54/9), 40 km each
- Variable fault resistance (0–20000 Ω)
- Variable fault location (5 different locations at the studied feeder and 4 different locations at the background network); fault locations in this study are at the beginning (fp1) or at the end (fp5) of the studied feeder or in the background network (fp9) at the beginning of second cable feeder
- Variable fault type (solid or intermittent earth fault)
- Loads at the studied feeder (2 MW) and background network (8 MW).

The purpose of this research is also to demonstrate how compensation method or the density and place of the compensation coils and the type of background network affect the fault current I_f and the admittance vector. The results are presented in the following sections.

Centralized compensation

As it was illustrated earlier, in the centrally compensated network there is only one compensation coil at the substation connected either to the neutral point of the main transformer or to a separate grounding transformer. In the centralized compensation case, the compensation coil was connected to the neutral point of the main transformer. The coil was adjusted so that the compensation degree of the network was 101 % or the network was fully compensated. First set of bars (centrally) in Fig. 4 shows the fault current in this case.

Mixed compensation

The share of central compensation in mixed compensation systems can be different, but in this study two different cases were simulated. In the first case, 50 km from the whole network is centrally compensated and the rest is decentrally compensated. This means that 10 km from the beginning of every feeder is centrally compensated (later referred to as compensation ratio 10 km). In the second case 20 km from the beginning of every feeder were centrally compensated (later referred to as compensation ratio 20 km). The density of compensation coils is 10 km in both cases. The total length of the network is 200 km. In these cases, the behavior of the fault current I_f at the feeder was studied when the ratio between centralized and decentralized compensation changes and the results can also be seen in Fig. 4 (ratio_10km and ratio_20km).

Decentralized compensation

The purpose of the simulations in this case was to find out how the density of compensation coils affects the fault current I_f at the studied feeder. The results are included in Fig. 4 (dec_5km, dec_10km, dec_20km and dec_40km). It must be noted that the sum of impedance of coils is same although the number of coils changes. In Fig. 4, the fault current as a function of the fault location (fp1, fp5 and fp9) and the compensation method is presented when compensation degree is 101 %, the total length of the network is 200 km, studied feeder length is 40 km and fault resistance is 0 ohm. In the dec_40km case there is only one compensation coil at the feeder. The location of this coil is at the beginning of feeder when a fault is at the beginning of feeder (fp1), in the middle of feeder when a fault is at the end of feeder (fp5) and at the end of feeder when a fault is at the background network (fp9).

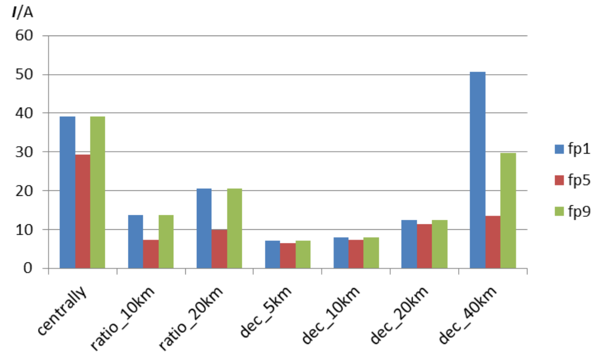

Fig. 4 Fault current as a function of the fault location, and compensation method when compensation degree is 101 %, studied feeder length is 40 km and fault resistance is 0 ohm.

Fig. 4 shows that the fault current is clearly larger in 'centrally' and 'dec_40km' than in other cases as it could be expected. However, in the 'dec_40km' case the fault current is almost the same level as the other decentralized cases when the compensation coil is in the middle of feeder (fp5). When the compensation ratio changes from 'ratio_10km' to 'ratio_20km', the fault current increases as expected. In the cases mentioned above as well as in the 'centrally' case it can be seen that the fault location does affect the fault current. This is due to resistive losses in cables, but in 'dec_5km', 'dec_10km' and 'dec_20km' cases this phenomenon cannot be seen. In Fig. 4, the fault current is almost the same when distance between coils is 5, 10 or 20 km. This means that resistive losses due to the transportation of reactive current are almost the same in these cases as Guldbrand and Samuelsson [3] have found in their study. Further, the level of fault current in these cases is smaller than in other cases due to distributed compensation. Generally, the fault current is the smallest when distance between coils is 5 or 10 km and even with 20 km in some cases.

Neutral point voltage

One method for indicating an earth fault is the change of neutral point voltage. Typically in a healthy state, the neutral point voltage of the network is about 2–4 % or in the MV (20 kV) network this is about 230–460 V. Fig. 5 shows neutral point voltage when the network is centrally compensated and Fig. 6 when the distance between coils is 5 km. In both cases the neutral point voltage is about the same as phase voltage when fault resistance is 0 Ω. When the fault resistance is 500 Ω or more, then the neutral point voltage is clearly larger as shown in Fig. 6 than in Fig. 5. Especially, the neutral point voltage is too small for reliable fault indication as in Fig. 5, when the fault resistance is 4000 Ω or more. On the contrary, in the distributed compensation cases (Fig. 6), an earth fault can be indicated reliably even with the fault resistance of 20 kΩ when the compensation degree is 101 %.

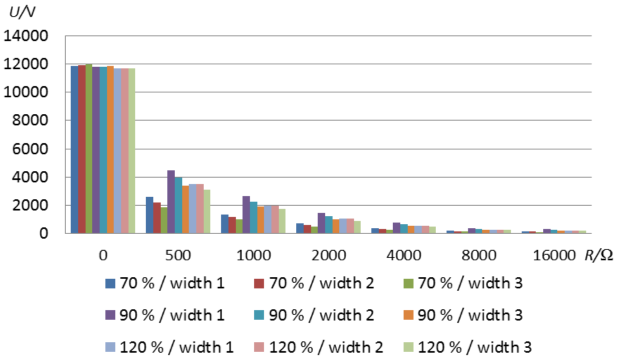

Fig. 5 Neutral point voltage when the network is centrally compensated. A fault is at the beginning of studied feeder.

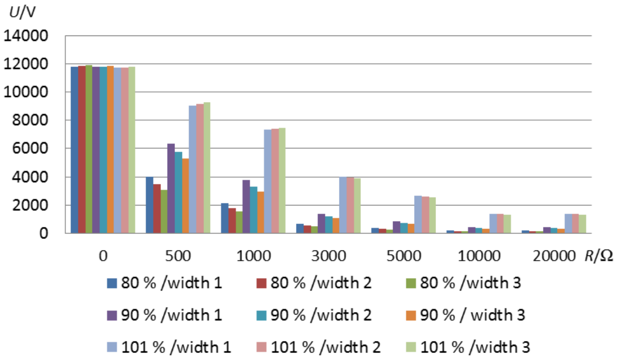

Fig. 6 Neutral point voltage when distance between coils is 5 km. A fault is at the beginning of studied feeder.

ADMITTANCE PROTECTION

Admittance vector is required in admittance protection. It makes it possible to identify the faulted feeder. In this study the question is whether the fault is in the studied feeder protected by a relay or somewhere at the background network? As stated by Wahlroos and Altonen [4], a fault is at the background when admittance vector is in left half plane and on the feeder protected by the relay (studied feeder) when vector is in right plane. In their paper it can also be seen that when vectors are aligned with the horizontal axis the network is in fully compensated as indicated in Fig. 7 by a red arrow.

Fig. 7 and Fig. 8 illustrate the admittance vector behavior when the density of compensation coils, the place of compensation coil and fault location is changing. In both figures the compensation degree is 101 % and fault resistance is 500 ohms. In the figures, short arrows mean that an earth fault is at the background network and long arrows mean that an earth fault is at the studied feeder. The fault location at the studied feeder does not matter, and thus the fp1 and fp5 vectors are completely overlapping.

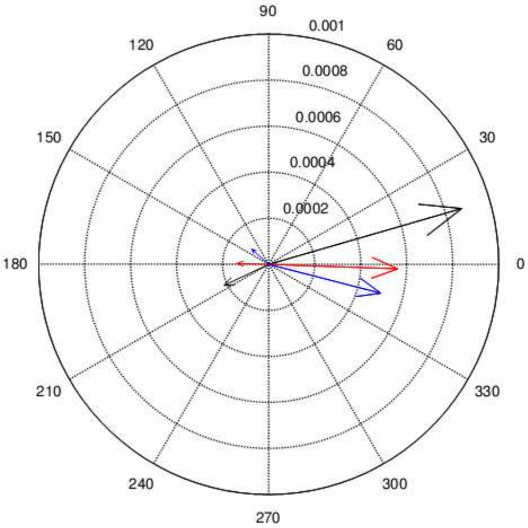

Fig. 7 The admittance vectors when the distance between compensation coils are 5(blue), 10(red) and 20(black) km, and the length of studied feeder is 40 km. Fault locations fp1, fp5 and fp9 are present.

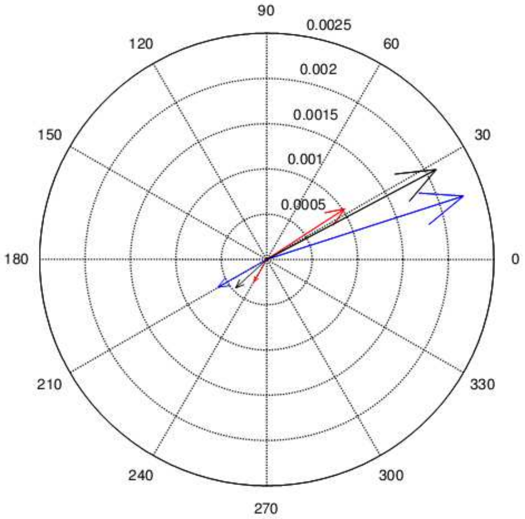

Fig. 8 The admittance vectors when distance between coils is 40 km and the location of the coil is varied (see text), and the length of studied feeder is 40 km. Fault locations fp1, fp5 and fp9 are present.

In Fig. 7, it can be noted that when the distance between the compensation coils increases, the magnitude of admittance vectors increases. In Fig. 8 the distance between coils is 40 km and there is only one compensation coil in the studied feeder that is located at any one of the following three locations: in the beginning (blue vector), in the middle (red vector) or at the end (black vector) of the feeder. In Fig. 8 it can be seen that the magnitude of the vector is the smallest and the angle of the vector is the biggest when a compensation coil is in the middle of the feeder. When the vectors in Fig. 7 and Fig. 8 are compared to the results in Fig. 4, it can be concluded that the magnitude of admittance vector is proportional to the fault current.

CONCLUSION

As can be seen in Fig. 4, there is an essential difference between the different compensation methods. The decentralized compensation produces clearly smaller fault current than the centralized compensation. There is no big difference between cases 'dec_5km', 'dec_10km' and 'dec_20km' and thus it is probably cost-efficient to install the coils with either 10 or 20 km intervals. However, at many MV substations there are already central compensation coils due to gradual change from overhead lines to cables. In this situation, the mixed compensation with the compensation ratio 10 km (ratio_10km) would turn out to be cost-efficient and the fault current would also be almost as small as in the cases mentioned above. Fig. 5 and Fig. 6 show that the neutral point voltage in decentrally compensated network is larger than in the centrally compensated network especially, with full compensation. Thus the earth fault indication based on neutral point voltage is also more reliable in decentrally compensated network. The simulation results also indicate that there is no problem in detecting the faulted feeder correctly by admittance vector based protection method when the decentralized compensation is applied.

Acknowledgments

This work was carried out in the Smart Grids and Energy Markets (SGEM) research program coordinated by CLEEN Ltd. with funding from the Finnish Funding Agency for Technology and Innovation, Tekes.

REFERENCES

[1] *Sähkömarkkinalaki (389/1995: 27 f §)*, (Electricity market act), Finland.

[2] Elfving H., Stråth N., Broo C. & Petersson A., 2006, *Nätkonsekvenser vid kablifiering av luftledningsnät.* (Network consequences due to underground cabling of overhead lines), Report 06:64, Elforsk, Stockholm, Sweden.

[3] Guldbrand A. & Samuelsson O., "Central or Local Compensation of Earth-Fault Currents in Non-Effectively Earthed Distribution Systems", *2007 IEEE Power Tech*, Lausanne, pp.1129-1134, 1-5 July 2007

[4] Wahlroos A & Altonen J., 2011, *Compensated Networks and Admittance Based Earth-Fault protection*, ABB Oy, Distribution Automation, Vaasa, Finland.