DISTURBANCES IN POLISH 15 KV NETWORK BY GROUND SHORT-CIRCUITS

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ABSTRACT

Reliable supply of electric power depends to a great extent on efficient performance of medium voltage (MV) distribution networks. In Poland, these are largely 6 kV to 30 kV networks with 15 kV being the most common voltage. Frequently these networks operate with neutral point grounded through Petersen coil which makes the work conditions for the network's earth fault protection systems particularly difficult. During recent years in Poland the protection systems with admittance criteria [1] have been widely implemented and since the earth faults are detected with better efficiency. In this paper 15 kV networks in Poland are briefly characterised, a relation between the magnitude of the earth fault disturbances in Poland's MV networks and the quality of PE insulation are discussed. The features of admittance earth fault protection systems and their earth fault detection efficiency are presented.

1. SHORT CHARACTERISTIC OF MV NETWORKS IN POLAND

General data about network sizes in Poland, at the end of 2001, in respect to the network voltage are following [2]:

- 400 kV 4 660 km
- 220 kV 8 116 km
- 110 kV 32 284 km
- MV 223 974 km
- LV 284 118 km
- terminals LV 145 270 km

Only overhead lines are used in the first two voltage levels. The share of cables in the 110 kV network is small but during last few years its rapid increase has been observed. The MV network also contains mainly overhead lines. Underground cables constitute only about 25% of the total MV network length. The cable share in the total length of LV network is 30%.

Every year the percentage share of cables in electrical power network increases. This tendency is observed in medium voltage and high voltage systems. The percentage of cable lines in the total length of MV network maintained by 33 Polish power distribution companies is between 8% and 93%.

Communicated in ref. information was a result of a survey conducted in 1996 in power substation on the voltage structure and working conditions of the neutral point in MV networks. The survey showed the following shares of the total length of all MV networks surveyed:

- 87% of 15 kV network,
- 8% of 20 kV network,
- 5% of 6, 10 and 30 kV.

It is estimated that around 5% of those networks work with neutral point grounded through resistance, 20% are isolated neutral point networks, and the remaining part (75%) work with Petersen coil.

A research conducted in the early 90's showed that in 90% of the networks a device forcing transient extra active current in earth fault circuit was used (a device known as AWSCz in Poland). In 20% of cases the forcing exceeded 20A, in 40% of cases those currents were in a range between 16-20A, in 35% forced currents were at a level of 10-15A, and in the remaining 5% the currents were less than 10A. The first group (20%) also included systems with permanent parallel connection of Petersen coil with resistors in which active current was around 0.8 of network's earth fault capacity current [3]. Such solutions are implemented in few networks with mixed cable and overhead lines in which it is necessary to reduce over voltage during earth fault while keeping the rise of shock voltage at minimum. Vast majority of Petersen coils are manually adjusted devices, very rarely automatic adjustment to actual capacity current in the network is used. Due to supply transformers having delta connected coils on MV side the star point of the station demand transformer is used for connecting the Petersen coil.

In Poland, the primary voltage in MV distribution system is 15 kV. The 20 kV voltage is used rarely. Small networks of 6 kV, 10 kV and 30 kV also exist in many cities. Still the most popular are MV cables with impregnated paper insulation. Some of this cable lines have been in use without failure for more than seventy years. Although cable designs are slightly different, the service experience is very satisfying. However, materials used for cable construction are different - draining and non-draining impregnant, various types of paper, etc. Cable manufacturing technology is relatively complicated. Equipment used for installation is often of considerable physical size and skilled personnel is required. Public perception of these cables is that they may create an ecological hazard with the possibility of impregnat leakage to underground waters when the cable's outer layer is ruptured [4].

Throughout the world MV cables with extruded insulation, mainly crosslinked polyethylene, are replacing cables with paper insulation. Also in Poland XLPE cables are becoming more popular due to the ease of laying, maintenance and very good properties. The circuit length of XLPE cable is growing and it is used as standard cable for medium voltage and for 110 kV lines. During the last few years almost all new installed cable lines had XLPE isolation.

2. SERVICE EXPERIENCE

Obtained relatively high failure rate of MV cables is still the result of very low reliability of the first generation of cables with PE isolation. Mainly affected are distribution companies which in the past eagerly introduced new technologies. Today they operate the longest networks made of PE isolated cables. Due to very low reliability of PE insulated cables some of distribution companies have service problems with MV cable network. Especially low reliability is demonstrated by cables with graphite paint on the outer surface of cable insulation and with screens on PE insulation in the form of semiconductor tape. These types of cables were manufactured when PE insulation was first introduced on the Polish market. The change of design of MV power cables with extruded insulation was in the same year when PE isolation had to be replaced by XLPE isolation.

Experience gathered by power distribution companies is shown on the example of services data from five utilities [4, 5]. A near 50 000 km of circuit length was taken account of in the statistics investigation. Figure 1 shows the percentage share of overhead (OHL)and cable (CL) lines content in distribution network for analysed utilities. Share of failure rate for two kinds of MV power in one year is presented on Fig.2.

Each distribution utility has different total length of underground cables with respect to types of cable insulation. Shares of cable types installed in the analysed MV cable network are shown on Fig.3.

Utility companies and cable manufacturers have shown interest in the results of cable service analysis. Figure 4 presents share of MV cable network failure in 2000 – for cables, accessories and due to mechanical damages (for instance: during installation). Among failures of cables in the first place are damages of PE insulated cables – this kind of cables is only a small part of the analysed underground network (Fig.5).

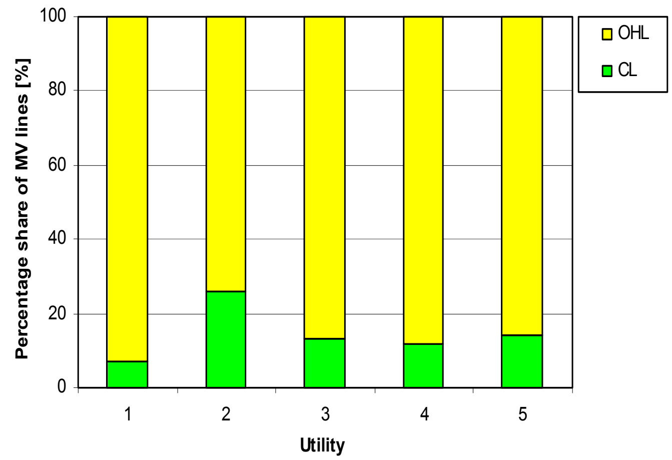

Fig. 1. Types of MV lines for 5 exemplary utilities

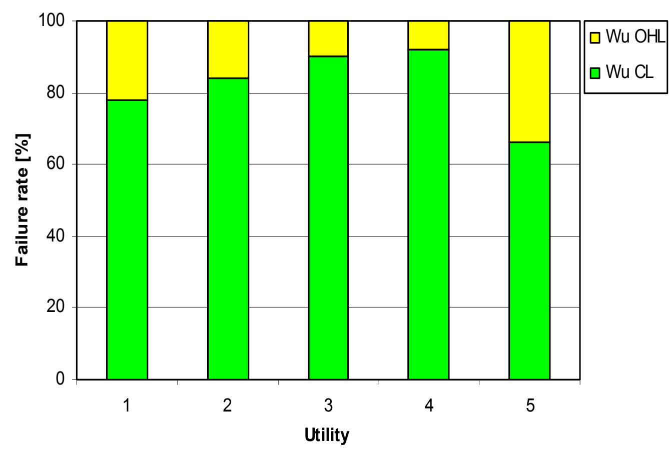

Fig. 2. Percentage share of cable and overhead lines failure rates

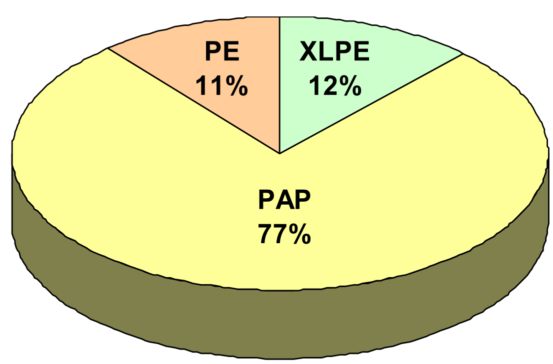

Fig. 3. Shares of cable type installed in the MV network of 5 Utilities at the end of 2000

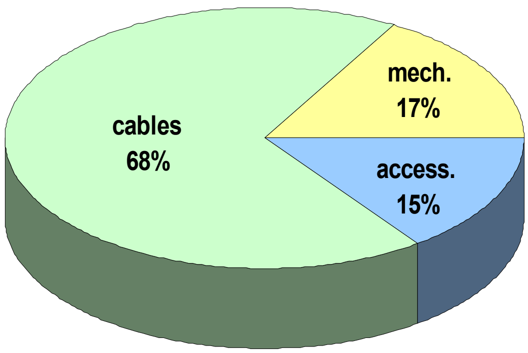

Fig. 4. Failures in analysed network – year 2000

The service data confirmed a very good quality of XLPE cables. In addition, it should be noticed that the first XLPE cable lines were installed in the beginning of the 70's.

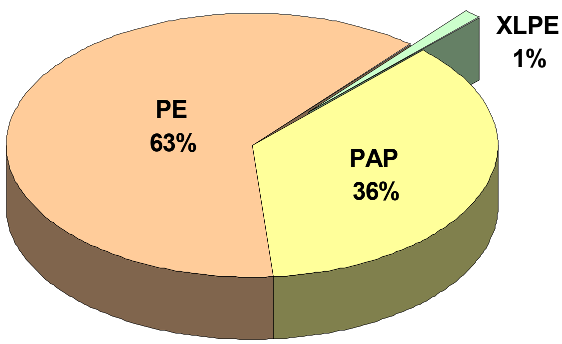

Fig. 4. Cables failures in respect to types of cable insulation – year 2000

Table 1. Failures in overhead MV lines

Failures in overhead lines			Utility	Major grounding system
1-phase failure [%]	2-phase failure [%]	3-phase failure [%]		
72	10	18	1	isolated
89	6	5	2	Petersen coil
85	5	10	3	Petersen coil
83	6	11	4	resistor
82	3	15	5	Petersen coil

Table 2. Failures in MV cable lines

Utility	Failures in cable lines		Major grounding system
	1-phase failure [%]	3-phase failure [%]	
1	84	15	isolated
2	61	39	Petersen coil
3	61	36	Petersen coil
4	35	62	resistance
5	60	34	Petersen coil

The data show that the number of disturbances along 100 km section of a line reaches few dozens per year. However, there are cases where this number exceeds 100. Standard earth fault protection systems in use until early 90's relied on two criteria. In the networks grounded through resistance mainly overcurrent protections, which survey the level of zero current component (I_o), were used. In the networks with isolated neutral point, or grounded through Petersen coil, the directional criteria for which the phase angle between Io and zero voltage component (U_o) is decisive were vastly applied.

Only protections used in the networks with resistor performed reliably, whereas protections in other types of networks usually failed to perform as expected. The weaknesses were particularly felt in the networks grounded through Petersen coil and unstable earth faults with breaking arc or high resistance.

The 90's saw the admittance criteria, developed in the Institute of Electric Power Engineering of Poznan University Technology [1,6], become commonly exploited. Below the main features of these criteria are discussed.

3. CHARACTERISTICS OF THE ADMITTANCE EARTH FAULT PROTECTION SYSTEMS

The admittance earth fault protection systems can be divided with respect to criteria on which they rely:

- excess admittance Y_o>,
- excess conductance G_o>,
- conductance-directional G_{ok},
- susceptance-directional B_{ok},
- comparative-admittance Y_{yo}.

In their operating all of these criteria make use of the values and arguments of measured line's zero sequence current and the network's zero sequence voltage. Earth fault protection driven by zero admittance module (Y_o>) switches on when:

$$U_o \ge U_n \text{ and } Y_{oi} = \frac{I_{oi}}{U_o} \ge Y_n \qquad (1)$$

where:

Y_{oi}- zero admittance of *i*-th line,
U_{oi}- zero component of network voltage,
I_{oi}- zero current component of *i*-th line,
Y_n- setting value for Y_{oi},
U_n- setting value for U_o.

Conductance criterion G_o acts upon a rise in absolute value of conductance measured in its zero component circuits. This phenomenon occurs with particularly big magnitude in the networks equipped with systems forcing the active component or permanently grounded through resistance.

The conductance criterion for protection systems is described by following relations:

$$U_o \ge U_n \text{ and } \left\| 1 + k_y Y_{oi} \right| - \left| 1 - k_y Y_{oi} \right\| \ge G_n \qquad (2)$$

where:

$k_y=ke^{jo}$ is a proportion coefficient,

G_n- setting value for the conductance.

The protection is conductance sensitive, of which the switching value is set by G_n. As the protection is operational at both negative and positive ranges of conductance there is no further need for phasing of the protection clamps and the filters of voltage and current zero components.

When conductance criterion is to be applied in the lines supplied from both ends the switching characteristics of such criterion has to be made directional. It can be achieved by splitting condition (2) into:

$$U_o \geq U_n \quad \text{and} \quad \left| 1 + k_y Y_{oi} \right| - \left| 1 - k_y Y_{oi} \right| \geq G_n \qquad (3)$$

Combining the modules of admittance criterion (1) and conductance criterion (2) results in a protection system of RYGo type. Such system allows to localise lines with earth fault in MV networks with different grounding of the star point. It is of major importance for the networks with varying grounding of the neutral point. By introducing an additional phase shift between I_{oi} and U_o during measurement such that

$$\underline{k}_y = k_y e^{j90}$$

conditions (3) transform into relations describing directional-susceptance criterion

$$U_o \geq U_n \text{and} \left| 1 + \underline{k}_y Y_{oi} \right| - \left| 1 - \underline{k}_y Y_{oi} \right| \geq B_n \qquad (4)$$

where:

B_n- setting value of the susceptance.

A more complex protection, comparative-admittance, makes use of a criterion described by the following

$$U_o \geq U_n \quad \text{and} \quad \left| [Y_{oi}]^{(2)} - [Y_{oi}]^{(1)} \right| \geq \Delta Y_n \qquad (5)$$

where:

$[Y_{oi}]^{(1)}$- zero admittance of the line before forcing additional earth fault current,

$[Y_{oi}]^{(2)}$- zero admittance of the line after forcing additional earth fault current,

ΔY_n- setting value.

4. CONCLUSION

Fair amount of research and construction work, having resulted in analogue and modern digital solutions, combined with providing professional training and expertise made admittance protections a widely used protection system, implemented in nearly 10 thousand MV line fields in Polish distribution networks. Based on service experience gathered in the power substations it is safe to conclude that described protection systems allow to detect at least 95% of all earth faults. Before, until early 90's, barely 50% of earth faults could be successfully detected.

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