Differential method for damage location determining in 10 kV distribution networks with isolated neutral

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Abstract. Half of the length of all transmission lines (TL) are medium voltage networks. Single-line-to-ground short circuit (SLGSC) in distribution networks is the most common type of damage, accounting up to 70% of all types of damage. Faults in damage repair leads to an overvoltage of two healthy phases, resulting in double shorts, two-, three-phase shorts, which contributes to consumers' disconnection. Remote damage location (DL) determination in tree-type networks is considered to be the most relevant, since these networks are spread over large areas, crossing rivers, ravines, lakes, forests, etc. This paper presents a differential method for DL determining based on steady-state voltage of damaged phase frequency. Measuring the parameters of emergency mode at the beginning and at the ends of 10kV TL allows compact stand-alone sensors using without their synchronization.

1 Introduction

6-35 kV air electric networks are tree-type. The choice of a neutral grounding mode in the given networks depends on the current of single-line-to-ground short circuit (capacitive current) [1], an isolated neutral being common in Russia.

Medium voltage networks operating experience shows that 70-80% of all types of damage occurs in the single-line-to-ground short circuit. Consumers' power supply being regular, the network can operate for a relatively long time. However, the late timing of the single-line-to-ground short circuit location leads to a transition to a two-, three-phase circuit shorts with a subsequent consumers' disconnection. The single-line-to-ground short circuit (SLGSC) is very dangerous for people and livestock being near the damage site (step voltage and touch voltage) [2].

Damage location (DL) is an integral function of modern substation automation systems. As practice shows, the DL takes the most of recovery time of a damaged line element. Therefore, to accelerate the DL timing is necessary to improve the DL methods. Remote methods are cost effective, due to the prevention of the transition of a single-phase circuit to more complex ones, power supply interruptions shortening, repair work time diminishing, transport costs decrease for detour lines. The question of the DL is considered in many papers, for example, in [3-10].

The purpose of this work is to study the differential method of the DL according to emergency voltage parameters of the damaged phase, being measured at the beginning and at the ends of 10 kV transmission lines (TL).

2 Line simulation without tapping

When SLGSC happens, the damaged phase voltage drops almost to zero, the minimum voltage being determined by line active resistance. In work [11] there was conducted the DL according to voltage residual values of a damaged phase in an intermediate mode, measured at the beginning and at the end of the TL. However, the line may be in a DL mode for a relatively long time, which justifies the possibility of studying line parameters in a steady state.

Intermediate resistance can be considered to be the most important factor at the DL. It reduces the DL accuracy in the problem. The attention to this parameter is a priority in DL algorithms development. According to the studies performed in [12], when using the differential method, the value of the intermediate resistance at the accident does not affect the DL. Three-phase voltage source parameters, consumers' load (active, capacitive, inductive, active-capacitive, active-inductive, etc. in the maximum and minimum mode) also do not affect when using this method.

Thus, measuring the phase steady-state voltage of industrial frequency of a damaged phase at the beginning and at the end of a TL with an insulated neutral, one can unambiguously determine the DL regardless of the intermediate resistance values at the accident site, parameters' source, consumers' loads. The accuracy of this method with a device error of $\pm 1V$ is ± 10 m.

All the above studies have been modeled in the Matlab Simulink program for a line without tapping. Medium voltage distribution networks are tree-type, so it is necessary to simulate a line with several taps and see

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the voltage dependence at the beginning and at the ends of the line from SLGSC distance.

3 Line simulation with two tappings

A 10 km line was made of AC 35/6.2 wires (producer Russia) [13] with TMTH 6300/110/10, TM-2500/10/0.4 transformers (producer Russia). The load at consumers' unitized transformer substation (UTS) are UTS 1, UTS 2, UTS 3 is $P = 200$ kW, ground resistance $R_g = 50$ Ohm·m, resistance at the accident site $R_a = 0.1$ Ohm (metal) [14]. The sensors for voltage measuring are conventionally indicated by black squares in Figure 1.

Fig. 1. Block diagram of line with two tappings.

The results of the simulation of A SLGSC along the line from the transformer substation (TS) to UTS 2 are presented in table 1.

The voltage level dependence of the damaged phase at the beginning and at the ends of the transmission line while SLGSC simulating along the line from the TS to UTS2, as shown in Table 1, is given in Figure 2.

According to schedule 1, it can be concluded that when SLGSC simulating along the line, the voltage up to 4 km increases / decreases linearly (at the distance of 4 km, the first tap is added), and then it increases / decreases nonlinearly.

The results of SLGSC simulation along the line from the TS to UTS 1 (the first tap) are presented in table 2.

Fig. 2. Voltage dependence of the damaged phase at the beginning (TS) and along the ends of the power transmission lines (UTS 1, UTS 2, UTS 3) while SLGSC simulating along the line from the TS to UTS 2.

The voltage level dependence of the damaged phase at the beginning and at the ends of the transmission line while SLGSC simulating along the line from the TS to UTS2 (table 1), along the line from the TS to UTS 1 (table2), and along the line from the TS to UTS 3 (table 3) is given in Figure 3.

Fig. 3. Voltage dependence of the damaged phase at the beginning (TS) and along the ends of the power transmission lines (UTS 1, UTS 2, UTS 3) while SLGSC simulating at different points of the line.

Figure 3 demonstrates the dependence of the damaged phase voltage and the distance to line-to-ground short circuit.

Table 1. Damaged phase voltage in SLGSC simulation along TS to UTS 2.

Distance to SLGSC from the beginning of the line (km)	Damaged phase voltage at TS U1 (V)	Damaged phase voltage at UTS 1 U2(V)	Damaged phase voltage at UTS 2 U3 (V)	Damaged phase voltage at UTS3 U4 (V)
0	27.97	219.68	276.22	262.07
1	59.98	177.02	233.42	219.29
2	100.40	134.58	190.72	176.64
3	142.21	92.68	148.21	134.22
4	184.47	52.58	106.09	92.34
5	212.67	31.13	78.58	65.26
6	240.91	28.07	52.25	40.33
7	254.98	36.23	40.26	30.96
8	269.04	47.27	30.33	26.24
9	283.10	59.60	25	28.55
10	297.15	72.56	27.13	36.58

Table 2. Damaged phase voltage in SLGSC simulation along the line from TS to UTS 1.

Distance to SLGSC from the beginning of the line (km)	Damaged phase voltage at TS U1(V)	Damaged phase voltage at UTS 1 U2 (V)	Damaged phase voltage at UTS 2 U3 (V)	Damaged phase voltage at UTS 3 U4 (V)
0	27.97	219.68	276.22	262.07
1	59.98	177.02	233.42	219.29
2	100.40	134.58	190.72	176.64
3	142.21	92.68	148.21	134.22
4	184.47	52.58	106.09	92.34
5	198.59	40.51	92.53	78.97
6	212.71	30.52	79.20	65.95
7	226.82	25.15	66.22	53.53
8	240.93	27.3	53.87	42.23

Table 3. Damaged phase voltage in SLGSC simulation along the line from TS to UTS 3.

Distance to SLGSC from the beginning of the line (km)	Damaged phase voltage at TS U1 (V)	Damaged phase voltage at UTS 1 U2 (V)	Damaged phase voltage at UTS 2 U3 (V)	Damaged phase voltage at UTS 3 U4 (V)
0	27.97	219.68	276.22	262.07
1	59.98	177.02	233.42	219.29
2	100.40	134.58	190.72	176.64
3	142.21	92.68	148.21	134.22
4	184.47	52.58	106.09	92.34
5	212.67	31.13	78.58	65.26
6	241.67	27.71	52.40	40.74
7	254.99	36.24	40.76	30.37
8	269.07	47.29	31.48	25.04
9	283.13	59.63	26.80	27.17

Figure 4 shows the dependence of the damaged phase voltage difference at the beginning and at the ends of the transmission lines on the SLGSC distance.

Fig. 4. Dependence of the damaged phase voltage difference at the beginning (U1) and the ends of the transmission lines (U2, U3, U4) on SLGSC distance.

According to Figure 4, while simulating the lines with two tappings, the DL may be definitely indicated by the voltage difference at the beginning and at the end of the transmission line.

4 Differential method approach for DL determining

1) Damaged phase voltage measurement at SLGSC at the beginning of the line (U1) and along the ends of the line (U2, U3, U4).

2) Calculation of the difference between the beginning and the ends of the lines (U1-U2, U1-U3, U1-U4).

3) Based on the presented dependencies, DL is determined (Figure 4).

5 Conclusions

Thus, by measuring the phase steady-state voltage of damaged phase frequency at the beginning and at the ends of the transmission line, the DL may be definitely determined regardless of intermediate resistance values at the accident site, consumers' source and load parameters, as well as the number of tappings.

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