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The influence of harmonics on ground-fault current

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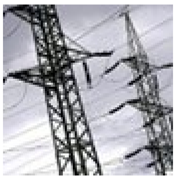

With the growing deployment of new electronic production equipment and energy consumption, the emphasis is on upholding the quality of electricity supply. Distribution networks are part of the power system with the high probability of higher voltage harmonics due to the connection of electronic household appliances, electronic frequency inverters and converters, the sodium discharge lamps, etc.

The increasing connection of photovoltaic power plants, public lighting reconstruction and another development of industry and traction systems has an influence on voltage and current distortion in the distribution network. Ground faults of overhead lines in isolated systems are compensated with compensation coil, and its compensated power is calculated to the first harmonic fault current. This paper is dedicated to problematic of ground faults in high voltage networks in the case of voltage and current harmonics.

1 GROUND FAULTS IN COMPENSATED NETWORK

In the case of conductive connection in compensated network between phase and ground a single phase fault appears. Through the place of the ground fault connection flows a relatively small current with the capacitance character and its value depends on the distance to the source (it is approximately the same in all locations).

In high voltage networks during normal operating condition flows through capacity line wire – ground capacitive currents. Their sum is zero in case of symmetric power supply and symmetric network. If in this operating condition ground fault occurs, the capacitive current of unaffected phases flows through their capacitive to ground and winding transformer to ground fault place. These ground-fault currents can reach significant values, especially in large distribution networks. Until the capacitive currents do not exceed a value, this network can operate in an allowed time range. To compensate the ground-fault currents in the ground connection is used compensatory power coil installed in the neutral node of the transformer. The current of compensated coil flows through the ground fault place and it is in opposite phase with capacitive ground-fault current. (Fig.1)

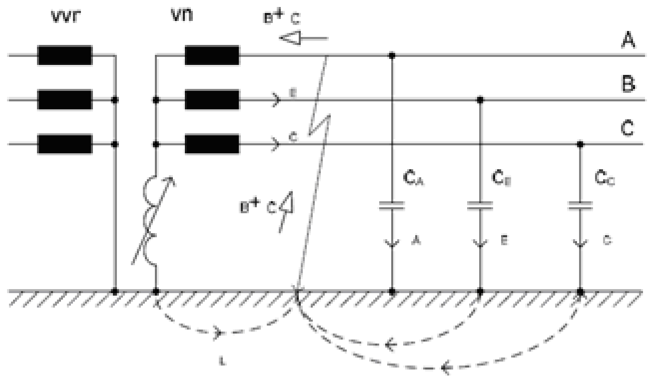

Fig. 1 The ground fault in compensated distribution network

2 THE DISTRIBUTION NETWORK MODEL AND GROUND-FAULT CURRENT CALCULATION

The distribution network model was created by using MATLAB SIMULINK (SIMPOWER SYSTEM). The model consists of a power source on the 110kV site, which supplies via a power transformer T1 distribution overhead line wires V1 to V5. The overhead line parameters are described in Tab. 1. In order to respect the values of higher harmonic voltage of 22 kV level, which are set in the standard STN EN 50 160, we set the voltage source in accordance with it. The simplified block diagram of distribution network is shown in Fig.2.

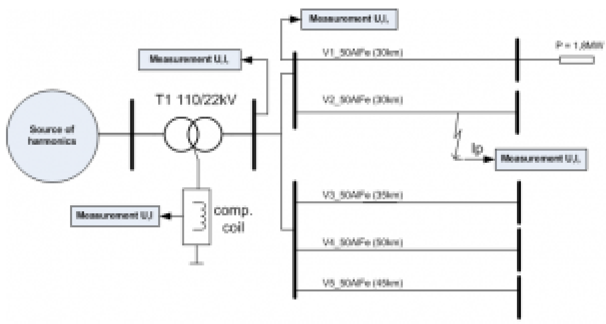

Fig.2 Graphic representation of distribution network model

Overhead line parameters we calculated based on the real size of pylon and phase disposition:

Tab. 1 Parameters of overhead lines V1 – V5

Pylon		**L1**		**L2**		**L3**	
		y[m]	x[m]	y[m]	x[m]	y[m]	x[m]
fmax=1,2m		7,417	-1,5	8,917	-1	7,417	1,5
Overhead line	**Type**	**Lenght [km]**		**R [ohm]**	**L [H]**	**C [F]**	**Co [F]**
V1	50_AlFe	30		7,56	0,036	2,96E-07	1,515E-07
V2	50_AlFe	30		7,56	0,036	2,96E-07	1,515E-07
V3	50_AlFe	35		8,82	0,042	3,46E-07	1,768E-07
V4	50_AlFe	50		12,6	0,06	4,94E-07	2,525E-07
V5	50_AlFe	45		11,34	0,054	4,45E-07	2,273E-07

3 CALCULATION OF GROUND-FAULT CURRENT AND THE COMPENSATION POWER OF PETERSEN COIL

Based on the calculated overhead line parameters which are listed in Tab. 1, the total capacity to ground C_0 equals to 9,586.10^{-7} F. It follows that the calculate value of the ground-fault current is:

$$I_P = I_{L2P} + I_{L3P} \tag{1}$$

$$I_{L2P} = E_{L2P} j\omega C_0 = 22.10^3 e^{j150^\circ} j.2\Pi.50.9,586.10^{-7} = \\ = 6,622.e^{j240^\circ} \quad A \tag{2}$$

$$I_{L3P} = E_{L3P} j\omega C_0 = 22.10^3 e^{j210^\circ} j.2\Pi.50.9,586.10^{-7} = \\ = 6,622.e^{j300^\circ} \quad A \tag{3}$$

$$I_P = 6,622.e^{j240^\circ} + 6,622.e^{j300^\circ} = 11,47.e^{j90^\circ} \quad A \tag{4}$$

Based on the value of the ground-fault current, we determined the value of the compensatory coil:

$$I_P = I_L = \frac{U_z}{\sqrt{3}.X_L} \tag{5}$$

$$L = \frac{U_z}{\sqrt{3}.2.\Pi.50.11,47} = \frac{22.10^3}{\sqrt{3}.2.\Pi.50.11,47} = 3,52 \quad H \tag{6}$$

4 SIMULATION RESULTS

For the simulation, we created three models. In first cause, we have not considered the influence of upper harmonics on ground fault. This model is used to verify the accuracy of calculating the value of ground- fault current and the proposed compensation power. In the second model we considered the influence of upper harmonics without connected compensative coil. With the influence of upper harmonics in compensated distribution network we considered in the third case. In the second and third case we considered the 2, 3, 5 and 7 harmonic voltage by STN EN 50160. The model in steady state is set to their amplitude as set out in this standard. Measurements for the simulation are located at points as shown in Fig. 2.

4.1 Compensated network – fundamental harmonic

Following charts describe development of currents and voltages of HV 22 kV network with only fundamental harmonic.

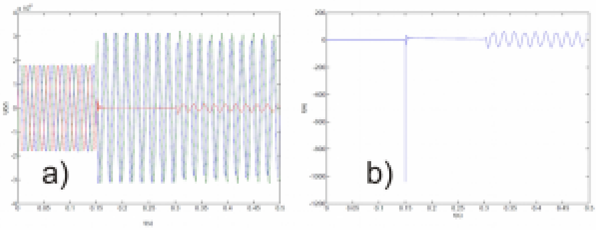

Fig. 3 Gragraphical representation of a) votage curve on secondar of transformer T1, b) fault current curve on line

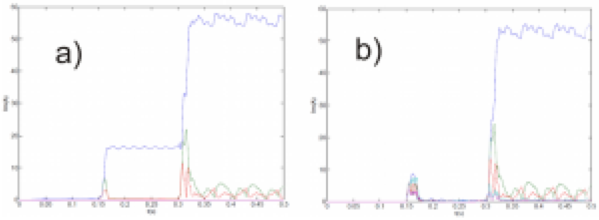

Fig. 4 Harmonics analisys of a) current of compensatory coil, b) ground-fault current

Fig. 3 shows the voltage curve at the secondary side of the T1. The fault was 0.15 at the beginning of the simulation (fault occured on phase L3). At Fig. 3 it seen the emergence of overvoltages on good phases. At the time 0.3 s was connected in parallel resistance to the reactor, which is at to increase the active component of fault. The fig.3b shows that the compensation power was calculated correct. The ground-fault current is offset to almost zero. Harmonic analysis in Fig. 4a, 4b shows the progress of the amplitude of each harmonic.

Table 2 summarizes the results of measurements of T1 at the secondary side, ground-fault current and compensation coil current.

Tab.2 Ground-fault in compensated network without the infuelnce of upper harmonics

Overvoltage	**22 203 V**
Compensated ground fault	**0,35 A**
Compensatory coil	**11,6 A**
Ground fault current with resistance	**37,7 A**

4.2 Compensated and uncompensated network with upper harmonics

The following graph describes the progress of current and voltage of 22kV network, which is powered by defined sizes 2, 3, 5 and 7 harmonic voltage by STN EN 50 160. (In these case the parallel resistance was connected at the time 0.4s in parallel to the reactor).

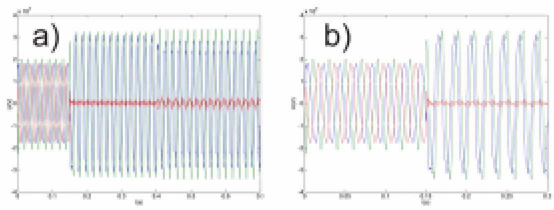

Fig. 5 The voltage curve before and after the ground fault at the secondary side of transformer T1 a) compensated network, b) uncompensated network

Table 3 describes the measuring data of the harmonic voltages on the secondary side of transformer T1 in the steady state and during the fault. The measurement data show that the steady-state harmonics fulfil the conditions of norm STN EN 50 160. Voltage sizes are given in effective values.

Tab.2 Ground-fault in compensated network without the infuelnce of upper harmonics

Scendary side of T1				
Harmonics	**STN EN 50 160**	**Before fault**	**Compensated ground fault**	**Uncompensated ground fault**
1	x	12,72 kV	22,01 kV	22,37 kV
2	2 %	2,03 %	2,13 %	2,14 %
3	5 %	4,68 %	5,32 %	5,37 %
5	6 %	5,77 %	7,84 %	7,73 %
7	5 %	4,84 %	1,28 %	1,14 %

Fig. 6 describes the ground-fault current course

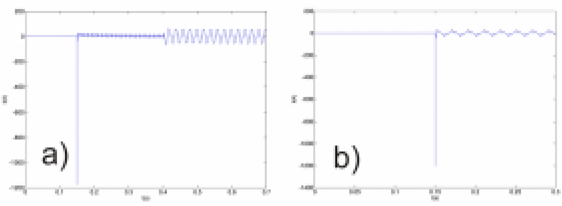

Fig. 6 Ground-fault current curve before and after failure of a) compensated network, b) uncompensated network

Table 4 describes the results of measurement ground-fault current and upper harmonic content in the uncompensated case overhead line and case of compensated overhead line with parallel resistor. Current values are given in effective values.

Tab. 4 Harmonic analysis of the ground-fault current

Ground-fault current						
Harmonics	**Uncompensated ground-fault current**		**Compensated ground-fault current**		**Compensated ground-fault current + resistance**	
1	100 %	11,6	100 %	0,35	100 %	41,05
2	4,50 %	0,52	166 %	0,38	3,30 %	1,41
3	19,14 %	2,22	831 %	1,88	7,05 %	2,89
5	63,34 %	7,35	3087 %	7,04	19,92 %	8,17
7	29,60 %	3,43	1516 %	3,45	8,50 %	3,50
		I_p = 23,3		**I_p = 11.32**		**I_p = 42,42**

At the Fig. 7 is shown the amplitude of harmonic analysis of the ground-fault current.

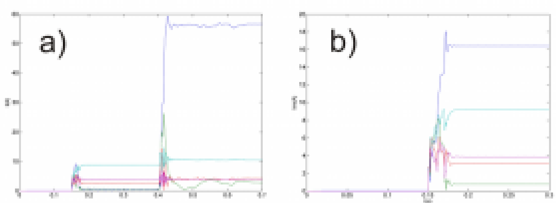

Fig. 7 Harmonic analysis and ground-fault current) compensated network b)

uncompensated network

5 CONCLUSION

The designed compensatory coil compensated the ground-fault current of fundamental harmonic in all cases to value about 0,35 A. In a network with upper harmonics the ground-fault current can not be compensated to the value 0,35 A. It is because the harmonic currents are not compensated by compensatory coil. In this case, ground-fault current is 11,32 A, which is almost 30 times more than in the case of a network that contains only fundamental harmonic. Uncompensated ground-fault current in the network with upper harmonics is approximately two times greater than the ground-fault current of the fundamental harmonic current network.

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