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Simulation Study of Single Line-to-Ground Faults on Rural Teed Distribution Lines

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Abstract. Teed lines are widely used in rural power networks in China. The paper theoretically analyzes the voltages and currents when a single line-to-ground fault occurs, constructs a new mathematical model for fault location on the teed lines, performs corresponding MATLAB simulations. Simulation results show that currents near the source (bus M) are almost independent of fault positions and fault resistances. However, voltages at bus M are sensitive to fault positions while fault voltages at fault position are only sensitive to transient resistances. A novel approach to fault location on teed lines is proposed. First, the faulted line is identified with remote control equipment. Then, the transient resistances are calculated according to the fault voltages. And at last, the fault distances are computed according to the voltages at bus M and the calculated transient resistances.

Key Words: simulation, fault location, teed line, single line-to-ground fault

1 Introduction

Power lines are typically teed in rural distribution systems in China. Faults occur when equipment insulation fails, due to system overvoltages, lightning, contamination or other mechanical causes. Single line-to-ground faults account for about 90% of the total faults according to the statistics[1-4]. Fault location equipment is developed to find and clear faults as soon as possible. Unfortunately, the accuracy and reliability of present location equipment for rural power networks are not satisfactory. Therefore, it is necessary to study the characteristics of faults in rural power networks and lay a solid foundation for developing corresponding fault location equipment.

2 Theoretical Analysis

Consider a single line-to-ground fault from phase a to ground at the general three-phase bus shown in Figure 1. For generality, a fault impedance Zf is included. In the case of a bolted fault, Zf=0, whereas for an arcing fault, Zf is the arc impedance. In the case of a insulator flashover, Zf equals the total fault impedance between the line and ground, including the impedance of the arc and the post or tower. Since any of the three phases can be arbitrarily labeled phase a, analysis results can be easily applied to phase b or phase c.

From Figure 1, fault conditions in phase domain are:

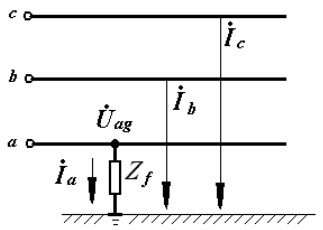

Fig. 1. Single line-to-ground fault

$$\dot{I}_b = \dot{I}_c = 0 . \tag{1}$$

$$\dot{U}_{ag} = Z_f \dot{I}_a . \tag{2}$$

Transforming fault conditions to sequence domain, the sequence components of the fault currents are obtained:

$$I_0 = I_1 = I_2 = \frac{U_f}{Z_\Sigma + 3Z_f} . \tag{3}$$

where U_f is prefault voltage and $Z_\Sigma = Z_0 + Z_1 + Z_2$.

The fault current on phase a can be derived by transforming the sequence components to the phase domain:

$$I_a = \frac{3U_f}{Z_\Sigma + 3Z_f} . \tag{4}$$

The line-to-ground voltages can then be determined from equation (2).

In the case of a bolted fault, Z_f=0, it can be easily obtained that the line-to-ground voltage U_{ag}=0, while U_{bg}=U_{cg}=1.732Uph, where U_{ph} is the phase voltage.

3 MATLAB Simulations

Typical teed lines are shown in Figure 2.

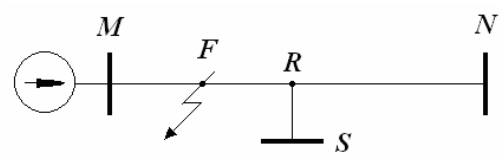

Fig. 2. Typical teed lines

The MATLAB/Simulink simulation circuit is illustrated in Figure 3.

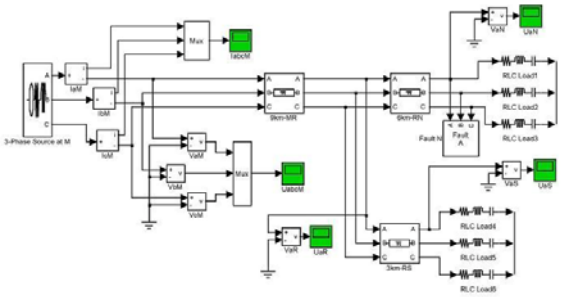

Fig. 3. Simulation circuit

In Figure 2, l_{MR}=9 km, l_{RN}=6 km, l_{RS}=3 km. Each line is equivalent to a pi-block as shown in Figure 3.

Parameters are from real statistics (written in MATLAB grammar).

Source parameters are:

Phase-to-phase rms voltage: 10500 V; Phase angle of phase A: 0 degree; Frequency: 50 Hz; Internal connection: Y; Source resistance: 0.1638 Ohms; Source inductance: 0.000236 H.

Loads are: PAN=PBN=PCN=100000W; QAN=QBN=QCN=40000Var;

PAS=PBS=PCS=300000W; QAS=QBS=QCS=40000Var.

Line parameters are: r1=0.330 Ω/km, L1=0.001126 H/km, C1= 9.14e-9 F/km.
Set Rf=[0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 200, 500, 1000] Ω, change the fault point one by one, run MATLAB /Simulink/ SimPowerSystems, and many pages of simulation results are acquired. Parts of the results are shown in Table 1.

Table 1. Parts of the Simulation Results

D/km	R_f=20Ω			R_f=500Ω		
	I_M/A	U_M/V	U_F/V	I_M/A	U_M/V	U_F/V
3	62.2	93.3	4.95	62.2	193	125
6	62.2	180	4.95	62.2	273	124
9	62.2	273	4.95	62.2	354	123

Table 1 implies that currents through bus M are almost independent of fault positions and fault resistances. In other words, fault currents are of little significance for fault location. However, voltages at bus M are sensitive to fault positions while fault voltages at fault position are only sensitive to transient resistances. Therefore, a new approach to fault location on teed lines is presented as follows. First, the faulted line, MR, RN, or RS, is identified with remote control equipment. Then, the transient resistances are calculated according to the fault voltages, which are approximately

equal to voltages at bus N or bus S. And at last, the fault distances are computed according to the voltages at bus M and the calculated transient resistances.

Take line MR for example, by using the least square method of MATLAB:

```
echo on
Rf=[0 20 100 500]
UN=[0 4.95 24.5 124]
plot(UN,Rf)
pause
Rfu2=polyfit(UN,Rf,1)      % fit the Rf-UN curve
end
```

The relation between Rf and UF can be obtained as

$$R_f = 4.0305U_F + 0.3812 . \tag{3}$$

Similarly, the relation among d (fault distance from M), Rf and UM can be also obtained by the least square method.

4 Conclusions

Fault currents through bus M are almost independent of fault distances and fault resistances. While voltages at bus M are sensitive to fault distances, and fault voltages at fault position are only sensitive to transient resistances. Therefore, a new idea to locate the fault on teed lines is propose. Firstly, identifying the faulted line; secondly, calculating the transient resistances; and at last, computing the fault distances.

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