Improvement of Power Quality in Four-Wire Distribution Systems

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Abstract –This paper explores the inherent characteristics of multigrounded three-phase four-wire distribution systems under unbalanced situations. As a result, the mechanism of profile voltage in MGN feeders becomes difficult to understand. The simulation tool that been used for this paper is Matlab under Windows platform. In this paper the equivalent model of a full-scale multi-grounded distribution system implemented by Matlab is introduced. The results are expected to help utility engineers to understand the impact of MGN on distribution system operations.

Keywords: Power quality, multi- grounded, neutral, three-phase four-wire

1. Introduction

The power quality problems in the low-voltage three-phase four-wire systems have become very important in recent years, due to the growing existence of single-phase nonlinearloads, such as personal computers, lighting, printers and air conditioning installations.A characteristic of these single-phase nonlinear loads is that in the spectrum of currentharmonics there are significantly low-frequency harmonics, and the triplen harmonics, which have a zero rotational sequence, are added up in the common neutral wire which issubjected to currents from all three phases. In addition, the unbalance leads to additionalzero rotational sequence currents and thus, the neutral conductor is overloaded [1], [2].

The different technical solutions that considered the neutral in medium voltage are: systems withoutneutral (Brazil), systems with an isolated neutral (Italy, Finland, Switzerland), systems with multiple grounding of the neutral and connecting the utility neutral with customer grounding (USA, Greece), systems with solid neutral grounding (U.K.), systems with resistance neutral grounding (France, U.K.), systems with reactance neutral grounding (Belgium, Spain, Portugal, Netherlands), and systems compensated via a "Petersen" coil (Germany), to name a few [5], [6]. Therefore, it is essential for power engineers to realize the inherent characteristics of this kind of power systems while doing system planning and operation. But recently power engineers ordinarily used three-phase power-flow programs to analyzing an unbalanced power distribution system. The commercial simulation software, Matlab for Windows, was adopted in this paper. The Matlab has powerful simulation ability and a friendly graphical interface. This software is commonly used for electronic circuit simulations, but it also can be used in power system analyzing to analyze steady-state and transient problems. Using suitable equivalent models of system components, the Matlab is capable of representing and simulating a power distribution system easily [3], [7]. The MGN configuration has the advantage of being easy to protect for most short-circuit faults. Power engineers often find that it is difficult to analyze the MGN configuration due to the presence of a fourth conductor and its multi-grounded topology. The symmetrical components-based methods are not applicable to such cases. There are various opinions about the effects of MGN. Substation GPR as higher fault current could flow through the substation [8]. The transient overvoltage (i.e., voltage swell) may also increase due to increased fault current and transient under-voltage (i.e., voltage sag) may also decrease due to increased fault current. Our analysis shows that there are several factors, such as the loop current in the neutral wire and the neutral-to-phase voltage induction, at play. Some of them produce opposite effects. The net effect is that the transient overvoltage and substation GPR are reduced and transient under-voltage increased. The current flow pattern and transient voltage components are illustrated. A multiphase load flow program was used to assist this

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analysis and explore the inherent characteristics of multi-grounded three-phase four-wire distribution systems under unbalanced situations[4], [9].

2. System Modeling Using Matlab

A distribution power system model is built with SimPowerSystems toolbox in MATLAB/Simulink. The parameters of transformers, lines and etc in model are obtained in practical system. The procedure for constructing an equivalent model is as follows:

1) Obtaining the equivalent model of each major system component

2) Setting the necessary parameters of all system components

3) Forming a full-scale system equivalent model by combining the suitable component models in accordance with the system structure

In this paper, the coupling-free equivalent circuits of system components were used to model a power distribution system. These coupling-free equivalent circuits are suitably applied in Matlab because they are represented with simple elements such as resistance, inductance, capacitance, voltage and/or current source. The coupling-free equivalent circuits of major system components such as co-generators, transformers, conductors and loads have been developed successfully [5]-[10].

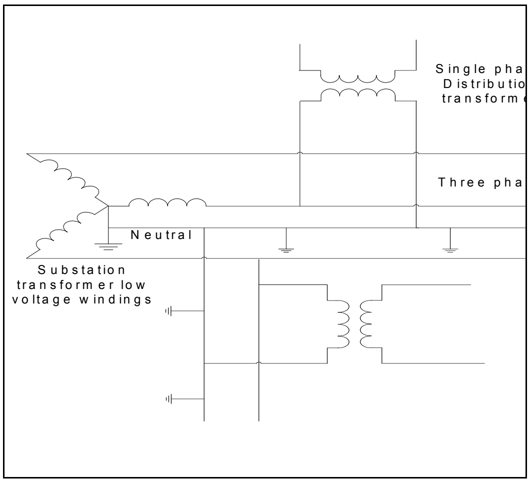

Fig. 1. Equivalent model of a multi-grounded four-wire distribution system by Matlab

If it is required, Users can modify the coupling-free equivalent networks within a reasonable range and then implement these equivalent circuits by Matlab. It is very important to set necessary parameters of system components. Unsuitable parameter settings may not only result in incorrect simulation results, but also make the program convergence difficult. After the equivalent models of system components are obtained and the necessary parameters of system components are set, a full-scale system equivalent model can be formed by combining these suitable component models in accordance with the system structure. For a multi-grounded three-phase four-wire distribution system, users must pay attention to the neutral grounding. If the neutral wires are multi-grounded, phase wires and neutrals have to be divided into shorter segments according to the number and location of grounds. Thus the neutral grounding can be represented explicitly [4].

With following the model of procedure, a system equivalent model can be constructed quickly and simulated by Matlab. The MATLAB/Simulink model is shown in Fig. 1. Every block in this, represents the equivalent circuit model of a system component. The high voltage side of the distribution substation was simplified as an ideal three-phase source. It is worthy of note that neutral wires and grounding are represented explicitly. The neutral can be grounded with a resistance, inductance or capacitance. The simulations make focus on the performances of substation GPR, voltage sags and voltage swell and in the customer during the faults.

3. Description of Sample System

The distribution system that showed in Fig. 2 is utilized for analysis. The sample feeder main is fed by a 69–11.4 kV, 25 MVA power transformer sited in the distribution substation. The primary feeders and laterals are all overhead construction. Their parameters are shown in Table II. The common point of the secondary side of the substation transformer with wye connection and the neutral wire were solidly grounded. The grounding resistance of the neutral point of the substation transformer and the grounding points along the neutral wire were assumed to be 0.7 and 5, respectively [11]. The dots represent the distribution transformers and their loads. There are 17 distribution transformers in the sample system to serve the customers that are distributed along a feeder [13]. With assuming that all the distribution transformers are operated in full-load condition with 0.85 lagging power factor, their ratings and connection phases are listed in Table I. Table I indicates that single-phase and open wye-open delta connections were used largely in this sample system. Hence, the sample system was usually operated under unbalanced conditions. They are typical and acceptable recommended values obtained from [11].

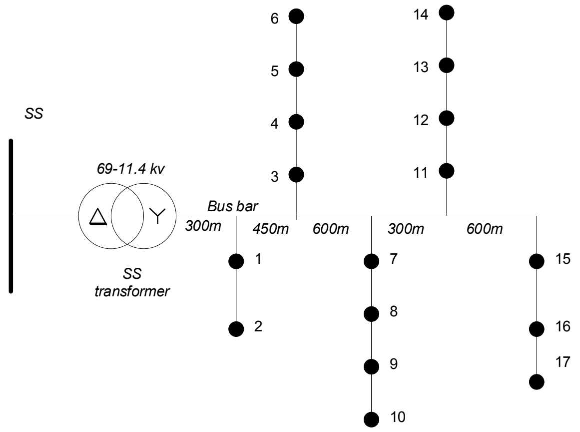

Fig. 2. A single-line diagram of the sample system

TABLE I
RATINGS AND CONNECTION PHASES OF DISTRIBUTION TRANSFORMERS IN THE SAMPLE SYSTEM

NO	Windings Connection	phase	Secondary Voltage(V)	Capacity (KVA)	Impedance (Z%)
1	Delta-Gnd. Wye	A,B,C	220	500	1.89
2	Single-phase	B	110	50	1.75
3	Single-phase	B	220/110	50	1.75
4	Single-phase	B	220/110	50	1.75
5	Delta-Gnd. Wye	A,B,C	220	500	1.89
6	Delta-Gnd. Wye	A,B,C	220	500	1.89
7	Open Wye	B,C	220	100,100	1.70,1.70
8	Open Wye	A,C	220/110	167,100	1.89,1.70
9	Single-phase	C	220/110	100	1.70
10	Single-phase	C	220/110	100	1.70
11	Delta-Delta	A,B,C	220	500	1.89
12	Open Wye	A,C	220	100,100	1.70,1.70
13	Single-phase	C	110	50	1.75
14	Single-phase	B	220	50	1.75
15	Open Wye	A,B	220/110	167,100	1.89,1.70
16	Single-phase	C	220/110	50	1.75
16	Single-phase	C	220/110	50	1.75

TABLE II
PARAMETERS OF CONDUCTORS IN THE SAMPLE SYSTEM

Conductor impedance	feeder		lateral	
	phase	neutral	phase	neutral
Resistance(Ω/km)	0.131	0.209	0.945	0.945
Reactance(Ω/km)	0.364	o.382	0.355	0.355

For such a system, the current flowing back to the substation neutral, I*N*, consists of three components:

• I*g* represents the return current through the substation ground and
• I*split* represents the current split by the neutral grounding resistances.

The resistances serve as current divider that splits the substation neutral current between the substation grounding resistance and neutral grounding resistances;

• I *induced* contains the current produced by the fault-current-induced voltage on the neutral.

This current is shown in Fig. 5 where the voltage sources represent the voltages induced by the fault current on the neutral conductor. As shown in Fig. 5, the current, I *induced*, has an opposite direction to that of I*N*, which further reduces. As a result of the currents I*induced* and I*split*, the substation ground current I*g* is actually less than the substation neutral current I*N*. the increase of fault current does not necessarily lead to an increase of I*g*. Since the ground potential rise in the substation is R*g**I*g*, the GPR does not increase necessarily either [12]. From Fig. 4, the voltages of the unfaulted phases such as V*b* can be determined by using equation (1)

$$Vb = Vn + Eb + Vinduced - a + Vinduced - n \quad (1)$$

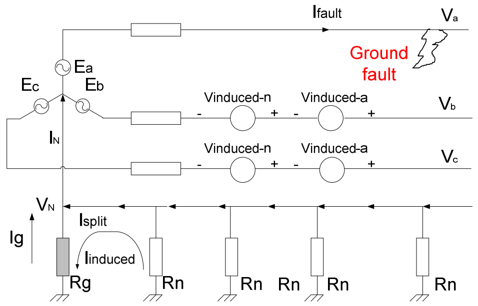

Fig3. MGN configuration under one-phase to ground fault.

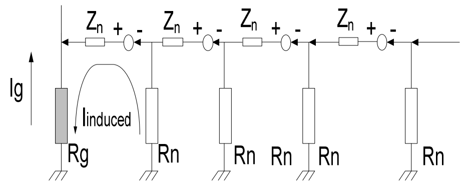

Fig4. Loop current of neutral due to voltage induction.

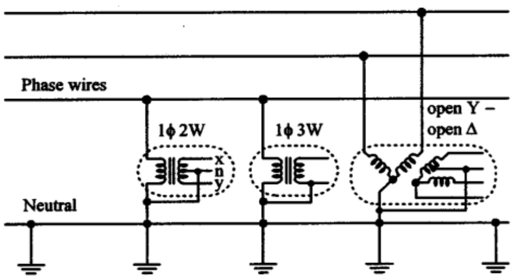

Fig5. Grounding of TFR in distribution system.

4. Case Study and Power Quality

Two cases are used to demonstrate the effects of the various factors. The first case is the MGN configuration for a 11 kV line. The second case has no neutral. This configuration is commonly called three-wire earth return (TWER) scheme. Fig. 4 shows the three components of the substation ground current, I*g*. It can be seen from Table III that the MGN scheme does increase the I*N* with comparison of the TWER scheme. However, the two current components, I*induced* and I*split* have an opposite direction to that of the I*N*. Consequently, the current that actually flows into the substation is less than the case of the TWER. The substation GPR is also reduced accordingly [14].

TABLE III
Components of substation Ground Current

currents	*TWER(A)*	*MGN*
I_N	1500	1602
I_{split}+$I_{induced}$	0	- 656
Total(=I_g)	1500	946

The results of voltage swell are shown in Table III for MGN and in Table IV for TWER and the results of voltage sags are shown in Table V for MGN and in Table VI for TWER for comparison. The values presented are projected in the direction of the corresponding phase voltages at the line first. It can be seen that the fault-current-induced voltage contributes most to the voltage swell and voltage sags. The net effect is that the both (V*a*) and (V*b*, V*c*) of the MGN scheme are less than that of the TWER scheme. Similarly, the neutral voltage V*N* can either support or oppose the voltage swell and voltage sag depending on the concerned phase of the line [13]. The objective in grounding a neutral wire in a distribution system is to stabilize system voltages and provide the return path for grounded-fault current [15]. Multi-grounded neutral wires can heighten system ground reliability effectively. Direct grounding is commonly used in distribution systems for saving costs and work days.

TABLE IV
Voltages swell in phase B and C (MGN)

Voltages phase (max)	*B(Volt)*	*C(Volt)*
V phase	926	9255
V phase fault	10255	10210
ΔV phase(swell)	280	34
V phase(swell)-(pu)	1.109	1.106

TABLE V
Voltage swells in phase B and C (TWER)

Voltages phase (max)	*B(Volt)*	*C(Volt)*
V phase	9255	9253
V phase fault	10788	12756
ΔV phase(swell)	1532	3450
V phase(swell)-(pu)	1.18	1.39

TABLE VI
Voltage sag in phase A (MGN)

Voltages phase (max)	A(Volt)
V phase	9255
V phase fault	6154
ΔV phase(sag)	-388
V phase(swell)-(pu)	0.674

TABLE VII
Voltage sag in phase A (TWER)

Voltages phase (max)	A(Volt)
V phase	9254
V phase fault	4560
ΔV phase(sag)	-1138
V phase(swell)-(pu)	0.50

5. Conclusion

In this paper the commercial simulation software, Matlab has been used to analyze the inherent characteristics of a multi-grounded four-wire distribution system. The analysis has considered the effects of neutral and grounding in detail. Simulation results indicate that if the effects of neutral wires are neglected, the solutions of voltages, currents and system imbalance will be incorrect. This application could benefit to system operation, but it also complicates the characteristics of the distribution system [16]. The results show that the neutral-induced and split currents are helpful for reducing the substation GPR (in spite of higher fault current experienced by the system) and also compare profile voltage in the MGN scheme with the TWER scheme.

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