A Calculation of Neutral Current for Two Step Type Pole in Distribution Line

K. W. Park*, O. S. Kwon, H. C. Seo, C. H. Kim

Abstract— *The one step type pole and two step type poles are used in KEPCO's distribution system. An unbalanced current may flow through neutral wire in three-phase four-wire distribution system due to unbalanced load. Generally, power line and communication line are installed at contiguity by effect of topography in Korea. To this end, the damaged such as electrostatic induction, electromagnetic induction, and harmonic induction will generated by induced voltage and current are occurred in power line and communication line. This paper calculates the neutral current in KEPCO's distribution system using EMTP by composing various simulated condition. Also, that result is verified by vector analysis.*

Keywords— **One Step Type Pole, Two Step Type Pole, KEPCO's distribution system, EMTP.**

1. INTRODUCTION

Korea Electric Power Corporation (KEPCO) distribution system is using 22.9[kV] Y-connected three-phase four-wire at high-tension line for voltage improvement and power damage reduction and low-tension wire boosts the voltage by 220/380[V] three-phase four-wire system and supplies to customer. KEPCO's distribution system using combination of one step type pole and two step type pole. Then, neutral current can generate by unbalanced current in three-phase. The neutral currents on the overhead distribution line produce a harmful induced voltage to a communication line. So, the KEPCO restricts within 20% of neutral current compare with normal phase current in overhead distribution line.

Due to topography factors in Korea, there are many areas where the power lines are installed at proximity to the communication lines. In such cases of proximity, both voltage and currents are induced by communication lines and may lead to damages such as electrostatic induction, electromagnetic induction, and harmonics induction.

In this paper, neutral current of KEPCO's distribution system of 'X S/S Y D/L' section and 'X S/S Z D/L' section, which is composed of one step type pole and two step type pole, was calculated using EMTP. Neutral current of two step type pole have calculated more exactly through 12,000 samplings per one cycle according to change of time using EMTP/MODELS. In addition, to identify an increase and decrease of the neutral current in the system composed of two step type pole has used vector analysis.

2. EMTP / MODELS

The EMTP (Electromagnetic transient program) is the simulation tool used to simulate the electromagnetic transient phenomenon, and it is one of the most widely used programs throughout electric utilities.

MODELS is a symbolic language interpreter for the EMTP that has recently gained popularity for the electromagnetic transients phenomenon modeling. The MODELS provides the monitoring and controllability of power system as well as some other algebraic and relational operations for programming MODELS is able to change dynamically states of power system in response to the simulated results of EMTP based power system[1-2].

In this paper, the EMTP program is used for calculation the neutral current. A system model had been drawn using EMTP/ATPDraw. Then defined the MODELS for calculation the neutral current of distribution system and connected it with the system model. We obtained the result of neutral current calculation after ran the simulation using EMTP. The parameters of system models are base on the real data of distribution system which are belong to the KEPCO.

3. DISTRIBUTION SYSTEM MODEL

In this paper, KEPCO's distribution system of 'X S/S Y D/L' section and 'X S/S Z D/L' section are targeted for calculation of neutral current for unbalanced load as shown in Fig. 1. In Fig. 1 'XZ 8~44' section is composed of two step type pole and the remaining sections is composed of one step type pole. The 'X S/S Y D/L' section on the upper portion is designated as PART 1 and the 'X S/S Z D/L' section on the lower portion is designated as PART 2. There are total of twenty-four

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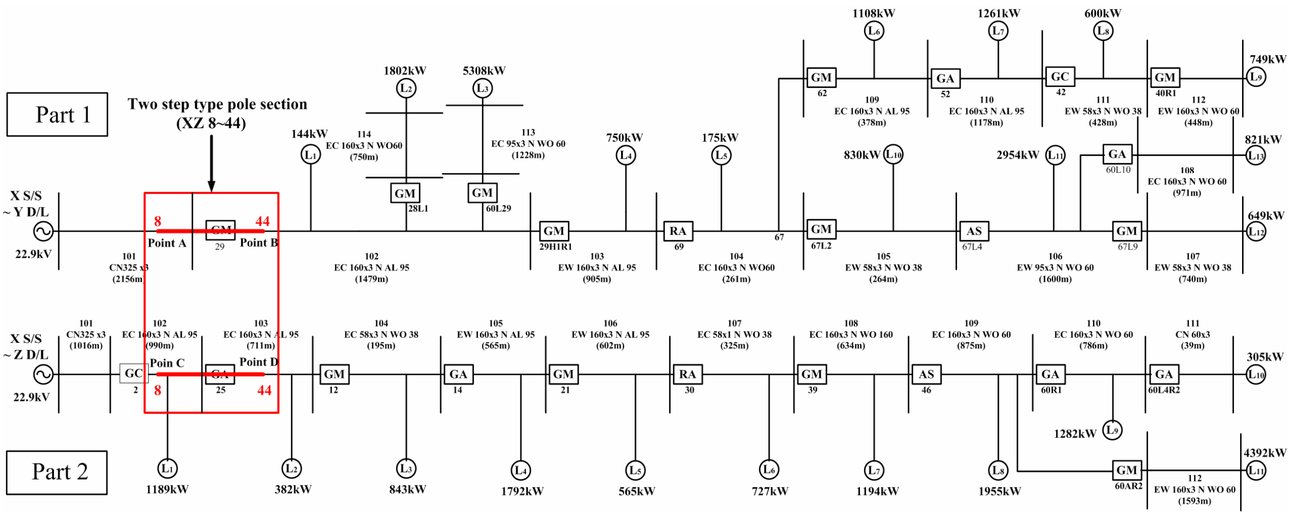
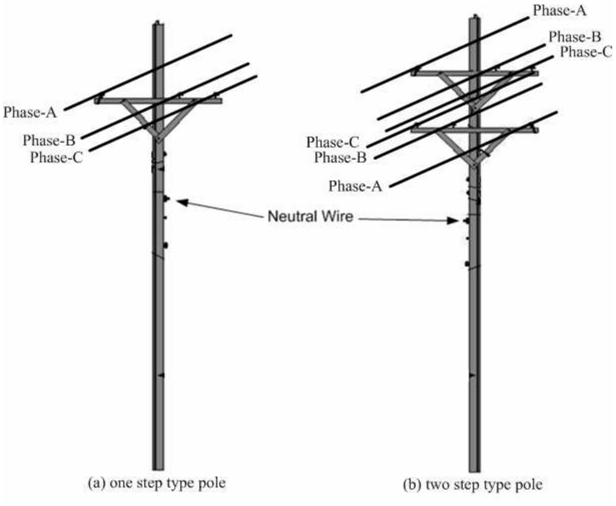


Fig. 1. Distribution System Model

There are total of twenty-four loads connected to PART 1 and PART2, and all loads are three-phase load. In here, X, Y and Z express place name of the Seoul city in Korea. S/S means substations and D/L means distribution line. So, X S/S Y D/L expresses the transmission line from substation of place X to the distribution line of place Y, and X S/S Z D/L expresses the transmission line from substation of place X to the distribution line of place Z.

Fig. 2. shows that the structure of one step type pole and two step type pole which are being used in KEPCO.

The left diagram is a one step type pole. The transmission lines are connected with a neutral wire. And right diagram is a two step type pole. The transmission lines of upper side and lower side are connected with the common neutral wire.



(a) one step type pole (b) two step type pole

Fig. 2. Structure diagram of pole type

4. MODEL SYSTEM USING EMTP

To identify the effects and the variations of the neutral current each of the distribution pole of the model system shown in Fig. 1, four different types of models were formed. CASE-1 is a model which combined entire sections of both ‘X S/S Y D/L’ and ‘X S/S Z D/L’. CASE-2 and CASE-3 was a model that is expressed only ‘X S/S Y D/L’ and ‘X S/S Z D/L’ section respectively from the CASE-1 model. In other words, CASE-2 and CASE-3 were made to examine the changes of neutral currents between the one step type pole and two step type pole ‘XZ 8~44’sections, which is the main purpose in this paper. In CASE-4, even though the model system is the same as in CASE-1, the difference is that the CASE-1 is a model system that does not common the upper and lower neutral grounding points of the two step type pole, where as the CASE-4 is a model system that common the upper and lower neutral grounding points of the two step type pole.

4.1 Load modeling

In order to maintain balance on the three phases, the value of the load must be same and the load impedance can be calculated as follows in (1), the power consumption during Autumn Season was assumed to be 30% of the maximum consumption amount of the Summer Season and power factor was assumed at 0.9. The load impedance was calculated as (2)[3-5].

$$Z_{load} = (\frac{V_{LL}^2}{P}) \times \cos\theta \qquad (1)$$

$$Z_{load} = (\frac{V_{LL}^2}{P \times 0.3}) \times 0.9 \qquad (2)$$

4.2 Line modeling

Depending on the length of the line, there are number of different line models including Lumped series line model, T-equivalent model, π-equivalent model, and Distribution line model in EMTP. The model distribution system is applicable to short distance line; therefore, the Lumped series line model was applied.

4.3 Calculation of neutral current

The calculation of neutral current on CASE-1~3 was used method that is presented to the reference [3]. The calculation of neutral current on CASE-4 was conducted with the assumption that the upper and lower side are common the neutral grounding points. The neutral current in ‘ZX 8~44’section were composed of EMTP/MODELS and their method of calculation are given in (3) ~ (6).

$$I_{N1} = I_{A1} + I_{B1} + I_{C1} \tag{3}$$

$$I_{N2} = I_{A2} + I_{B2} + I_{C2} \tag{4}$$

$$I_{NEU} = I_{N1} + I_{N2} \tag{5}$$

$$I_{NEU\_RMS} = \sqrt{\frac{1}{T}\int_0^T I_{NEU}^2 dt} \tag{6}$$

where

$I_{A1,A2}$: Phase-A current in upper and lower side

$I_{B1,B2}$: Phase-B current in upper and lower side

$I_{C1,C2}$: Phase-C current in upper and lower side

$I_{N1,N2}$: Phase-N current in upper and lower side

I_{NEU} : Total neutral current

I_{NEU_RMS} : RMS values of I_{NEU}

5. CALCULATION OF NEUTRAL CURRENT AND DISCUSSION OF THE RESULTS

5.1 In case of equal upper and lower unbalanced load ratio

In this paper, from the largest load downwards on each PART, four loads were selected for the simulation samples. Simulation was conducted with consideration to the states that the unbalanced ratio must not exceed 30[%], the ratio of unbalanced load impedance was assumed at ‘1.35:1.2:1.0’.

Therefore, the loads, L3, L11, L2, and L7 was simulated changing depend on the unbalanced load ratio in PART1.

In PART 2, selected loads L11, L8, L4, and L9 was adjusted and simulated.

The adjusted unbalance occurrence states of load impedance for simulation the unbalanced loads condition are as follows.

- Case in which unbalance has occurred in the largest load (PART 1-L3, PART 2-L11) in each PART
- Case in which unbalance has occurred in the two loads (PART 1-L3·L11, PART 2-L11·L8) in each PART
- Case in which unbalance has occurred in the three loads (PART 1-L3·L11·L2, PART 2-L11·L8·L4) in each PART
- Case in which unbalance has occurred in the four loads (PART 1-L3·L11·L2·L7, PART 2-L11·L8·L4·L9) in each PART

Above 4 cases were set as EXAMPLE 1, 2, 3 and 4, and with consideration to load unbalance state, neutral currents were calculated after conducting simulation using CASE-1, CASE-2, CASE-3, CASE-4 model system. The following Figre.3 is the graph showing the variation in neutral current per unbalanced load rates.

The results of analysis conducted per each points shows that the neutral current was the largest in EXAMPLE-4, followed by EXAMPLE-3, and then EXAMPLE-2. Therefore, the neutral current increases as the number of unbalanced load increase.

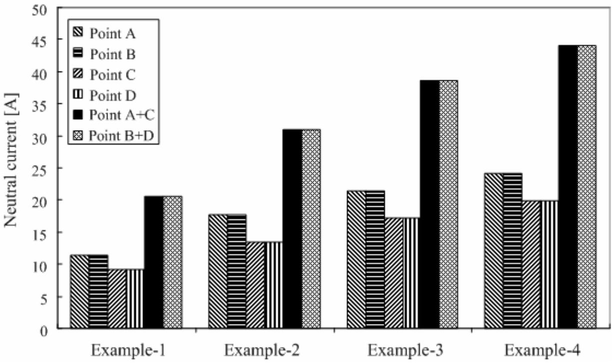


Fig. 3. Variation of neutral current by the number of unbalanced load

Each point in Fig. 3 are as follows,
Point A : XZ Point No. 8 in ‘X S/S Y D/L’
Point B : XZ Point No. 44 in ‘X S/S Y D/L’
Point C : XZ point No. 8 in ‘X S/S Z D/L’
Point D : XZ point No. 44 in ‘X S/S Z D/L’
Point A+C : Common neutral point of Point A and C
Point B+D : Common neutral point of Point B and D

5.2 In case of unequal upper and lower unbalanced load ratio

CASE-4 was tested in this simulation with various changes of unbalanced load ratio in each phase of the upper and lower side. This was set as EXAMPLE-5 and its neutral current was compared with EXAMPLE-1.

The unbalanced ratio of upper and lower load impedance in EXAMPLE-1~4 was made equal but in EXAMPLE-5, the upper and lower load impedance was simulated with different unbalanced ratio as shown in Table 1.

To compare the value of the neutral current of the upper and lower load unbalanced ratio when neutral grounding point is common. The ratio of upper and lower side was based on EXAMPLE-1, which has the same ratio. With such basis, the value of the neutral current in point A+C and B+D of EXAMPLE-5-1~5 were compared and that is shown as a graph in Fig.4.

Table 1. Unbalanced load ratio of each phase at EXAMPLE-5

EXAMPLE -5	Section	Load	Ratio of each phase (A:B:C)
EXAMPLE -5-1	PART 1	L3	1.35:1.2:1.0
	PART 2	L11	1.35:1.0:1.2
EXAMPLE -5-2	PART 1	L3	1.35:1.2:1.0
	PART 2	L11	1.2:1.35:1.0
EXAMPLE -5-3	PART 1	L3	1.35:1.2:1.0
	PART 2	L11	1.2:1.0:1.35
EXAMPLE -5-4	PART 1	L3	1.35:1.2:1.0
	PART 2	L11	1.0:1.2:1.35
EXAMPLE -5-5	PART 1	L3	1.35:1.2:1.0
	PART 2	L11	1.0:1.35:1.2

Fig.4 is the case where the unbalanced load ratio of upper is fixed and variation was made only the loads of lower.

In Fig.4, EXAMPLE-1 can be noted as the largest. This case shows that the unbalanced load occurrence in upper and lower is extreme in specific phase. In other words, the unbalanced loads ratio in phase A, B, C was the upper at 1.35:1.2:.1.0, and the lower at 1.35:1:21.0. Therefore, in case where unbalanced load ratio is the largest in both upper and lower, and neutral current is also the largest.

It can provably that the next largest case is the EXAMPLE-5-2.

It can see that at specific phase in EXAMPLE-2, the synthetic of the unbalanced load ratio was 2.55 in two specific phases. In EXAMPLE-5-1, the unbalanced load ratio in specific phase was 2.7.

In addition, the next large value was EXAMPLE-5-3 and EXAMPLE-5-5. In these two cases, specific phases showed unbalanced load ratio of both 2.55 and 2.35 simultaneously. In smallest case is EXAMPLE-5-4. The synthetic of the unbalanced load ratio was 2.4. As a result, it can be confirmed that the neutral current will also become larger in specific phase of higher unbalanced load ratio.

In cases of same unbalanced load ratio only in the same phase, the value of the neutral current was resulted as the scalar sum of neutral current in upper and lower. However, in case of different upper and lower load unbalanced ratio, Fig.4 show that the value of the neutral current always is not the scalar sum of upper and lower neutral current, even though the two step type pole is common the neutral grounding point.

Results of the principal of superposition and vector analysis, that because each neutral current of each different phase is counterbalanced. In other words, regardless of common the neutral grounding point, changes of the neutral current becoming the scalar sum of the one step type pole is extremely unlikely.

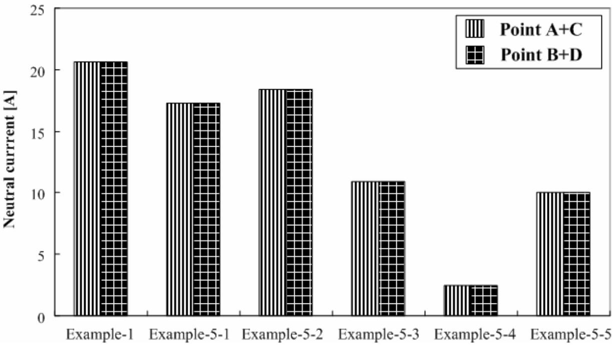


Fig 4. Neutral current of each phase by various unbalance factors

6. CALCULATION OF UNBALANCE FACTOR AND DISCUSSION OF THE RESULTS

Each of phase current and neutral current in various conditions were measured, unbalance factor was able to be obtained based on such that. The unbalance factor was based on Electric Facility Standards and its as shown in (7).

$$\begin{matrix}\text{Facility}\\\text{Unbalance}\\\text{Factor}\end{matrix} = \frac{\begin{matrix}\text{The difference between maximum and minimum}\\\text{of total facility capacity of the single phase load}\\\text{connected to each line}\end{matrix}}{\text{Facility value of all load / 3}} \times 100 \qquad (7)$$

Prior to verification at each of the measuring point of the KEPCO's distribution system, total facility capacity of the single phase load connected to each line was unknown, but the phase current in each measuring points were identifiable. Since P=VI, and the load capacity is proportional to current, the equation (7) was able to be calculated as shown in (8).

$$\begin{matrix}\text{Unbalance}\\\text{Factor}\end{matrix} = \frac{\begin{matrix}\text{The different between maximum and}\\\text{minimum of three-phase current}\end{matrix}}{\text{Sum of three-phase current / 3}} \times 100 \qquad (8)$$

6.1 Change in unbalance factor corresponding to the increase in the number of unbalance loads in upper and lower side

Using the results of the unbalance factor calculated with (8) with CASE-1 as the basis, it was confirmed that the unbalance factors were the same in all of CASE-2, CASE-3, and CASE-4. Therefore, with CASE-1 as the basis, the unbalance factor corresponding to increase the number of loads in upper and lower side is shown as Fig. 5.

The unbalance factor in cases of increased number of loads in unbalanced load was calculated and its results are as follows.

- In all cases, the unbalance factor was the same on the same measuring point. In case of unbalance factor the two step type pole, common or not of the neutral grounding point made no difference whether the upper and lower side are explicated separately. In other words, the unbalance factor in one step type pole and two step type pole are equal.
- As the number of unbalanced loads in upper and lower side increases, the unbalance factor also increases.

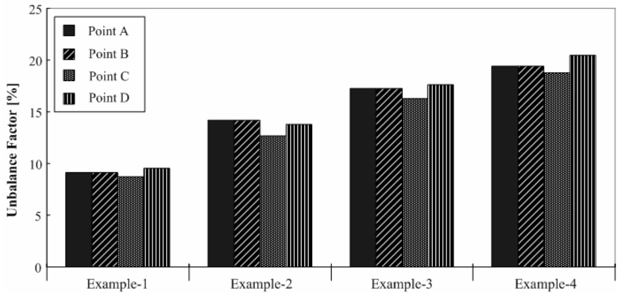


Fig. 5. Unbalance factor by increase o f the number of unbalanced load at upper and lower side

6.2 In case where the unbalanced load ratio in upper and lower side are unequal

In the same measuring point of CASE-1 and CASE-4, the unbalance factors are also equal. Through this, the unbalance factor in two step type pole is not effected whether the neutral grounding point is common or not and make no difference whether the upper and lower side are explicated separately. In other words, the unbalance factor is the same as in one step type pole.

In Fig. 6, it can be seen that unbalance factors in Point A and Point B are equal. That's there are no load existing between Point A and Point B. As a result, it can be seen that the circuit is connected in direct line and phase current in the same. Therefore, the unbalance factor is also equal. But, it can note that between Point C and D, the unbalance factor in Point D is larger. Because there exists load between the Point C and D, and since Point D is in close with the unbalanced load.

Since the unbalance factors in each measuring Point of CASE-1 and CASE-4 are equal, it is confirmed that the unbalance factor has no relationship with the common of the neutral grounding point.

7. VERIFICATION BY VECTOR ANALYSIS

In two step type pole distribution system, it was verified by EMTP, that the value of neutral current is shown to be largely different whether neutral grounding point in upper and lower side are common or not. Even though the neutral grounding point was common, if the unbalanced ratio of neutral current in upper and lower side are different, the neutral current does not become the scalar sum of the upper and lower neutral current, also may even be smaller than the neutral current of one step type pole.

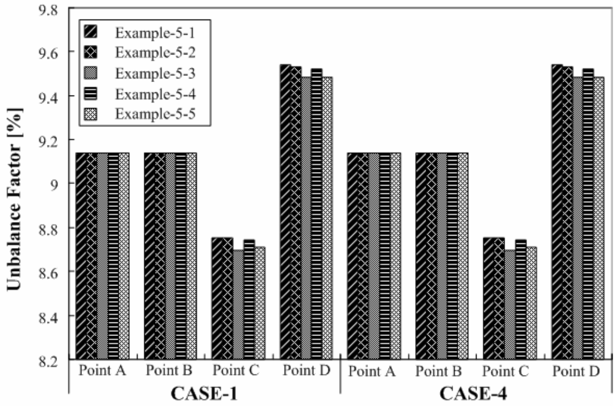
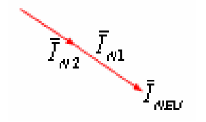
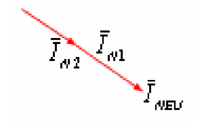
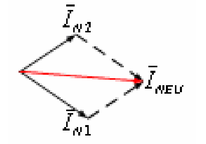
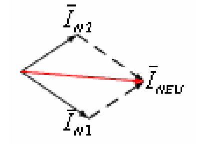
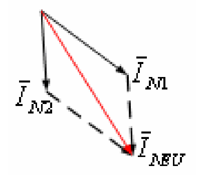
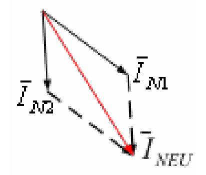
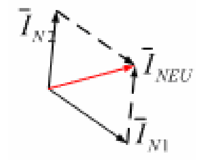
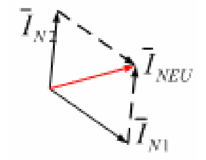
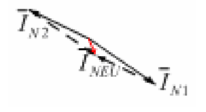
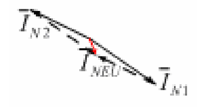
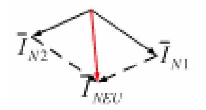
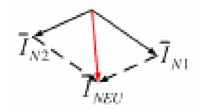


Fig. 6. Each point unbalance factor of CASE-1 and CASE-4

Table II. Resultant Vector of the Each Example

	Resultant Vector Point (A+C)	Resultant Vector Point (B+D)
EXAMPLE-1		
EXAMPLE -5-1		
EXAMPLE -5-2		
EXAMPLE -5-3		
EXAMPLE -5-4		
EXAMPLE -5-5		

The neutral current of the three-phase power system composed of Y-Y circuit was shown to be the resultant vector by the phase current of three-phase[6][7].

Table 2 is the calculation result of the resultant vector. It shows the neutral current of point (A+C) and point (B+D) in EXAMPLE-1 and EXAMPLE-5 in accordance with the vector analysis.

As shown in the results of EXAMPLE-5-1~5, if the unbalanced loads of upper and lower side are different, the neutral current of two step type pole does not become the scalar sum of neutral current in upper and lower side. It is verified through that resultant vector both cancels out each other. In addition, in cases where both do not cancel out each other by resultant vector, but become the scalar sum, it's in the case as in EXAMPLE-1, where the value and direction of the neutral current in upper and lower side are equal (in other words, each phases of unbalanced loads in upper and lower are equal) but chances of such cases are extremely unlikely.

8. CONCLUSIONS

In this paper, analysis using EMTP was conducted to identify the superposition of the neutral current, which is the inductive current that causes the inductive disturbance when the neutral wire of extra high voltage power line was common. The results of the research are as follows.

(1) In the distribution system composed of two step type pole, the phase current in each level had no difference in common or not of the neutral grounding point. Only the current pertaining to the value of the load exists.
(2) In case each phase unbalance ratio is different in the upper and lower side, the current in the common neutral wire is decreased. However, if the combination of load unbalanced ratio in specific phase is increased, then the neutral current may also increase.
(3) The neutral current flow increases as the number of unbalanced load is increased.
(4) If each of the neutral grounding points on the two step type pole distribution system is no common, value of neutral current is the same as the individual interpretation of upper and lower side.
(5) In general, since the load unbalance in upper and lower neutral current are different in most cases, current value of the neutral grounding is resultant vector of the upper and lower individual current and it is smaller than the scalar sum of both currents. Composition value of the neutral current becomes smaller than the maximum current size of the upper and lower neutral current.

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