A Calculation Method of Neutral Current of Two Step type Pole in Distribution Line

K. W. Park, S. B. Rhee, H. C. Seo, C. H. Kim

Abstract—In most wye connected distribution system, a neutral current exist and flow on the neutral line because of unbalanced three-phase current. The neutral current which on the overhead distribution line, produces a harmful induce voltage to a communication line. So, the Korea Electric Power Corporation (KEPCO) restricts within 20% of neutral current compare with normal phase current in overhead distribution line. For reliable operation, a One Step Type Pole (OSTP) is changed into a Two Step Type Pole (TSTP). But, there are many different views whether unbalanced current increase or decrease in neutral wire. This paper conducts the calculation and analysis of neutral current in OSTP and TSTP using the equivalent circuit analysis, vector analysis and EMTP simulation. To compare and analyze neutral current according to the type of distribution pole, this paper carried out the simulation using EMTP by changing the simulation conditions.

Keywords: One Step Type Pole, Two Step Type Pole, Distribution Line, Equivalent Circuit Analysis, Vector Analysis, EMTP.

I. Introduction

THE OSTP and TSTP are used in KEPCO distribution line. When the three phases are unbalanced, the current in neutral wire of distribution line is not zero. Then, the unexpected induced voltage, which is on the communication line, can be generated by neutral current. To reduce and analyze the OSTP's neutral current, the previous researches have been accomplished by authors [1]. When the distribution poles change over from OSTP to TSTP for reliability, there are many different consideration view exist, one most important fact is whether unbalanced current in neutral wire increases or decreases by phase configuration, load change, and line impedance variation. This paper studies and analyzes about the neutral current both OSTP and TSTP in distribution line. And calculation methods, which based on equivalent circuit analysis and vector analysis, are presented for neutral current in distribution poles. In order to validate the calculation methods, various condition of phase configuration have been tested and compared with EMTP.

II. A Calculation of Neutral Current

A. *Cause of Unbalance*

On three-phase wye systems, neutral current is the vector sum of three line-to-neutral currents. With balanced, three-phase, which consist of sine waves spaced 120° apart, the sum at any instant in time is zero, and so there is no neutral current. But line impedances or load impedances of each phase is not equal to others, the unbalance is occurred in power system and at this time the neutral current is not zero.

B. *Calculation of Neutral Current of OSTP by Equivalent Circuit Analysis*

The equivalent circuit of wye-wye connected OSTP is as shown in Fig. 1[2].

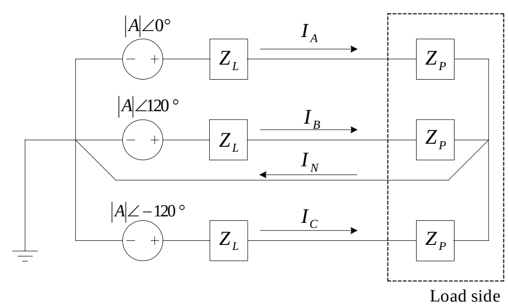

Fig. 1 Equivalent circuit of TSTP

In Fig. 1, Z_L and Z_P are line and load impedance. The line current can be written as below.

$$\bar{I}_A = \frac{\bar{A}\angle 0°}{Z_L + Z_P} \tag{1}$$

$$\bar{I}_B = \frac{\bar{A}\angle -120°}{Z_L + Z_P} \tag{2}$$

$$\bar{I}_C = \frac{\bar{A}\angle 120°}{Z_L + Z_P} \tag{3}$$

Then, with (1), (2), and (3) the neutral current is

$$\bar{I}_N = \bar{I}_A + \bar{I}_B + \bar{I}_C \tag{4}$$

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C. Calculation of Neutral Current at TSTP by Equivalent Circuit Analysis

If upper and lower side of TSTP has common ground and wye-wye connected, the equivalent circuit as shown in Fig. 2 [1].

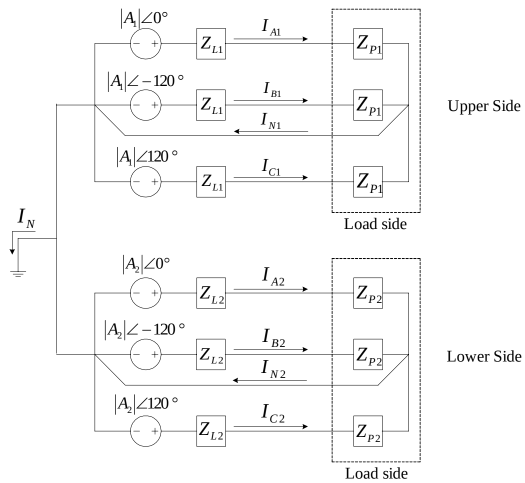


Fig. 2 Equivalent circuit of TSTP

The neutral current of a TSTP can be obtained by using principle of superposition. The total neutral current can be calculated as below.

$$I_{N1} = I_{A1} + I_{B1} + I_{C1} \quad (5)$$

$$I_{N2} = I_{A2} + I_{B2} + I_{C2} \quad (6)$$

$$I_N = I_{N1} + I_{N2} \quad (7)$$

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_N : Total neutral current

III. Calculation of Neutral Current at Distribution Pole Using EMTP

EMTP program is used for calculate the neutral current according to distribution pole type. The unbalanced condition is occurred at OSTP and TSTP, respectively, and it is simulated by using EMTP. The simulation results are compared and analyzed about each distribution pole type.

A. EMTP of Neutral Current at OSTP

The Fig. 3 shows the model system of OSTP. When the simulation is performed by using EMTP, the composition of distribution pole is using branch card and then the current in neutral line can be calculated.

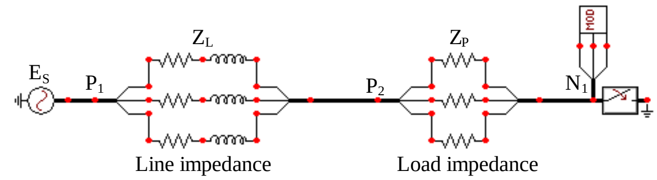


Fig. 3 Model system of OSTP by EMTP/ATPDraw

A balanced three-phase wye connected source with positive sequence has an internal voltage of 380[V] and load is connected ac BUS P_2. The neutral line is connected at BUS N_1, and the current in neutral can be measured [3].

B. EMTP of Neutral Current at TSTP

A TSTP is a type in which a neutral wire has common grounded, so that the composition of the model system used in EMTP simulation as shown in Fig. 4. When carrying out simulation using EMTP, the composition of a pole generates a branch card. By using the branch card like that, the system using as shown in Fig. 4 is composed and the neutral current is calculated by EMTP/MODELS.

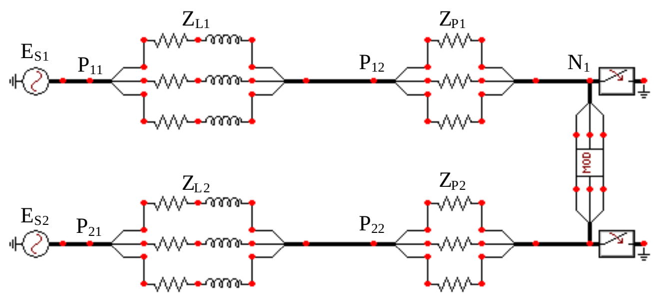


Fig. 4 Model system of TSTP by EMTP/ATPDraw

The balanced three-phase wye connected E_{S1} and E_{S2} sources have internal voltage of 380[V] and load is connected at BUS P_{12}, P_{22}. The neutral line is connected at BUS N_1, and the current in neutral line can be measured.

C. Equivalent Circuit Analysis Technique and Verification of Method using EMTP Simulation

Example 1; Line impedance of arbitrary one phase among the three phases in OSTP becomes twice.

The simulation result using EMTP must be equal to the calculation result of neutral current based on equivalent circuit analysis. The calculation result of neutral current based on equivalent circuit analysis is 22.68[A]. Fig. 5 shows instantaneous wave and maximum value of neutral current by EMTP simulation in case where line impedance become twice of OSTP. The maximum instantaneous value of simulation using EMTP is 22.68[A] as shown in Fig. 5.

Example 2; Line impedance of both upper and lower side in TSTP becomes twice.

The calculation result based on equivalent circuit analysis is 45.36[A]. EMTP simulation result is 45.362[A] as shown in Fig 6. In example 1 and 2, it is found that the simulation results by using EMTP are equal to calculation results of equivalent circuit analysis in both OSTP and TSTP. Therefore, equivalent circuit analysis and EMTP simulation of distribution pole are validated.

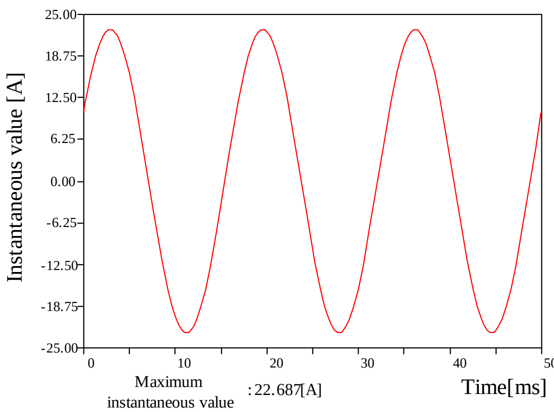


Fig. 5 Result of EMTP simulation at OSTP (example 1)

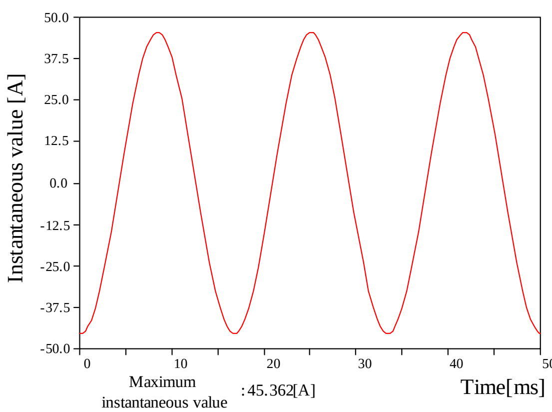


Fig. 6 Result of EMTP simulation at TSTP (example 2)

IV. CASE STUDY USING EMTP

For the case study of OSTP and TSTP, this paper used rms value for neutral current calculation and various simulation conditions considering in EMTP simulations. Table I, and II are simulation conditions of CASE A, and B. The rest simulation condition is listed in [1].

A. *In Case of OSTP*

Fig. 7 is compared value of neutral current by change of line impedance in OSTP. CASE A-1, A-2, A-3 value are 0.57618[A], 0.57618[A], and 0.577681[A] respectively in Fig. 7. There are differences with three cases in the graph however, substantially neutral current is similar.

TABLE I Simulation Conditions of A

CASE	Line Impedance Ratio	CASE	Line Impedance Ratio
A-1	A : 1.5 B : 1.5 C : 1.0	A-2	A : 1.5 B : 1.0 C : 1.5
A-3	A : 1.0 B : 1.5 C : 1.5		

TABLE II Simulation Conditions of B

CASE	Phase	Load Ratio	CASE	Phase	Load Ratio
B-1	A	1.2	B-2	A	1.5
	B	1.5		B	1.2
	C	1.0		C	1.0
B-3	A	1.5	B-4	A	1.2
	B	1.0		B	1.0
	C	1.2		C	1.5
B-5	A	1.0	B-6	A	1.0
	B	1.5		B	1.2
	C	1.2		C	1.5
B-7	A	1.2	B-8	A	1.2
	B	1.2		B	1.0
	C	1.0		C	1.2
B-9	A	1.0	B-10	A	1.2
	B	1.2		B	1.0
	C	1.2		C	1.0
B-11	A	1.0	B-12	A	1.0
	B	1.2		B	1.0
	C	1.0		C	1.2

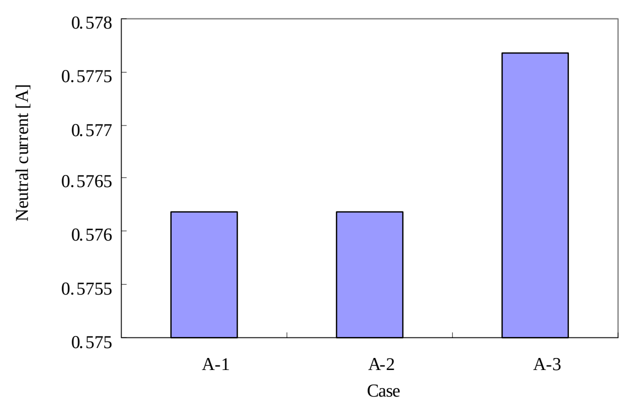


Fig. 7 The magnitude of neutral current by line impedance variation

Fig. 8 is that compared magnitude of neutral current by change of load impedance in one step type pole. In these cases is other two phase line impedance of three phases become twice, accordingly even if line impedance changes in what, neutral current is fixed almost.

Confirm that CASE B-1~B-6 become about 2 times than CASE B-7~B-9. Unbalanced load ratio of CASE B-1~B-6 are 1.2: 1.5: 1.0, that is A, B and C phases are changed by different ratio. And then, unbalanced ratio of CASE B-7~B-9 are 1.2: 1.2: 1.0, that is other two phases changed by same unbalanced ratio among three phases. Therefore, case that A, B and C phases in load of three phase changes by different ratio compared with case load ratio of any two phase of three phase is equal know that neutral current flows more. Also, B-10~B-12 is when load ratio changes by 1.0: 1.2: 1.0 and in this case, magnitude of neutral current is smallest. Through in theses cases, know that degree of unbalanced load is proportional in magnitude of neutral current.

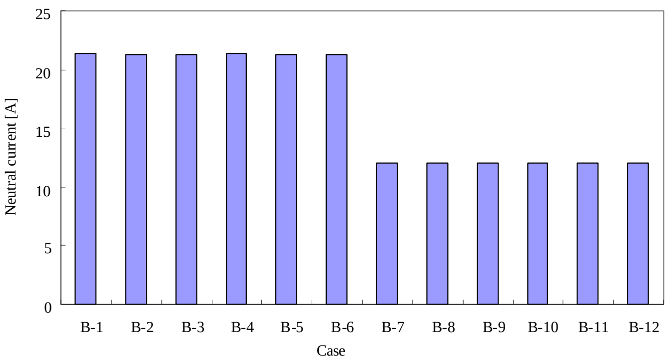


Fig. 8 The magnitude of neutral current by load impedance variation

B. In Case of TSTP

Fig. 9 is compared magnitude of neutral current when line impedance changed in TSTP. In case of C-1~C-7, that ratio of two phases among three phases in upper side is 1.5times, and ratio of remainder one phase is 1 time and established by ratio that lower side is identical. And then, CASE C-1 and C-6 are that line impedance same phases changed in upper and lower side. Except theses case(C-2~C-5 and C-7) are when line impedance of each other phases changed in upper and lower side.

Therefore, as shows in Fig.9, in case line impedance of same phase changed all, neutral current becomes 2 times in two step type pole and difference cases resemble with the others.

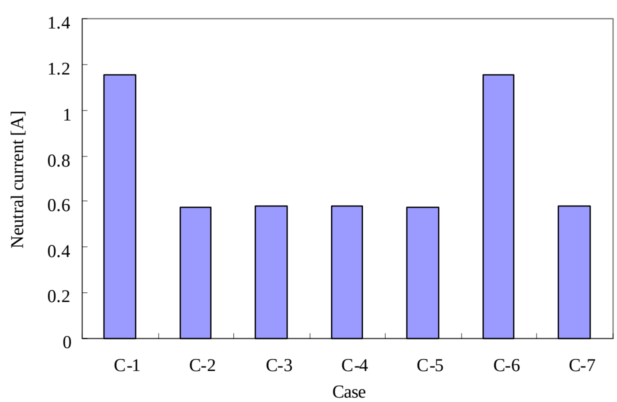


Fig. 9 The magnitude of neutral current by line impedance variation

Fig. 10 is expressed magnitude of neutral current by change of load impedance in TSTP. CASE-D (D-1~D-30) and E (E-1~E-8) are changed load. However, CASE-D is load ratio of two phases changed on three phases in upper or lower side and, CASE-E is different ratio only one phase of three phases. CASE-D is shows that three forms of neutral current. The largest values of neutral current are D-1, D-4, D-7, D-8, D-14, D-17, D-21, D-24, D-28, D-29, D-33, D-36. It can provably that the next largest cases are D-5, D-6, D-10, D-12, D-15, D-16, D-19, D-20, D-25, D-27, D-32, D-35. The load impedance ratio in upper and lower side is fixed that 1.2:1.2:1.0, 1.2:1.0:1.2 and 1.0:1.2:1.2 and, the load ratio of other side is 1.2:1.5:1.0 that is variable variously.

Sum of maximum load impedance is 2.7 (1.2+1.5) in some specific phase. The smallest case in CASE-D is D-2, D-3, D-9, D-11, D-13, D-18, D-22, D-23, D-26, D-30, D-31, and D-34.

In this case, load impedance ratios in upper and lower side are equality, but the sums of maximum load impedance in specific phases are 2.4.

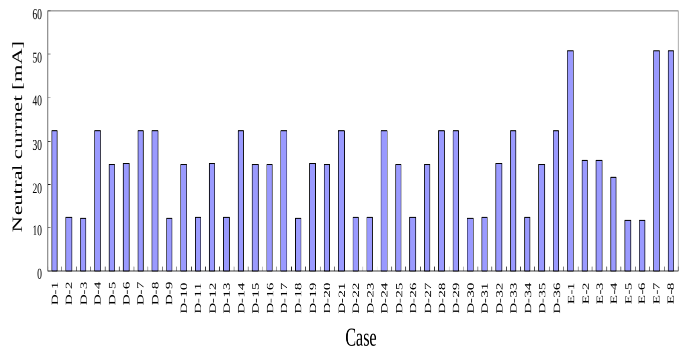


Fig. 10 The magnitude of neutral current by load impedance variation

In the case of E is expressed magnitude of neutral current of four forms. The largest magnitudes of neutral current are E-1, E-7, E-8. Maximum load impedance is 1.5 times, and composite of maximum load impedance is 3.0(1.5+1.5) on specific one phase in upper and lower side. The next large values are E-2, E-3. Maximum load impedance is 1.5 times and does not have composite of maximum load impedance in same phases of upper and lower side. It can provably that the next large cases are E-4, and smallest cases are E-5 and E-6. Composite of load impedance is 2.2. As a result, it can be confirmed that the neutral current will also become larger in specific phase of higher unbalance load ratio.

C. Compare OSTP with TSTP

Fig. 11 is compare case that line impedance changed in one step type pole and two step type pole. It knows that C-1 and C-6 become 2 times than other cases in Fig. 11. This is that line impedance of same phases changed in upper and lower side in two step type pole.

There is no particular difference when compare one step type pole and two step type pole in different cases. Therefore, if the load impedance of same phase in upper and lower side changes, the neutral current become 2 times then the case where the line impedance in different phases change. While, the load impedance of difference phases in upper and lower side changes, magnitude of neutral current in two step type pole is not become 2 times than one step type pole and that is analogous to magnitude of neutral current in one step type pole. Actually, probability that line impedance changes is rare extremely.

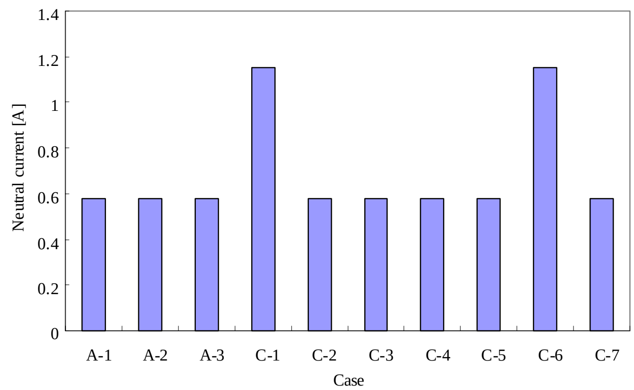


Fig. 11 The magnitude of neutral current by line impedance variation in distribution pole

D. *Result of Simulation and Analysis using EMTP*

The rms value of the neutral current in OSTP and TSTP according to variance of line impedance and load impedance are calculated using EMTP. And the calculation results of the distribution poles are following.

a. In case of TSTP, when line impedance or load impedance of a different phases changes, neutral current of TSTP is similar to that of OSTP. However, if the load impedance of same phases in upper and lower side changes, the neutral current become 2 times than the case where the line impedance in different phases change.
.

b. Regardless of a type of pole, neutral current is more increased in case where line impedance changes than case where load impedance changes.

c. In case of a TSTP, when line impedance or load impedance changes of the same phase in the upper side and lower side, the larger neutral current flows.

d. In case of a OSTP, when line impedance on arbitrary two phases changes, the neutral current is almost constant regardless of the changed phase.

e. In case of a OSTP, the larger unbalance degree of load increases, the more magnitude of neutral current increases.

f. In case of a TSTP, when the unbalance degree is the same, the more total of unbalance ratio of upper side and lower side are large, the more neutral current increases.

e. In case of a TSTP, the larger total of maximum load capacity among three-phase load capacity ratio and the more phase indicating the total of maximum load capacity, the more neutral current increases.

V. Verification by Vector Analysis

To verify neutral current by the type of distribution pole, vector analysis technique is applied [4][5]. CASE 1 is the case that the line impedance on upper and lower side in the same phase changes and CASE 2 is the case that the line impedance upper and lower side in the different phases changes. As a result of calculation of neutral current based on equivalent circuit analysis in these two cases, neutral current of CASE 1 becomes almost twice as compared with CASE 2.

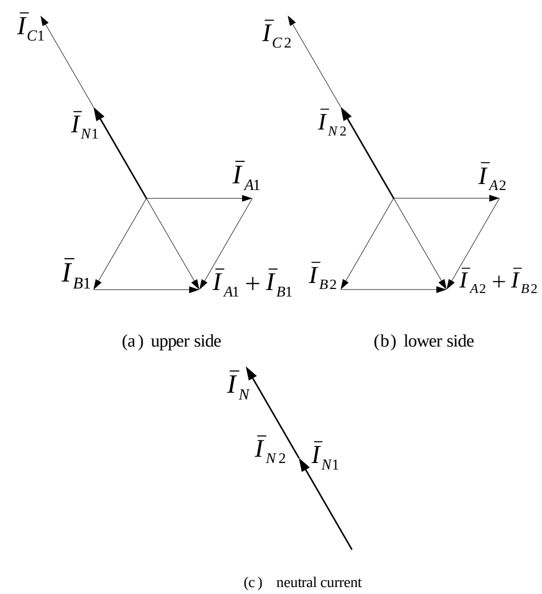


Fig. 12 Magnitude neutral current in CAES 1 of two step type pole

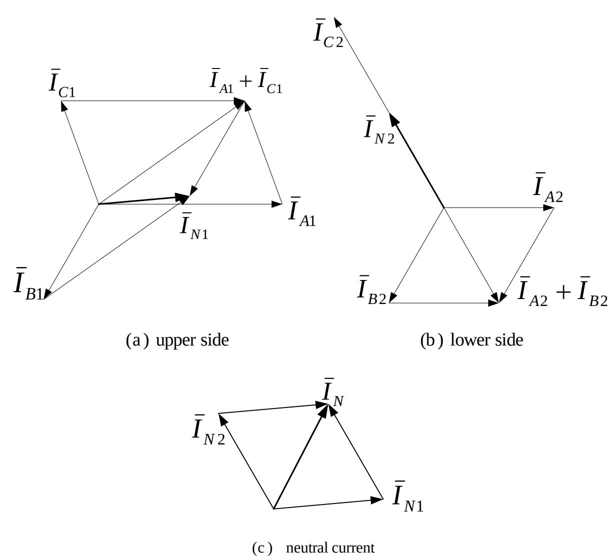
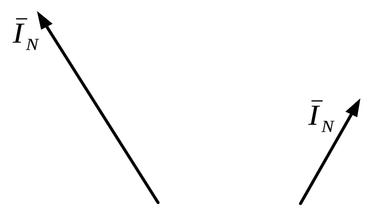


Fig. 13 Magnitude of neutral current in CAES 2 of two step type pole

Fig. 12 shows resultant vector of CASE 1 in TSTP. Also, Fig. 13 shows resultant vector of CASE 2 in TSTP.

The magnitude of neutral current is obtained using resultant vector of three-phase in CASE 1 and CASE 2 of TSTP. Fig. 14 shows direct composition of neutral current in CASE and CASE 2.

As shown in Fig. 14 in case of TSTP, when line impedance of same phase on upper and lower side changes, neutral current becomes twice. However, as a result of vector analysis in case where unbalance of different phase occurs on upper and lower side, it can be ascertained that neutral current does not become twice.



(a) Case 1 (b) Case 2

Fig. 14 The comparison of neutral current in CASE 1 and CASE 2

VI. Conclusions

This paper calculates the neutral current of OSTP and TSTP using equivalent circuit analysis and vector analysis, and the EMTP is used to verify the theoretical analysis. Also, various cases are simulated by using EMTP in respect of the current of OSTP and TSTP and the simulation results are analyzed. The simulation results show that the neutral current in cases of TSTP does not always become twice as compared with that of OSTP and these results are verified by vector analysis.

VII. References

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VIII. Biographies

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Hun-Chul Seo was born in Korea on January 19, 1982. He received the B.S. degrees and M.S. degrees in electrical and computer engineering from Sungkyunkwan University, Korea, in 2004 and 2006, respectively. He has been worked for Korea Electrical Engineering and Science Research Institute. His current research interests include power system transients. Now he is preparing doctor’s thesis in Sungkyunkwan University.

Chul-Hwan Kim was born in Korea on January 10, 1961. In 1990 he joined Cheju National University, Cheju, Korea, as a Full-time Lecturer. He has been a visiting academic in university of BATH, UK, in 1996, 1998 and 1999. Since March 1992, he has been a Professor in School of Electrical and Computer Engineering, Sungkyunkwan University, Korea. He is research interests include power system protection, artificial intelligence application to protection and control, the modeling/protection of underground cable and the EMTP software. He received B.S and M.S degree in Electrical Engineering from Sungkyunkwan University, Korea, 1982 and 1984, respectively. He received a PH.D in Electrical engineering from Sungkyunkwan University in 1990.