A Model for Analysis the Induced Voltage of 115 kV On-Line Acting on Neighboring 22 kV Off-Line

S. Woothipatanapan, S. Prakobkit

Abstract—This paper presents a model for analysis the induced voltage of transmission lines (energized) acting on neighboring distribution lines (de-energized). From environmental restrictions, 22 kV distribution lines need to be installed under 115 kV transmission lines. With the installation of the two parallel circuits like this, they make the induced voltage which can cause harm to operators. This work was performed with the ATP-EMTP modeling to analyze such phenomenon before field testing. Simulation results are used to find solutions to prevent danger to operators who are on the pole.

Keywords—Transmission system, distribution system, induced voltage, off-line operation.

I. INTRODUCTION

INDUCED voltage that occur between distribution system and transmission system can do harm to the operators, such as injury or death. Effect of such induced voltage was taken as the point for analysis.

The induced voltage of a 22 kV distribution system which has a 115 kV transmission system mounted on the same poles arises as a result of the magnetic and electric fields. The induced voltage occurs when the current flowing in the 115 kV transmission lines. The magnitude of the induced voltage depends on the size of the current in the 115 kV system, distance of the grounding point of 22 kV system, form of the lines placement, and the size of the voltage in the power supply circuit [1]–[3].

This article has calculated the value of the induced voltage by the effects of electromagnetic fields in normal and fault conditions of 115 kV with balanced load. Estimate equations and program ATP-EMTP are used to calculating such values for safe operation compliant with the IEEE standard, as in [4].

II. PRINCIPLES

For determining the induced voltage of 1 phase power distribution system, starting from the analysis of the electromagnetic field between the 115 kV on-line power system which is parallel to the 22 kV off-line power system. Using the example of the mutually coupled in phase-A for analysis and calculate the value of the induced voltage, such equivalent circuit is shown in Fig. 1.

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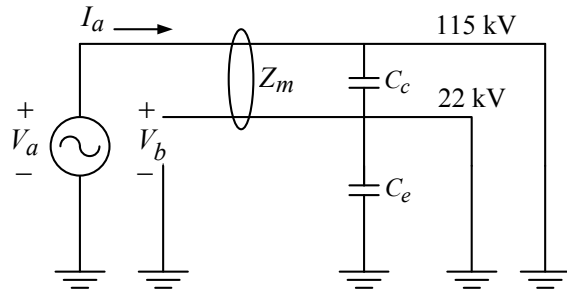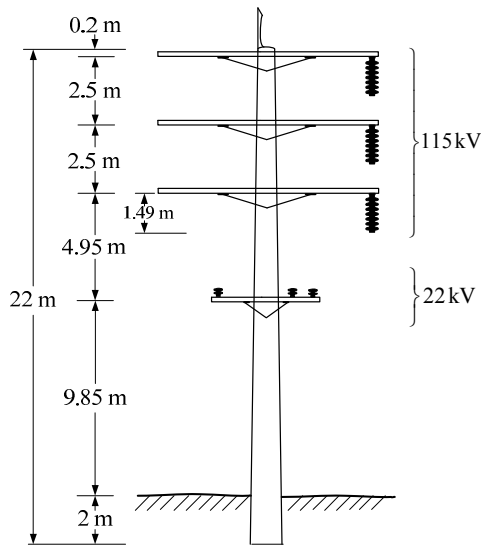
Fig. 1 Equivalent circuit of mutually couple for 1 phase system

From Fig. 1, the equation to calculate the induced voltage caused by the effects of magnetic fields [5] can be found as,

$$V_b = Z_m I_a \tag{1}$$

where, Z_m is the mutual impedance of 115 kV system - 22kV system. I_a represent the load current of 115 kV system.

Furthermore, from Fig. 1, the equation of the induced voltage caused by electric field [5] can be expressed as,

$$V_b = \frac{C_e}{C_e + C_c} V_a \tag{2}$$

where, C_e and C_c denote the capacitance of 22 kV system - ground and 115kV system - 22 kV system, respectively. V_a is the phase voltage of 115 kV system.

For calculating the induced voltage of 3-phase power distribution system [6], lines placement will be arranged as shown in Fig. 2, and such equivalent circuit is shown in Fig. 3.

From Fig. 3, an equation to find the induced voltage for 3 phase system can be found as,

$$V_{in} = Z_{ma} I_a + Z_{mb} I_b + Z_{mc} I_c \tag{3}$$

where, Z_{ma}, Z_{mb}, and Z_{mc} represent the mutual impedance of 115 kV system – 22 kV system in phase-A, the mutual impedance of 115 kV system – 22 kV system in phase-B, and the mutual impedance of 115 kV system – 22 kV system in phase-C, respectively. I_a, I_b, and I_c denote the load current of 115 kV system in phase-A, the load current of 115 kV system in phase-B, and the load current of 115 kV system in phase-C, respectively.

Fig. 2 Lines placement of 115 kV and 22 kV systems
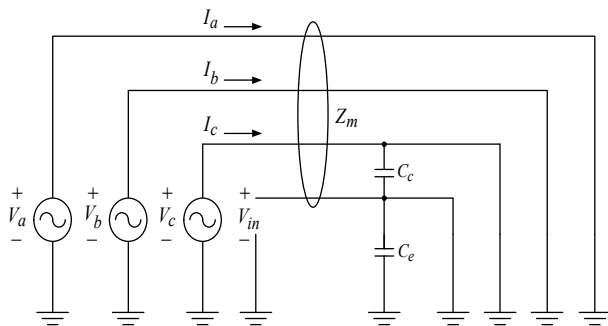
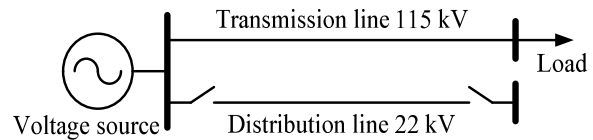Fig. 3 Equivalent circuit of mutually couple for 3 phase system

Fig. 4 Single-line diagram of transmission and distribution systems
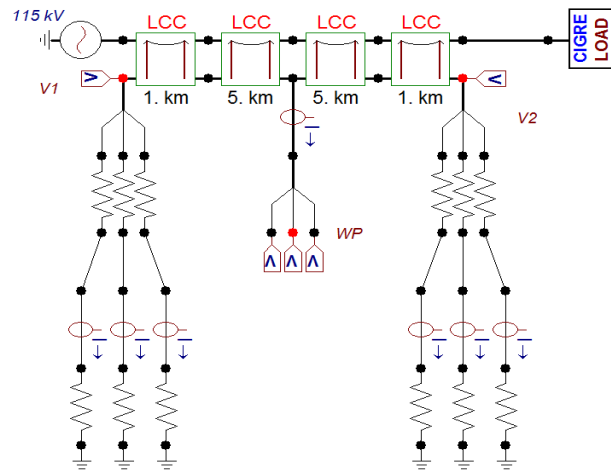
Fig. 5 Equivalent circuit obtained by using program ATP-EMTP

TABLE I
FEATURES OF THE SYSTEM

Features	System	
	115 kV	22 kV
size of conductor (mm^2)	400	185
number of conductor	2	1
outside diameter of conductor (cm)	1.283	0.882
resistance of conductor (Ω/km)	0.055	0.055
distance between conductor and ground		
phase-A (m)	17.05	10.33
phase-B (m)	14.55	10.33
phase-C (m)	12.05	10.33
sag		
phase-A (m)	16.34 m	9.47 m
phase-B (m)	13.84 m	9.47 m
phase-C (m)	11.34 m	9.47 m
resistance of ground (Ω)	100	
resistance of ground-rod (Ω)	5	

kV = kilovolt, mm^2 = square millimeter, km = kilometer, m = meter, Ω = ohm.

III. THE SIMULATION OF TRANSMISSION AND DISTRIBUTION SYSTEMS

Transmission and distribution system used in this study were 115 kV and 22 kV (radial type) as shown in Fig. 4. Given distance of transmission lines and distribution lines from the power station to load is not more than 23 km.

The induced voltage of a 22 kV off-line distribution power system that has a 115 kV on-line transmission power system mounted on the same poles can be obtained by simulating with program ATP-EMTP. Assigned to the transmission system and the distribution system have a distance of 12 km, and the operators work away from the source by a distance of 6 km. The equivalent circuit in such case that using program ATP-EMTP is presented in Fig. 5.

Cable type of the transmission lines is All Aluminum Conductors (AAC), and cable type of the distribution lines is Partial Insulated Cable (PIC). Features of the system used in the simulation are displayed as the average values in Table I.

IV. SIMULATION RESULTS

A. Operation without Grounding of a 22 kV System

This case study has simulated the operation of a 22 kV off-line system without grounding. The induced voltage is divided into three points, i.e., source, endways, and work point, which voltage waveforms of the induced voltage in these position are shown in Figs. 6, 7, and 8, respectively.

Simulation results of such cases are recorded in Table II, it shows that the maximum induced voltage occurs at phase-A.
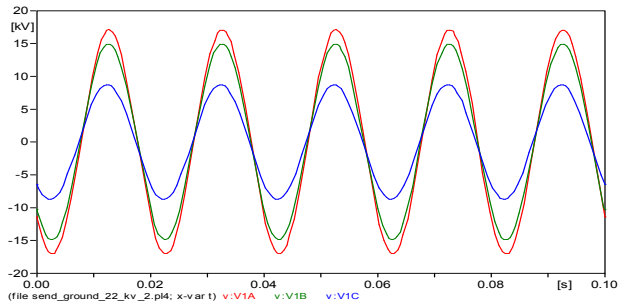
Fig. 6 Simulated induced voltage at source of a 22 kV system without grounding
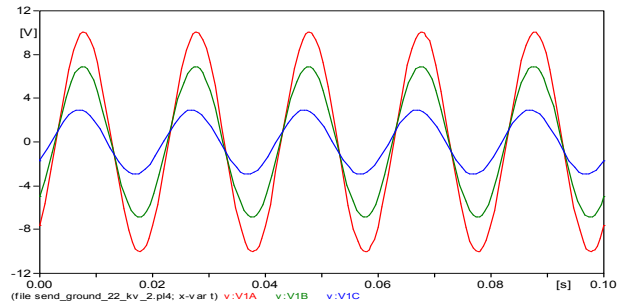

Fig. 9 Simulated induced voltage at source of a 22 kV system with grounding at source
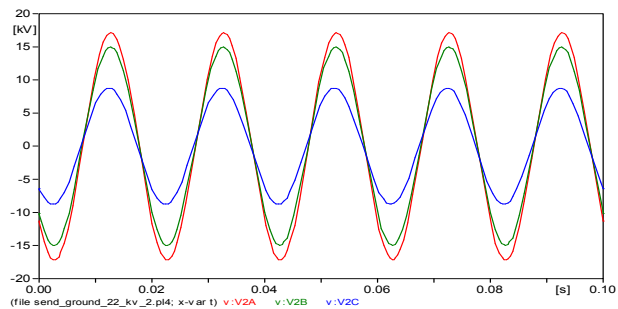

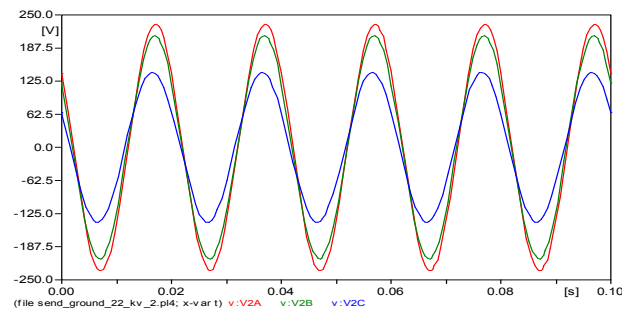Fig. 7 Simulated induced voltage at endways of a 22 kV system without grounding

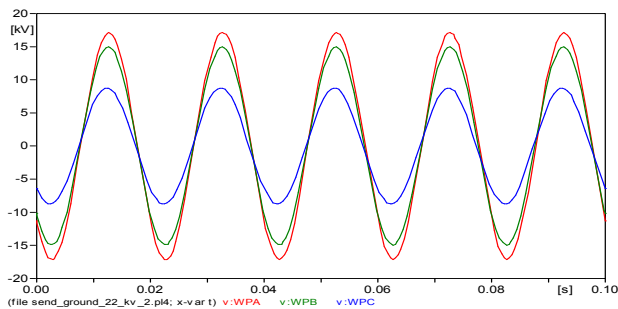Fig. 10 Simulated induced voltage at endways of a 22 kV system with grounding at source

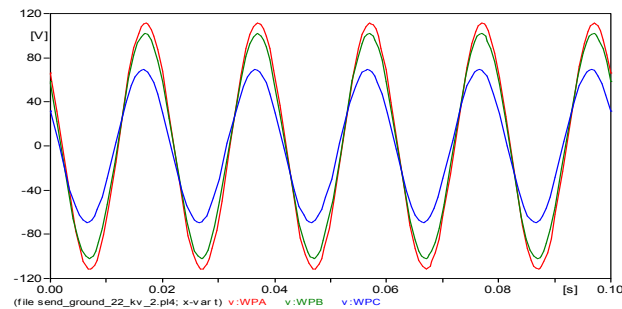Fig. 8 Simulated induced voltage at work point of a 22 kV system without grounding

Fig. 11 Simulated induced voltage at work point of a 22 kV system with grounding at source

TABLE II
SIMULATION RESULTS OF A 22 KV SYSTEM WITHOUT GROUNDING

Position	Phase		
	A	B	C
induce voltage at source (kV)	17.07	14.91	8.72
induced voltage at endways (kV)	17.07	14.91	8.76
induced voltage at work point (kV)	17.09	14.91	8.74

kV = kilovolt.

B. Operation with Grounding at Source of a 22 kV System

This case study has simulated the operation of a 22 kV system with grounding at source, which has an impedance of $100\,\Omega$. The simulated induced voltage waveforms at source, endways, and work point can be shown in Figs. 9, 10, and 11, respectively. Fig. 12 shows the current caused by the induced voltage.
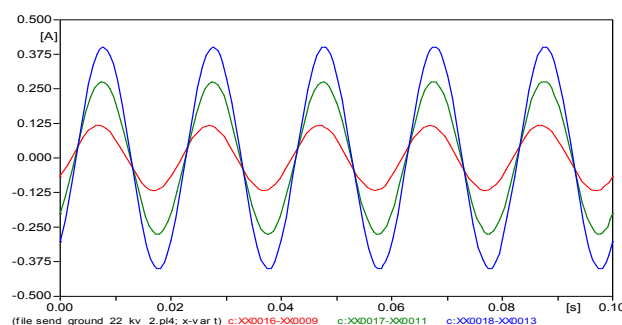

Fig. 12 Simulated current caused by induced voltage of a 22 kV system with grounding at source

Simulation results from operation with grounding at source of a 22 kV power distribution system are summarized in Table III. It can be seen that the maximum induced voltage appears

at phase-A in all the test position, while the maximum current generated by the induced voltage of phase-C which is the minimum induced voltage.

TABLE III
SIMULATION RESULTS OF A 22 KV SYSTEM WITH GROUNDING AT SOURCE

Position	Phase		
	A	B	C
induce voltage at source (kV)	10.03	6.89	2.94
induced voltage at endways (kV)	231.96	210.17	141.15
induced voltage at work point (kV)	111.22	101.67	69.11
current caused by induced voltage (A)	0.11	0.28	0.40

kV = kilovolt, A = ampere.

C. Operation with Grounding at Source and Endways of a 22 kV System

This case study has simulated the operation of a 22 kV system with grounding at source and endways, which has an impedance of $100\,\Omega$. Waveforms of induced voltage from simulation at source, endways, and work point can be shown in Figs. 13, 14, and 15, respectively. The current generated by the induced voltage is shown in Fig. 16.

Simulation results from operation with grounding at source and endways of a 22 kV power distribution system are summarized in Table IV. Notice that the maximum induced voltage occurs at phase-A in all the test position, while the maximum current generated by the induced voltage of phase-C as in the previous section.
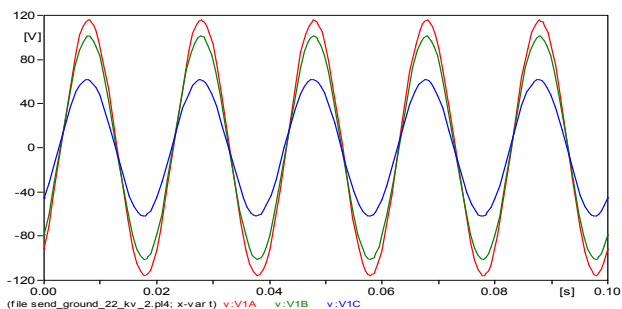

Fig. 13 Simulated induced voltage at source of a 22 kV system with grounding at source and endways
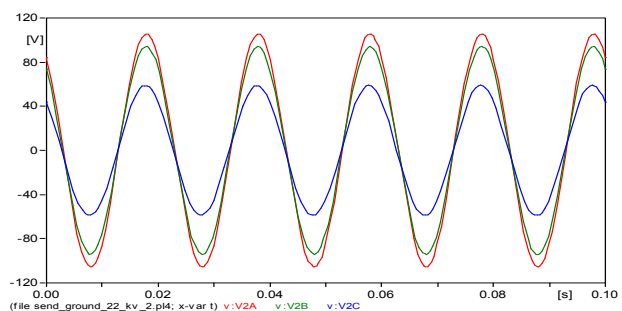

Fig. 14 Simulated induced voltage at endways of a 22 kV system with grounding at source and endways
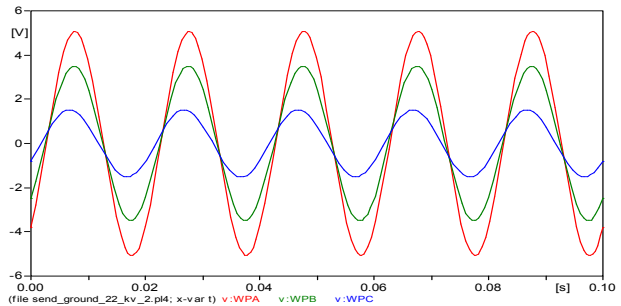

Fig. 15 Simulated induced voltage at work point of a 22 kV system with grounding at source and endways
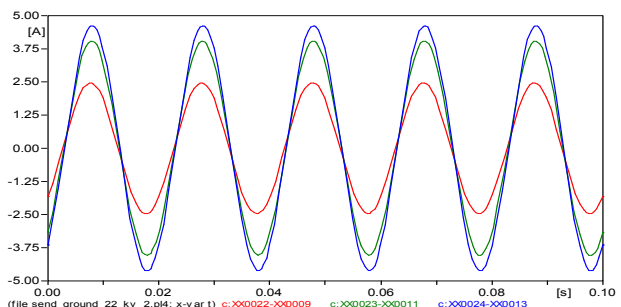

Fig. 16 Simulated current caused by induced voltage of a 22 kV system with grounding at source and endways

TABLE IV
SIMULATION RESULTS OF A 22 KV SYSTEM WITH GROUNDING AT SOURCE AND ENDWAYS

Position	Phase		
	A	B	C
induce voltage at source (kV)	115.48	100.88	61.61
induced voltage at endways (kV)	105.45	94.00	59.74
induced voltage at work point (kV)	5.06	3.49	1.51
current caused by induced voltage (A)	2.46	4.04	4.62

kV = kilovolt, A = ampere.

D. Operation with Grounding at Source and Endways of a 22 kV System When a Fault Occurs in 115 kV System

This case study has simulated the operation of a 22 kV with grounding at source and endways when a fault occurs at 0.05 second in a 115 kV system. The simulated induced voltage waveforms at work point are shown in Fig. 17.
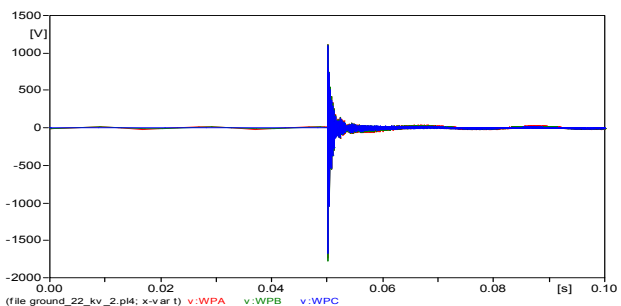

Fig. 17 Simulated induced voltage of a 22 kV system with grounding at source and endways when fault occurs in a 115 kV system

From simulation results in Fig. 17, it can be seen that the maximum induced voltage is 1,770 V. All values of simulated induced voltage occurs at the work point in each pattern are summarized in Table V.

TABLE V
SIMULATED INDUCED VOLTAGE AT WORK POINT IN EACH PATTERN

Pattern	Induced Voltage (V)
without grounding	1,709
grounding at source	111.22
grounding at source and endways	5.06
grounding at source and endways when a fault occurs in 115 kV system	1,770

V = volt, kV = kilovolt.

V. CONCLUSION

The induced voltage arising from 22 kV off-line distribution systems come from two main reasons. The first reason was the effects of magnetic fields which are based on the pattern of wiring, the resistance of grounding point, the magnitude and balancing of current in the 115 kV on-line transmission system that is installed above such distribution system. Another reason stems from the effect of electric fields, depending on the magnitude of voltage above the distribution system.

The simulation showed that off-line operating in a 22 kV power distribution system without grounding will make high induced voltage which cause harm to the worker. When grounding at source of the distribution system, the induced voltage at work point is reduced. When grounding at source and endways of the distribution system, the induced voltage at work point is minimum.

It should be grounded at the source and endways of the work point in the distribution system to reduce the effect of induced voltage caused by electric field. Operators must wear rubber gloves with leather gloves at all times to reduce the effect of induced voltage caused by a magnetic field. Moreover, the distribution system should be grounded at work point to make the impedance that paralleled with the worker is less valuable. In compliance with the recommendation, it can reduce harm in the event of electrical contact between the on-line and the off-line circuit which resulted in a safety for operators.

ACKNOWLEDGMENT

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