Analysis of the Operation of 115 kV Rated Circuit Breakers for the Maintenance and Stabilization of Power Distribution

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Supawud Nedphokaew
Department of Electrical Engineering
Faculty of Engineering
Rajamangala University of Technology
Phra Nakhon
Bangkok, Thailand
supawud.n@rmutp.ac.th

Nattachote Rugthaicharoencheep
Department of Electrical Engineering
Faculty of Engineering
Rajamangala University of Technology
Phra Nakhon
Bangkok, Thailand
nattachote.r@rmutp.ac.th

Pakawat Kerpasit
Department of Mechanical Engineering
Faculty of Industrial Education
Rajamangala University of Technology
Phra Nakhon
Bangkok, Thailand
pakawat.k@rmutp.ac.th

Natchapol Ruangsap
Department of Electrical Engineering
Faculty of Engineering
Rajamangala University of Technology
Phra Nakhon
Bangkok, Thailand
natchapol@ieee.org

***Abstract*—Due to the current practice of the Electricity Generating Authority of Thailand (EGAT) using mesh fences around high voltage substations, and with transmission lines running parallel to these fences, induced voltage can occur on the mesh fences. Therefore, this research aims to study the theory of induction on the mesh fences of high voltage substations constructed parallel to the transmission lines, determining the induced voltage on the mesh fences. Additionally, it presents methods to mitigate the effects of induced voltage and current on the mesh fences to ensure the safety of individuals who come into contact with them.**

This research investigates the induction on the mesh fences of high voltage substations operating at 115 kV using the Electromagnetic Transient Program/Alternative Transient Program (EMTP/ATP) to simulate the transmission towers and mesh fences of EGAT. The study results, particularly when the mesh fences are grounded at both ends (at the starting and ending points) into the substation's ground grid system, show that the voltage and current at each node are minimal and do not pose any harm to human contact, regardless of the contact duration (according to IEC 60364 standards).

Keywords—115 kV Circuit Breaker, Maintenance, Stabilization of Power Distribution

I. Introduction

Currently, the population living near high-voltage substations is increasing because people believe that these substations bring prosperity to the community. Therefore, it is necessary to construct fences around high-voltage substations to prevent dangers from the public entering the substations. The reason for using chain-link fences is because they are easy to dismantle and construct, especially when additional transmission lines need to be installed to meet electricity demand.

Fences that run parallel to the transmission lines can induce coupling between the transmission lines and the chain-link fences in terms of inductive and capacitive effects due to currents and voltages in the transmission lines. Paddle type transmission line model is shown in Fig. 1.

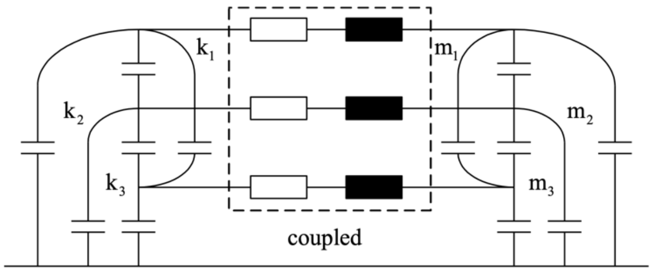

Fig. 1. Paddle type transmission line model.

Mitigating the impact of induced voltage:

- Proper Grounding Connection: Properly connecting the fence to the ground to reduce induced voltage.
- Use of Non-magnetic Materials: Using non-magnetic materials in constructing the fence to reduce electromagnetic induction.
- Increasing Distance: Positioning the fence further away from high-voltage power lines to decrease electromagnetic induction.

In 2011, Prasit Mongkholkaset and colleagues conducted an analysis on the effects of induced voltage. They measured corona discharge voltages generated by electric and magnetic fields using voltage transformers. These measurements were then compared with simulations from the ATP/EMTP program, which models 115 kV transmission lines and 22 kV distribution lines. The study aimed to assess the impact of electrostatic and capacitive coupling-induced voltages. Their analysis, employing ATP/EMTP simulations, also evaluated the environmental effects in proximity to transmission lines [1]. In 2012, A. Isaramongkolrak conducted an analysis on the influence of magnetic fields around the ground and conductors of 115 kV transmission lines. The study was divided into two cases: a single-circuit setup with individual conductors and a single-circuit setup with bundled conductors. The research emphasized comparing these two case studies. The findings indicated that magnetic field values at ground level and around the individual conductors in the single-circuit configuration were lower compared to those around the bundled conductors

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[2]. In 2016, Ketsana Ratanalangsy and colleagues conducted a study on induced voltages in parallel 115-kilovolt transmission lines caused by electric induction. The research examined how induced voltages correlate with the distance between parallel transmission lines and the neutral conductor. This investigation utilized the alternative transient program - electromagnetic transient program (ATP-EMTP) for testing. The findings indicated that induced voltages decrease as the distance between transmission lines increases [3].

Therefore, this paper study of the induced voltage and current on the mesh fence of a high voltage substation, which runs parallel to a live transmission line. The study focuses on a 115 kV transmission line circuit parallel to the mesh fence at an average distance of 6.0 meters, and examines the grounding effects within the system from the Phetchaburi high voltage substation to the Cha-am high voltage substation. The objectives of the article are:

- To study the theory of corona discharge on the mesh fence of a high-voltage substation parallel to the transmission lines.
- To investigate the effects of corona discharge on the mesh fence of a high-voltage substation.
- To study solutions for mitigating the effects of voltage and current induced by corona discharge on the mesh fence of a high-voltage substation, particularly through grounding methods, aiming to enhance human safety around the substation fence.

II. Calculation of Transmission System Parameters

Double circuit high-voltage transmission tower is shown in Fig. 2.

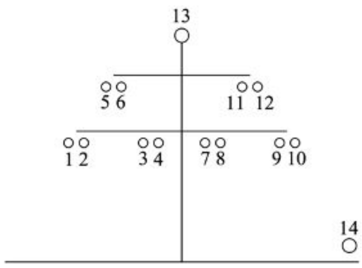

Fig. 2. Double-circuit high-voltage transmission tower.

Fig. 2. illustrates the components of a double-circuit transmission tower, which includes one ground wire, two sets of three-phase conductors (six phase conductors in total), and one line of fencing. Line phase 13 is earth line. Line phase 14 is mesh fence.

The impedance matrix of the 14-wire conductor will be described in terms of the impedance matrix 14x14 and calculated using Carson's formula, which considers the effects of the Earth return path is shown in Fig. 3.

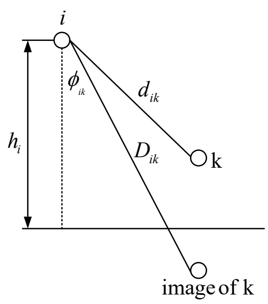

Fig. 3. Double-circuit high-voltage transmission tower.

Where:

- R_i is conductor wire resistance (Ω/km)
- H_i is average height above ground of conductor cable (m)
- D_{ik} is distance between conductor i and image of the conductor, kilograms (m)
- d_{ik} is distance between conductor i and other conductors, kilograms (m)
- GMR_i is geometric mean radius of the conductor (m)
- ω is angular frequency
- $\Delta R, \Delta X$ is Carson's correction, which considers the effect of Ground return.

The equation for the voltage between the phase conductor and the ground of a 14-conductor line, as well as the ground and the charge on the conductors, is related to Maxwell's potential coefficients and can be calculated in equation (1)

$$\begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ \vdots \\ V_{14} \end{bmatrix} = \begin{bmatrix} P_{1,1} & P_{1,2} & P_{1,3} & \cdots & P_{1,14} \\ P_{2,1} & P_{2,2} & P_{2,3} & \cdots & P_{2,14} \\ P_{3,1} & P_{3,2} & P_{3,3} & \cdots & P_{3,14} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ P_{14,1} & P_{14,2} & P_{14,3} & \cdots & P_{14,14} \end{bmatrix} \begin{bmatrix} Q_1 \\ Q_2 \\ Q_3 \\ \vdots \\ Q_{14} \end{bmatrix} \quad (1)$$

III. Calculation of Induced Voltage and Current

When a mesh fence is erected parallel to transmission lines, it can lead to induced coupling between the transmission lines and the fence. This induced coupling manifests in two distinct ways: electrostatic coupling and electromagnetic coupling.

A. Calculation of electrostatic induction

1) Calculation of induced voltage due to static electricity.

From equation (1) specifies that voltages on conductors 1 to 6 are supplied as a matrix $[V_e]$, while voltages on conductors 7 to 12 and conductor 14, which is not supplied with power, are represented as matrix $[V_d]$.

$$\begin{bmatrix} V_e \\ V_d \end{bmatrix} = \begin{bmatrix} P_e & P_{ed} \\ P_{de} & P_d \end{bmatrix} \begin{bmatrix} Q_e \\ Q_d \end{bmatrix} \quad (2)$$

The circuit that is not supplied with power does not have a grounding connection. Therefore, $Qd = 0$.

$$[V_d] = [P_{de}][Q_e] \quad (3)$$

2) Calculation of induced current due to static electricity.

$$[Q_d] = [P_d]^{-1}[V_d] \quad (4)$$

$$[I] = j2\pi fl[Q_d] \quad (5)$$

Where:

f is frequency unit is Hertz (Hz).

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l is the length of the transmission line is measured in meters.

B. Calculation of Electromagnetic induction

$$\begin{bmatrix} V_e \\ V_d \end{bmatrix} = \begin{bmatrix} Z_e & Z_{ed} \\ Z_{de} & Z_d \end{bmatrix} \begin{bmatrix} I_e \\ I_d \end{bmatrix} \quad (5)$$

1) Calculating induced voltage due to electric magnetic field.

A circuit not powered has grounding.

$$\left[V_d\right] = \left[Z_{de}\right]\left[I_e\right] + \left[Z_d\right]\left[I_d\right] \quad (6)$$

The circuit that is not powered does not have a grounding connection.

$$\left[V_d\right] = \left[Z_{de}\right]\left[I_e\right] \quad (7)$$

2) Calculating the induced current due to electromagnetic induction.

The circuit that is not supplied with electricity has a grounding connection.

$$\left[I_d\right] = \left[Z_d\right]^{-1}\left[Z_{de}\right]\left[I_e\right] \quad (8)$$

IV. Test System

Study of the induced voltage and current on the mesh fence of a high voltage substation, which runs parallel to a live transmission line. The study focuses on a 115 kV transmission line circuit parallel to the mesh fence at an average distance of 6.0 meters, and examines the grounding effects within the system of the Electricity Generating Authority of Thailand (EGAT) from the Phetchaburi high voltage substation to the Cha-am high voltage substation. The case study is divided into four scenarios:

Case 1: mesh fence without grounding.

Case 2: mesh fence grounded on one side.

Case 3: mesh fence grounded on both sides.

Case 4: mesh fence grounded on both sides to the substation ground grid system.

TABLE I. Properties and Sizes of Conductors

Data	Capacity
Voltage level	115 kV
Type of conductor	477 MCM AAC
Number of Al/St stranded wires	19
Outer diameter of conductor (mm)	4.025
Inductive free actant (ohms/km)	0.2781
Resistance at 50 hertz (ohms/km)	0.119
Maximum current carrying capacity (amperes)	600
Number of wires per phase (lines)	1
Number of ground wires (lines)	1
Soil resistance (ohms/km)	100

TABLE II. Properties and Shape of Transmission Towers

Data	Capacity
Voltage level	115 kV
Pole type	Single circuit
Type of arrangement of conductors	Triangle
Number of ground wires (lines)	1
Maximum Sag (meters)	12
Distance from ground of lowest conductor to maximum ground clearance (Ground Clearance) (meters)	12

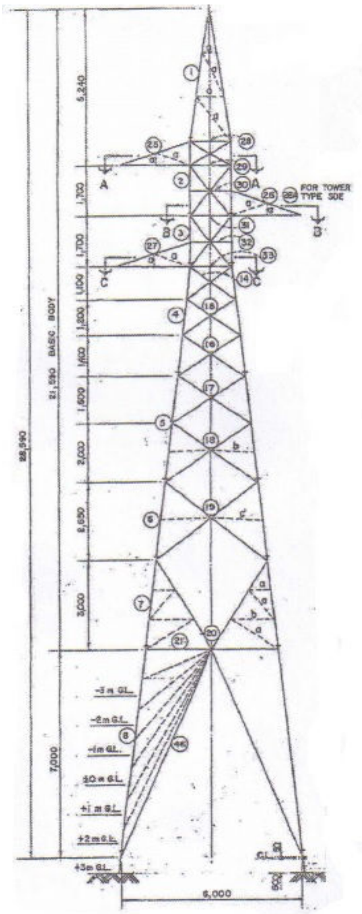

Fig. 4. The structure of the 115 kV transmission tower from Phetchaburi high voltage substation to Cha-am high voltage substation in Thailand.

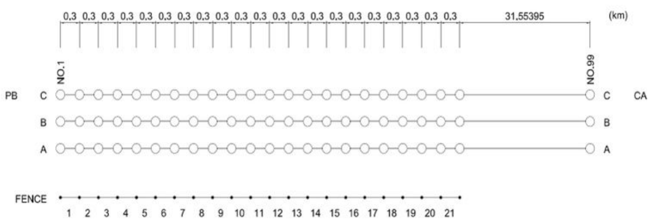

Fig. 5. The phase arrangement of the 115 kV transmission line from Phetchaburi high voltage substation to Cha-am high voltage substation.

V. Results

The results of the induced voltage magnitudes at various nodes on the mesh fence of the Phetchaburi high voltage substation is shown in Table III.

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TABLE III. THE RESULTS OF THE INDUCED VOLTAGE MAGNITUDES AT VARIOUS NODES ON THE MESH FENCE OF THE PHETCHABURI HIGH VOLTAGE SUBSTATION.

Node	Induced voltage magnitudes (V)			
	Case 1	Case 2	Case 3	Case 4
1	4.45	3.32	4.91	1.29
2	3.36	2.24	3.84	0.74
3	2.32	1.20	2.81	0.25
4	1.32	0.25	1.83	0.23
5	0.40	0.75	0.93	0.62
6	0.47	1.56	0.31	0.89
7	1.28	2.38	0.81	1.17
8	2.05	3.15	1.54	1.39
9	2.76	3.86	2.24	1.56
10	3.41	4.51	2.87	1.66
11	4.00	5.09	3.45	1.69
12	4.53	5.63	3.97	1.67
13	5.00	6.10	4.43	1.59
14	5.42	6.51	4.83	1.45
15	5.78	6.88	5.19	1.25
16	6.09	7.19	5.48	1.01
17	6.36	7.45	5.74	0.73
18	6.58	7.67	5.95	0.40
19	6.76	7.86	6.13	0.14
20	6.91	8.01	6.27	0.41
21	7.03	8.12	6.38	0.84
22	7.12	8.22	6.46	1.29

Comparison results of the induced voltage magnitudes at various nodes on the mesh fence of the Phetchaburi high voltage substation is shown in Fig. 6.

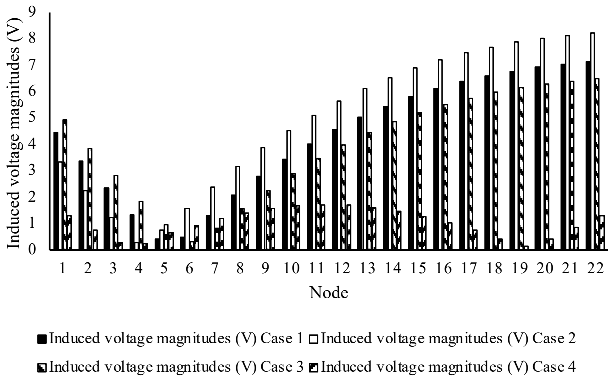

Fig. 6. Comparison results of the induced voltage magnitudes at various nodes on the mesh fence of the Phetchaburi high voltage substation.

TABLE IV. THE INDUCED CURRENT FLOWING TO GROUND

Node	Induced current magnitudes (A)			
	Case 1	Case 2	Case 3	Case 4
1	-	3.32	4.91	1.29
22	-	-	6.64	1.29

VI. DISCUSSION

The analysis of the induced voltage and current magnitudes can be summarized as follows:

The magnitude of the induced voltage depends on the distance between the fence and the transmission line. The results from scenarios where the mesh fence is ungrounded, grounded on one side, grounded on both sides, and grounded on both sides to the high voltage substation ground grid show that the fence at node 4, which is the farthest from the transmission line, has the lowest induced voltage. Conversely, the fence at node 22, which is closest to the transmission line, has the highest induced voltage.

The study of induced voltage resulting from the 115 kV transmission line in all scenarios indicates that the induced voltage is not harmful to humans (IEC 60364 standard).

Grounding the mesh fence on both sides results in a reduction of the induced voltage magnitude compared to the ungrounded scenario and the scenario where the fence is grounded on one side.

In scenarios where the mesh fence is ungrounded, grounded on one side, or grounded on both sides, if a person comes into contact with the fence (using a human body resistance value of RB = 1,000 ohms according to IEEE-80(2000) standard), the current passing through the human body could approach levels that are potentially harmful (IEC 60364 standard).

Grounding the mesh fence on both sides and connecting it to the high voltage substation ground grid effectively reduces the induced voltage magnitude. In this case, even at nodes with the highest induced voltage, the current passing through a human body in contact with the fence remains within safe limits, regardless of the duration of contact.

VII. CONCLUSION

This paper presents an analysis of the operation of 115 kV rated circuit breakers for the maintenance and stabilization of power distribution. This study using the Electromagnetic Transient Program/Alternative Transient Program (EMTP/ATP) to simulate the transmission towers and mesh fences of EGAT. The result found that grounding the mesh fence on both sides and connecting it to the high voltage substation ground grid effectively reduces the induced voltage magnitude. In this case, even at nodes with the highest induced voltage.

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