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TECHNICAL AND ECONOMICAL ASSESSMENT OF SHIELDING WIRE ELIMINATION IN IRAN'S 400KV TRANSMISSION LINES

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The losses and their reduction are one the most important deals in the transmission and distribution systems. In the high-voltage levels, there are some additional ohmic losses which should be considered due to importance; these are shielding wire losses. This concern is presented in this paper analytically and by a comprehensive EMTP simulation. Presented in this paper is also a case study in which a lightning waveform is simulated and the minimum distance of shielding wires is proposed for a 400kV line. This has some good advantages in case of the Iran's 400kV lines which is shown afterwards.

Keywords: Overvoltage, shielding wire losses, transmission lines, lightning.

1. Introduction

The reduction of losses in the transmission and distribution systems deals with a vast amount of research work and is a broad and ongoing topic [1]. In the high-voltage levels, the additional ohmic losses due to shielding wires must be considered. This shown to be important; therefore, this paper examines the level of importance for such a case dealing with shielding wires, their structure and performance. The results of a comprehensive simulation for a 400kV line are presented to prove whether the losses due to shielding wires are important or not. Afterwards, the optimal length of shielding wires is introduced as a longer length may cause losses excess. Meanwhile, very short lengths of shielding wires may cause serious problems for the lightning performance of the line [2]. Therefore, a lightning is modeled and linked with the simulation of shielding wires over a 400kV line and the optimal length is proposed. These analyses are finally treated in Iran's 400kV network and its benefits of reduction are verified.

2. Shielding wire and its installation basics

The use of shielding wires in HV transmission lines is basically for protection of power lines from lightning surges. These wires are usually made

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from strings of steel that connected to earth through the towers. This can provide a suitable electromagnetic shielding over the phase lines. A typical construction of a transmission line along with the required shielding wires is illustrated in Fig. 1.

Due to the larger distance between phase bundles in this figure, two shielding wires are employed. It should be mentioned that the lightning may strike the phase conductors in some rare occasions.

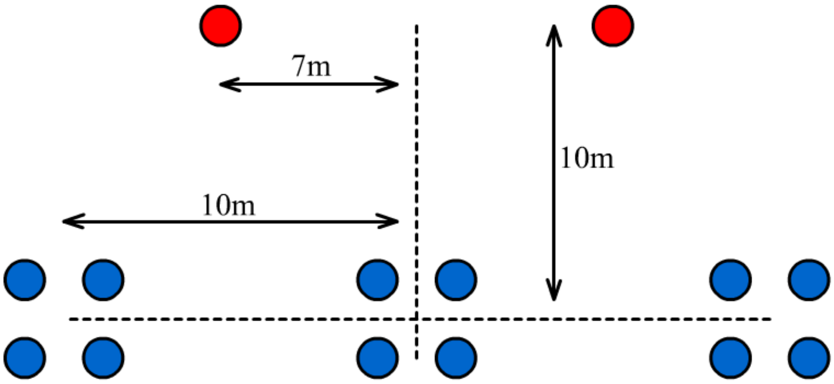

Fig. 1. A typical construction of a transmission phase lines along with the shielding wires.

3. The effects of shielding wires in the impedance matrix of the line

Ideally speaking, the shielding wires should not play a role in the impedance matrix of the line. However, this wires change the impedance values somehow. It may be useful to see analytically what happens. For the transmission line of Fig. 1, the following equations can be written:

$$\begin{cases} \dfrac{dV}{dx} = -\bar{Z}.I \\ \dfrac{dI}{dx} = -\bar{Y}.V \end{cases} \Rightarrow \begin{cases} \dfrac{d}{dx}\begin{bmatrix} V_c \\ V_e \end{bmatrix} = \begin{bmatrix} Z_{cc} & Z_{ce} \\ Z_{ce}^T & Z_{ee} \end{bmatrix}\begin{bmatrix} I_c \\ I_e \end{bmatrix} \\ \dfrac{d}{dx}\begin{bmatrix} I_c \\ I_e \end{bmatrix} = \begin{bmatrix} Y_{cc} & Y_{ce} \\ Y_{ce}^T & Y_{ee} \end{bmatrix}\begin{bmatrix} V_c \\ V_e \end{bmatrix} \end{cases}$$

$$Z_{cc} = \begin{bmatrix} z_{aa} & z_{ab} & z_{ac} \\ z_{ba} & z_{bb} & z_{bc} \\ z_{ca} & z_{cb} & z_{cc} \end{bmatrix} \quad Z_{ce} = \begin{bmatrix} z_{g1a} & z_{g2a} \\ z_{g1b} & z_{g2b} \\ z_{g1c} & z_{g2c} \end{bmatrix} \quad Z_{ee} = \begin{bmatrix} z_{g11} & z_{g12} \\ z_{g21} & z_{g22} \end{bmatrix}$$

$$Y_{cc} = \begin{bmatrix} Y_{aa} & Y_{ab} & Y_{ac} \\ Y_{ba} & Y_{bb} & Y_{bc} \\ Y_{ca} & Y_{cb} & Y_{cc} \end{bmatrix} \quad Y_{ce} = \begin{bmatrix} Y_{g1a} & Y_{g2a} \\ Y_{g1b} & Y_{g2b} \\ Y_{g1c} & Y_{g2c} \end{bmatrix} \quad Y_{ee} = \begin{bmatrix} Y_{g11} & Y_{g12} \\ Y_{g21} & Y_{g22} \end{bmatrix} \tag{1}$$

where, Z_{cc} is the impedance between phases without considering shielding wires, Z_{ce} is the impedance between phases and shielding wires, Z_{ee} is the impedance between shielding wires without considering phase conductors, V_c is the voltage of phase conductors, and V_e is the voltage of shielding conductors.

$$\begin{cases} \dfrac{d^2}{dx^2}\begin{bmatrix} V_c \\ V_e \end{bmatrix} = \begin{bmatrix} Z_{cc} & Z_{ce} \\ Z_{ce}^T & Z_{ee} \end{bmatrix}\begin{bmatrix} Y_{cc} & Y_{ce} \\ Y_{ce}^T & Y_{ee} \end{bmatrix}\begin{bmatrix} V_c \\ V_e \end{bmatrix} \\ \dfrac{d^2}{dx^2}\begin{bmatrix} I_c \\ I_e \end{bmatrix} = \begin{bmatrix} Y_{cc} & Y_{ce} \\ Y_{ce}^T & Y_{ee} \end{bmatrix}\begin{bmatrix} Z_{cc} & Z_{ce} \\ Z_{ce}^T & Z_{ee} \end{bmatrix}\begin{bmatrix} I_c \\ I_e \end{bmatrix} \end{cases} \tag{2}$$

This equation can be solved for the current of shielding wire which leads to a measure of its losses.

3.1. Estimating the losses of shielding wires by simulation

The current calculated in equation 2, is dissipated in the form of losses by the ohmic effects of towers and shielding wires. The amounts of losses for a typical 400kV transmission line have been calculated by a comprehensive EMTP simulation. The length of the line is 600km, the transmitted power equals 600MW, the average span is 300m, the resistance of each tower is 25Ω, and the resistance of each shielding wire is 3.34 Ω/km. A circuit configuration for the measurement of voltage and current of a shielding wire is shown in Fig. 2.

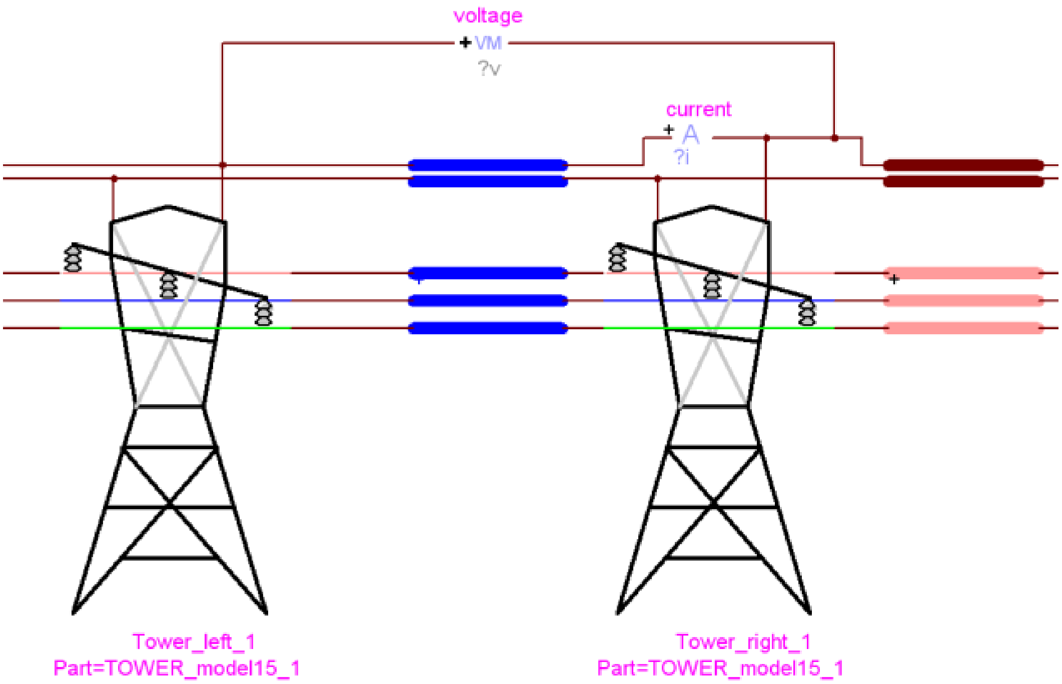

Fig. 2. Measurement of voltage and current of a shielding wire.

The simulation results of Fig. 2 are shown in Fig. 3. In the normal connection of Fig. 2, the voltage appeared on the shielding wires is a sine-wave with the magnitude of 80V; nonetheless, the current of shielding wires has a magnitude of 310A and phase of 88.5 degrees.

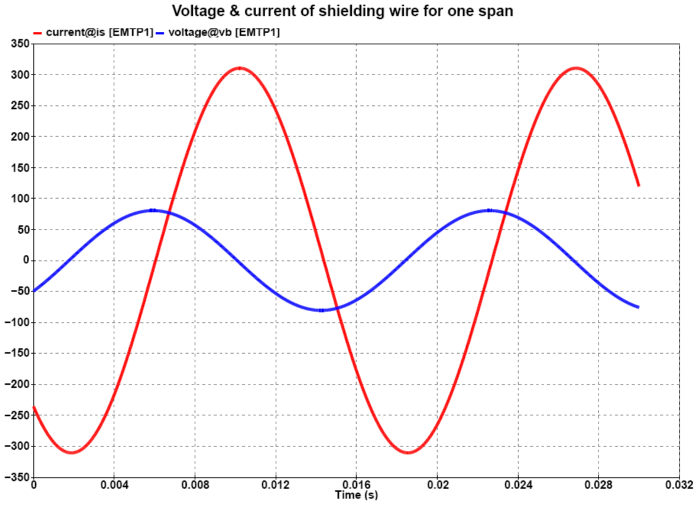

Fig. 3. The voltage and current appeared on the shielding wires with normal installation.

The reason that the currents are so high is a difference equal to 170 degrees between induced voltages on each shielding wire. This can be understood from the Fig. 4. The power loss of each shielding wire for a single span can be calculated:

$$P_{loss} = \frac{310}{\sqrt{2}} \times \frac{80}{\sqrt{2}} \times \cos(88.5) = 325W$$

Then, the total losses of shielding wires for a single span will equal to 650W.

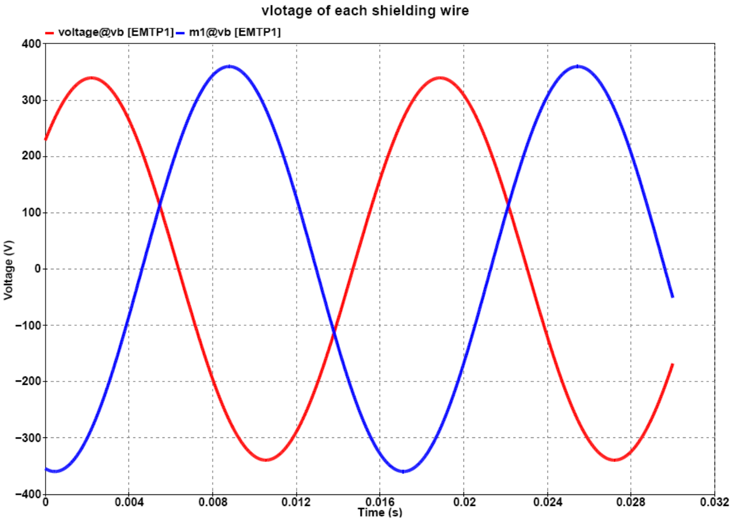

Fig. 4. The voltage on the each shielding wire in open circuit.

3.2. Estimating the losses of tower by simulation

Following the previously mention simulation, Fig. 5 shows the magnitudes of currents and voltage drop across a single tower. The total power loss of towers is then equal to 30W.

3.3. Estimating the total losses of line

The obtained results so far lead us to the losses of a line span as follows:

$$P_{Loss-t} = 650W + 30W \approx 680W$$

Therefore, in terms of the total line length, the loss reaches 1.36 MW. This seems negligible as the total transmitted power over the line equals 600 MW.

Anyhow, if we consider the cost of electrical energy as 6 cents per kWh, a noticeable amount of 714,000 dollars will spend annually.

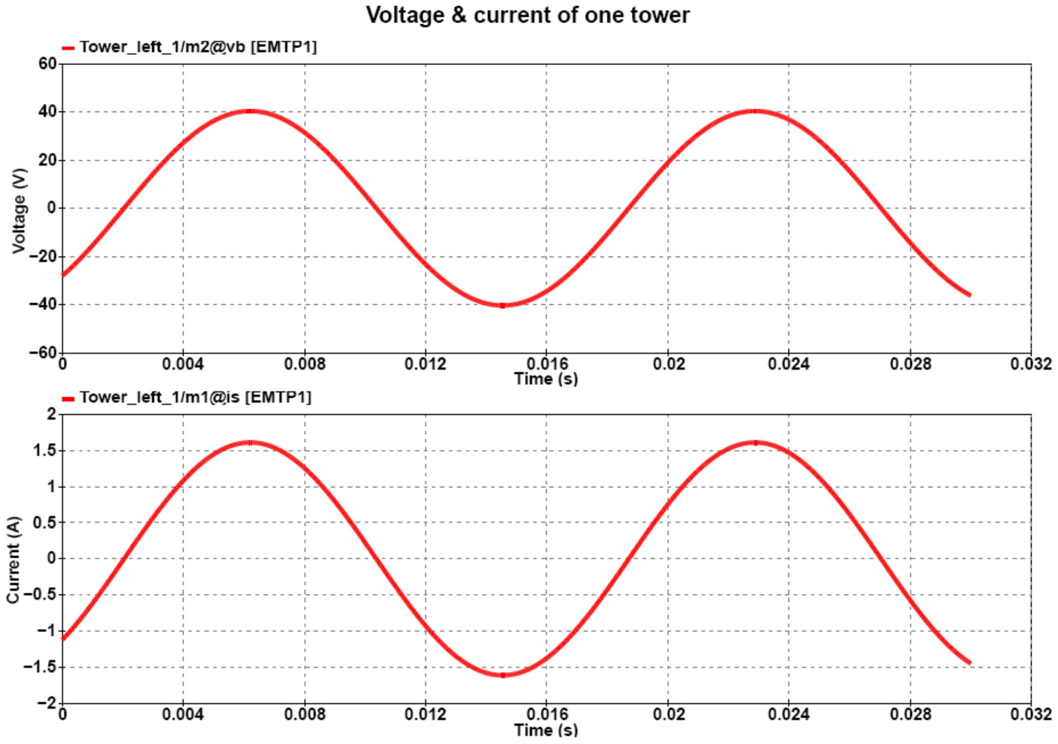

Fig. 5. The voltage and current of a 400kV line.

It should be noticed that these numbers may be also obtained by calculating the transmitted power mismatch for the line with and without the shielding.

4. The possibility of length reduction for shielding wire

In this section, the possibility for optimizing length of shielding wires is evaluated. It is clear that the main role of shielding wires is to protect the phase conductors against lightning. Indeed, lightning injects an impulse-shaped current to the line which then converted to an overvoltage impulse through the impedance of line. According to CIGRE standard, a waveform with a front duration of 0.8 us, a tail of 30 us, and a magnitude of 40 kA is proposed for a standard lightning surge. We also used this popular standard for all simulations. First of all, the possibility that we limit the shielding to a restricted sensitive area is checked. To do so, two simulations are organized; one with a lightning stroke shielding and another with a lightning stroke a phase conductor. In each case, the over voltages at the striking point along with the nearest end of line to the striking point are recorded providing a measure of the critical conditions. Furthermore, to provide a comparison with an ordinary switching overvoltage, an additional simulation is performed including the opening of a circuit breaker under nominal power at one end. Some of important results can be concluded as follows:

1) The produced overvoltage at the striking point for each case, including striking the shielding or the phase, do not show a great difference as seen in Figs. 7 and 8.
2) The overvoltage at the end of the line is tolerable if the lightning strikes 30km away where the switching overvoltage at this point is at its critical level. This can be inferred from Figs. 10 and 11.

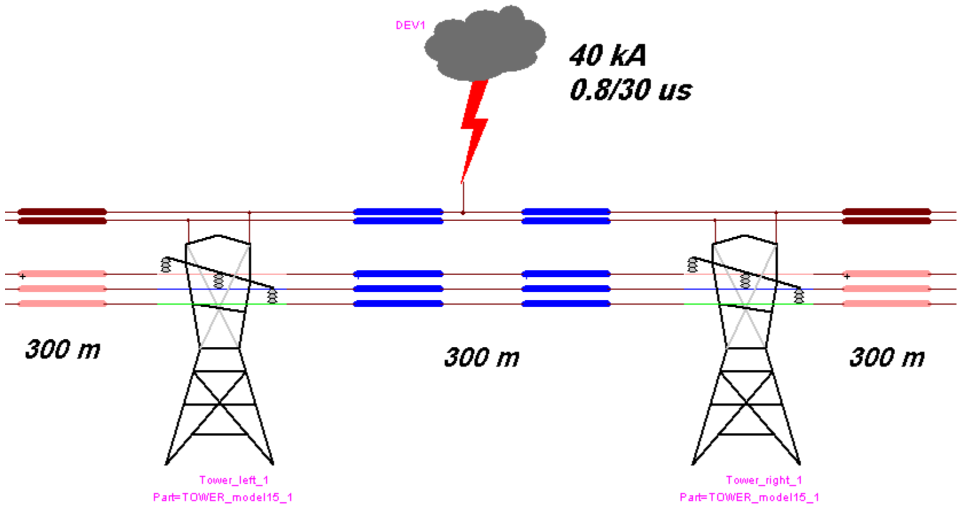

Fig. 6. The case of striking a lightning to the shielding.

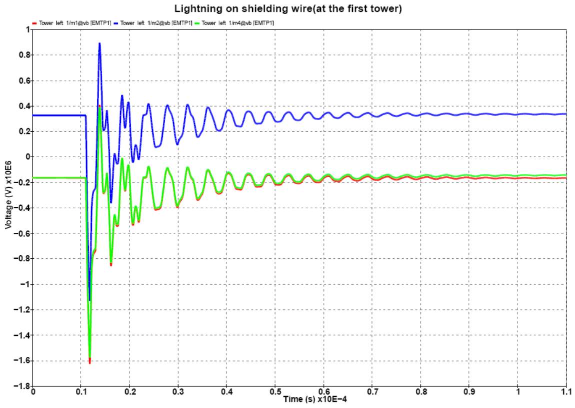

Fig. 7. The produced three-phase overvoltage at the striking point when lighting stroke the shielding.

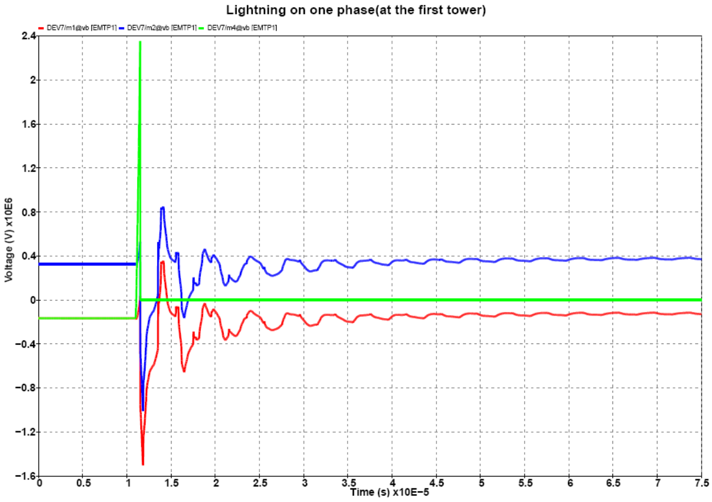

Fig. 8. The produced three-phase overvoltage at the striking point when lighting stroke a phase conductor.

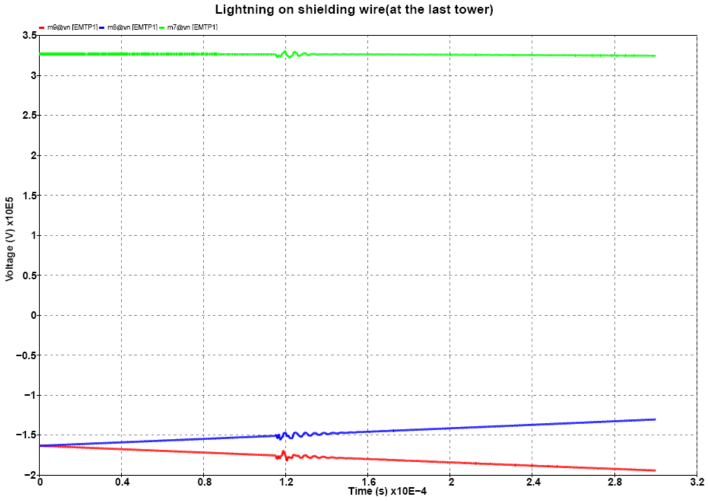

Fig. 9. The produced three-phase overvoltage at the ending point when lighting stroke the shielding.

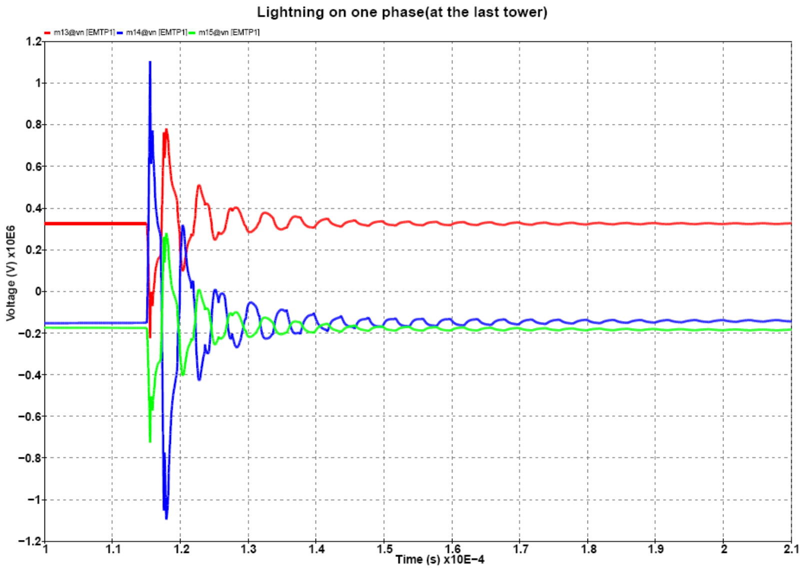

Fig. 10. The produced three-phase overvoltage at the ending point when lighting stroke a phase.

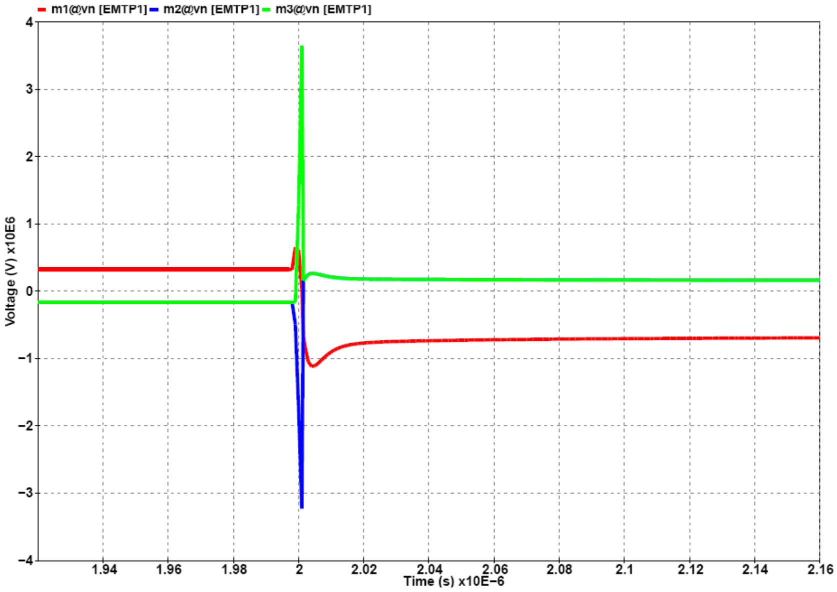

Fig. 11. The produced three-phase overvoltage at the ending point due to the operation of the breaker.

It can be also implied from the figures 8, 10 and 11 that even if the lightning stroke as close as 30 km to a phase conductor, the resultant overvoltage at the end is smaller than the switching overvoltage which is an estimated predesigned level based on strict insulation coordination. Therefore, it will be enough to install the shielding wires only for the 30 km distance from the ends of the line. This has the following benefits:

1) A proper protection of utilities at the line endings is maintained against lightning events.
2) The overall losses are reduced to impressive levels.
3) The costs of shielding are eliminated.

5. The effects of shielding wire elimination for Iran's 400kV transmission lines

The Iran's power transmission network includes 116 of 400kV lines with a total length 14,191km. These lines use shielding wire for whole-length protection. Regarding the results obtained in subsection 3.3, the total power due to the unnecessary shielding is about 32MW which results in an annual cost as 16,500,000 dollars. Using the results of the previous section, as the shielding can be limited to both line ends for a length of about 30km; the noticeable saving of 16MW in the total power can be established. This finally leads to a saving in the total annual cost equal to 8,000,000 dollars.

6. Conclusion

The problems of shielding losses for 400kV lines have been presented. The performance of a typical 400kV line against lightning with and without a shielding along with various measures of energy loss has been simulated using EMTP. The obtained results have proved that by restricting the shields to 30km-span at the ends of the line, the losses can be reduced in an effective manner. It has also shown that this could not cause any utility damage; since the potential over voltages are estimated to be under the critical values in comparison with the predetermined switching surges.

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