BACKFLASHOVER ANALYSIS FOR 132 KV TRANSMISSION LINE AND THE ASSOCIATED OVERVOLTAGES ON NEARBY GAS PIPELINE

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Abstract: A preceding paper by the authors investigated induced voltages on gas pipeline and phase conductors of a transmission line of length 1.6 km under the influence of lightning strokes. This paper improves the previous study in two separate areas. Firstly, the length of the transmission line is increased to 2 km and the towers modelled were increased from 3 to 7. The increase in towers is necessary to account for reflections on adjacent towers that could possibly affect the overvoltages on the struck tower. Additionally, other parameters are incorporated into the study which includes effect of variations of peak height of pipeline above ground, distance of pipe from tower, tower footing resistance in addition to soil resistivity and peak currents. Results show that increasing the height of the gas pipeline from ground does not correspond to an increase in induced voltage on the pipeline at critical height of the pipe above ground surface. Variations of other parameters conform to the expected results. The maximum touch voltage on the pipeline reached at 341 V due to 110.7 kA. This voltage surpasses the acceptable limit of touch of 287 V and as such voltage on the pipe could be too dangerous for personnel.

1 INTRODUCTION

In areas of high lightning activities where the coexistence of electrical power networks and of gas pipeline systems are predominantly raising issues associated with electromagnetic coupling. The issues to redress are the effect of lightning overvoltages on pipelines infrastructures related to the interaction of lightning discharges on high voltage transmission line. Up to date, the effect of lightning transient over voltages on a gas pipeline in parallel to an overhead transmission line is not commonly investigated[1-2].Very few researchers have ventured into this area of research[1-10].Lightning strikes on overhead power lines are the principal reasons for accidental outages [11-14]. In recent years research has been more focused on lightning produced overvoltages on transmission lines and telecommunication lines due to their influence in insulation coordination and lightning related electromagnetic hazards [10]. The probability of a lightning strike terminating on a shield wire or tower top is higher than that of a phase conductor. However voltages produced during shielding failure on gas pipelines are more significant than that of backflash [4-8]. This paper discusses the induced voltages on gas pipelines when the lightning strokes were terminated on the tower top. The amplitude of the strikes was varied from 10.7 kA to 100 kA. This study further aims to establish the impact of backflashover on a 132 kV transmission line tower by incorporating variations of peak height of pipeline above ground, distance of pipe from tower, tower footing resistance in addition to soil resistivity and peak currents. Results show that increasing the height of the gas pipeline from ground does not correspond to an increase in induced voltage on the pipeline at critical height of the pipe above ground surface. The other parameters when altered, matched the expected results. The maximum touch voltage on the pipeline reached at 341 V due to 110.7 kA. This voltage surpasses the acceptable limit of touch of 287 V and as such voltage on the pipe could be too dangerous for personnel.

2 MODELLING SCENARIOS

Several cases are considered during in the simulations to analyse the induced voltages on the gas pipeline. Single lightning strokes are injected on the shield wire or tower top resulting in large overvoltages appearing on the towers, line conductors as well as the gas pipeline. The lightning injected onto the tower gave rise to modelling of capacitive and inductive modelling.

2.1 Transmission line and gas pipeline

Al The basic arrangement of a 132 kV transmission line and a gas pipeline is given in Figure 1

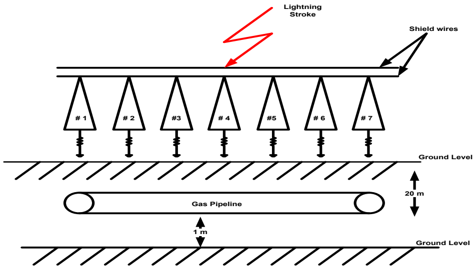

Figure 1: A schematic diagram of a 132 kV line

2.2 Description of transmission line and gas pipeline

The system modelled is made up of a 132 kV overhead transmission line consisting of 7 towers. The transmission line model is based on a typical 132 kV twin circuit line geometries as shown in Figure 2.

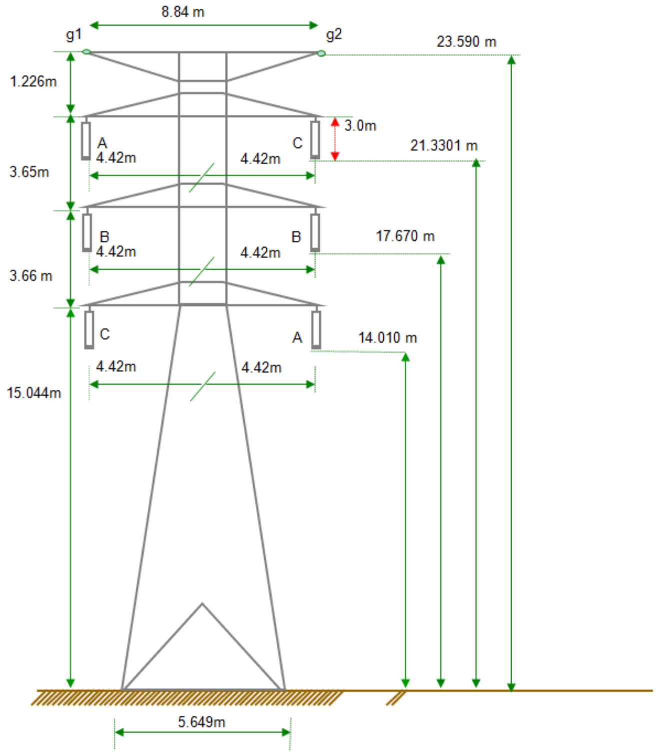

Figure 2: A typical configuration of a double-circuit transmission line tower of Tenaga Nasional Berhad in Malaysia

The transmission line is of length 2 km length. The lowest conductor from the ground is 14.01 m. the span length of the line is 300 m terminated on its both ends with an impedance of 160 Ω equivalent to the surge impedance of the line. The pipeline consists of an external radius of 0.3048 m, and the thickness of its wall is 0.00790 m. it is made of steel of DC resistance of 5.79555×10^{-11} ohm/km which is equivalent to a resistivity of 2.2×10^{-7} Ωm. the pipeline is positioned 1 m above ground and is subjected to capacitive and inductive coupling.

2.3 Simulation methods

The simulations are performed with Power Systems Computer Aided Design/Electromagnetic Transient with Digital Computer (PSCAD/EMTDC) software package. The PSCAD/EMTDC program has the best time domain line model available, as it solves for the impedances and admittances over a wide range of frequencies, and applies accurate curve fitting methods in order to achieve a time domain model accurate over a wide frequency range. Investigations were carried out by varying a number of parameters which are expected to have an effect on the pipeline with respect to lightning strike on the tower. These parameters include variation of peak currents, tower footing resistance, height of pipeline above ground, distance of pipeline from tower and soil resistivity. The reaction of the pipeline due to energisation of the line by lightning is evaluated.

3 RESULTS

In the simulations, single stroke lightning are injected on the shield wire of the over head line and the resulting voltage waveforms are used to evaluate the associated induced voltages on the gas pipeline.

3.1 Effect of current on induced voltage

Analysis has been performed based single lightning stroke terminating on tower 4. Variation of the peak current highlighted a corresponding increase in the induced voltage on the pipeline. A summary of the results is listed in Table 1.

Table 1: Induced voltage on pipeline due to lightning

A plot of the induced voltage against peak current

Injected current /kA	Induced voltage/ V	Height / m
10.7	39.6	1
20.7	61.6	1
30.7	91.0	1
40.7	120.1	1
50.7	149.0	1
110	340.6	1

is given in Figure 3.

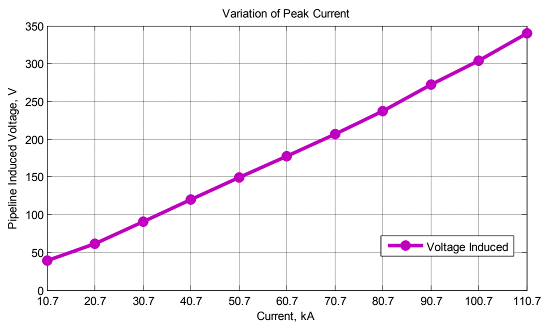

Figure 3: A plot showing the induced voltage on the pipeline when the peak current is varied at different magnitudes.

From the plot of Figure 3, it is observed that there was a linear relationship between the voltage and current. The severity of the induced voltage on the pipe is established owing to an increase of the lightning stroke as expected. The waveform of the induced voltage on the gas pipeline due to the strike of 30 kA lightning current is given in Figure 4.

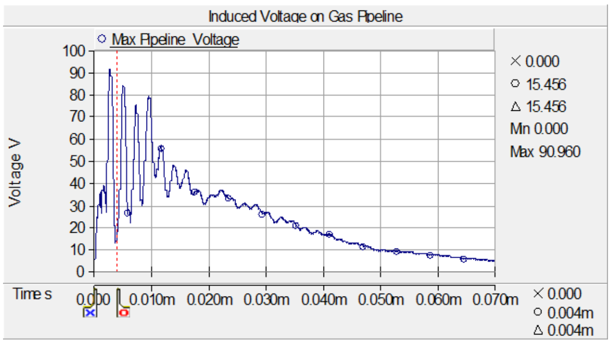

Figure 4: Induced voltage observed along the gas pipeline due to single lightning stroke of 30.7 kA intercepted by the shield wire of the tower

3.2 Effect of height on induced voltage

A negative lightning stroke current of 30.7 kA was injected on the shield wire as the pipeline was adjusted at different heights above the ground. The pipeline was 20 m away from the transmission tower struck by lightning. By injecting a fixed current of 30.7 kA, the height is varied as 0.3, 0.5, 0.7, 0.9, 1.0, 1.5, 2.0, 2.5, and 3.0 m. The voltage produced on the pipeline is illustrated in Figure 5. A sharp increase of the induced voltage between 0.3 m to 0.5 m was observed. The voltage almost remained constant from 0.7 m to 3.0 m. nonetheless, it is obvious that at 0.7 m – 1.5 m the induced voltage increased slightly and started to decrease at 2.0 m. A summary of the result is given in Table 2.

Table 2: Variation of height of pipeline above ground

Injected Current/ kA	Height of pipeline above Ground / m	Induced Voltage / V
30.7	0.3	72.6
30.7	0.5	89.0
30.7	0.7	90.2
30.7	0.9	90.8
30.7	1.0	90.1
30.7	1.5	91.5
30.7	2.0	91.2
30.7	2.5	91.1
30.7	3.0	91.1

Maxumum overvoltage is observed when the height of the gas pipeline was raised to 1.5 m. this is illustrated in Figure 6. the peak pipeline voltae is 91.4 m which occurred at 2.6 μ sec.

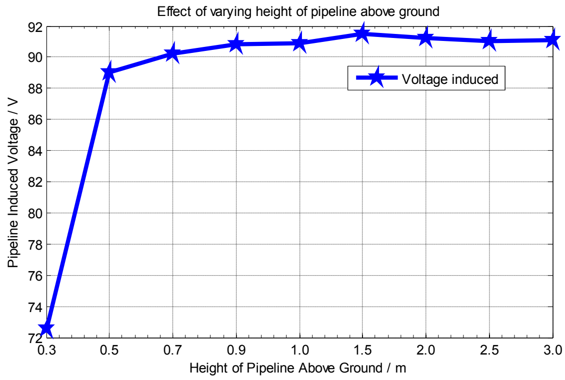

Figure 5: A plot of induced voltage on pipeline when the height is varied from ground when a single lightning stroke of 30.7 kA struck the shield wire of the tower

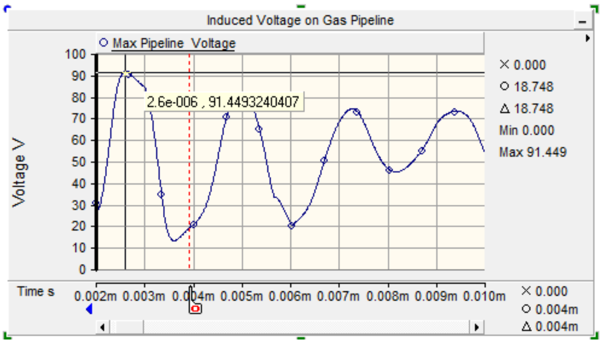

Figure 6: Waveform of induced voltage on pipeline when the height of the gas pipeline is at 1.5 m above the ground.

3.3 Effect of distance of pipeline from tower on induced voltage

The same lightning stroke current of 30.7 kA was injected on the shield wire The distances of the pipeline from the tower were altered at distances of 5 m, 10 m, 20 m, 25 m 30 m, and 50 m. The pipeline was positioned 1 m above the ground .The voltage induced on the pipeline is depicted in Figure 7. It is seen from the figure that the induced voltage diminished when the pipeline was taken further away from the tower.

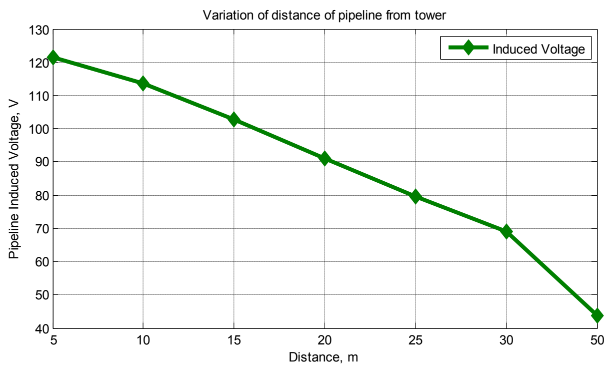

Figure 7: The induced voltage on pipeline when the distance of pipeline from the tower ground is altered during a lightning stroke of 30.7 kA terminating the shield wire of the tower

3.4 Effect of tower footing resistance on induced voltage

The tower footing resistance (TFR) of a steel tower of a distributed parameter line represents a resistance that is terminated at the end the tower. The peak overvoltage on the tower is due to the TFR resistance given that the reflections from the base of the tower will arrive much quicker than reflections from adjacent towers. The response time and the current dependence establish the control of the TFR on the tower top voltage.
During a lightning strike on a tower, a travelling wave is created which travels to and fro the length of the tower. The wave is then reflected along the TFR and at the tower top which may cause the voltage of the cross-arms may rise and therefore stressing the insulators. By varying the TFR, it is manifested from Figure 8 that the pipeline induced voltage increased when the TFR was increased.
A possible reason for the induced voltage on the pipe to increase could be due to the rise of the voltage at the tower top. The resistances of TFR that adjusted were 5 Ω 10 Ω, 15 Ω, 20 Ω, 25 Ω, 50 Ω and 100 Ω respectively. These modifications were made in order to determine their effects on the pipeline.
Again the pipeline was placed at 1 m above the ground and 20 m away from the struck tower.

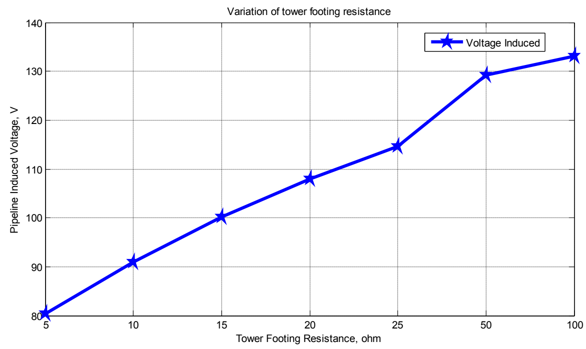

Figure 8: The induced voltage on pipeline when the tower footing is altered during single lightning stroke of 30.7 kA hitting the shield wire of the tower.

The waveshape of the lightning current that hit the overhead transmission tower is illustrated in Figure 9. The magnitude of the current is seen as 30.7 kA. It is double ramp current waveshape which is the preferred choice because of its simplicity and ease of use [15]. The front time of stroke is set at 1μsec and the time to half at 50μ sec.

Figure10 describes the waveform obtained with respect to a 100 Ω footing resistance. A voltage of 147.8 V was detected along the pipeline which confirms that high magnitudes of footing resistances corresponds to higher induced voltages on metallic structures in close proximity of an high voltage transmission line. The peak voltage was established at 9.57 μsec.

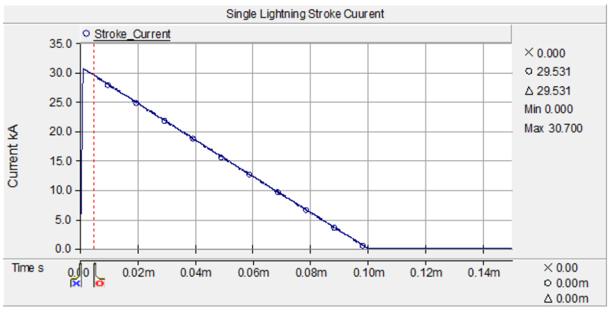

Figure 9: The waveshape of a single lightning stroke intercepted by shield wire of the 132 kV tower.

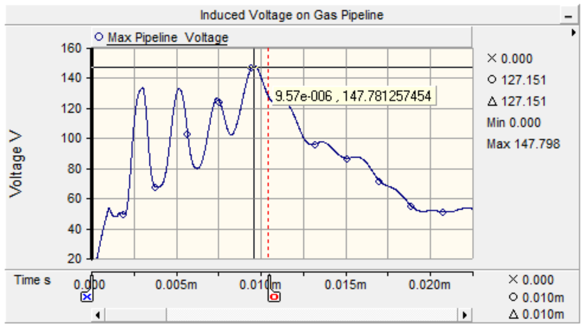

Figure 10: Peak induced voltage along the pipeline associated with a tower footing resistance of 100 Ω on the transmission towers

3.5 Effect of soil resistivity on induced voltage

The impact of soil resitivity due to the interaction of steady-state electromagnetic fields and pipelines is universally known that increased of soil resistivity will result to an increase in induced voltage. The relationship is non-linear in nature. To ascertain this assumption with lightning studies, various simulations were executed with different soil resistivity being utilized in each model. Figure 7 demonstrates the disparity of the peak induced voltage on the pipeline associated with soil resistivity values between 10 Ω-m and 3000 Ω-m. A pattern of an increased in induced voltage dependable with the log of soil resistivity is observed.

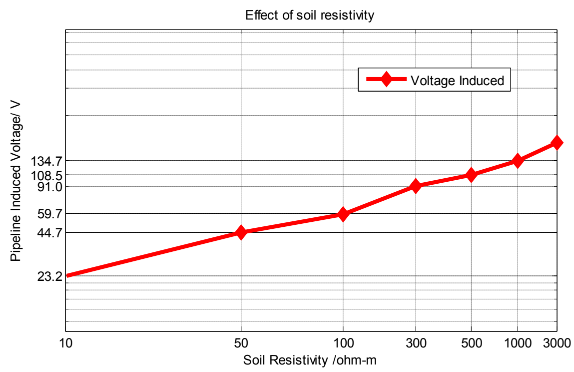

Figure 7: Variation in the induced voltage on pipeline with respect to modification of soil resistivity

4 CONCLUSION

This paper has examined the impact of single lightning surges on a gas pipeline positioned in parallel to a transmission line by incorporating variations of certain parameters which include currents magnitudes, tower footing resistances, soil resistivities, heights of pipeline above ground surface and distances of pipeline from tower.

Results show that increasing the height of the gas pipeline from ground does not correspond to an increase in induced voltage on the pipeline at critical height of the pipe above ground surface.

Variations of other parameters conform to the expected results. The maximum touch voltage on the pipeline reached at 341 V due to 110.7 kA.

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