International Journal of Electrical and Computer Engineering (IJECE)
Vol. 6, No. 2, April 2016, pp. 495~503
ISSN: 2088-8708, DOI: 10.11591/ijece.v6i2.9395

Induced Voltages on a Gas Pipeline Due To Lightning Strikes on Nearby Overhead Transmission Line

Ali I. El Gayar*, Zulkurnain Abdul-Malek*
* Institute of High Voltage & Current (IVAT), Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), (Fax) +(6)07-5578150, Tel +(60)07-5535860

Article Info

Article history:

Received Nov 11, 2015
Revised Dec 22, 2015
Accepted Jan 10, 2016

Keyword:

CDEGS and PSCAD
Gas pipeline
Induced voltages
Lightning strike
Overhead transmission line

ABSTRACT

The purpose of this paper is to investigate the severity of lightning induced voltages on a gas pipeline installed in parallel with overhead transmission line using two different simulation packages. The results from this study using CDEGS, which solves a given problem based on electromagnetic computations, reveal that the induced voltages on the pipeline are more accurate compared to that obtained by PSCAD simulation, which is based on the circuit approach. Unlike PSCAD, CDEGS considers many salient factors such as soil model, inductive, capacitive and conductive couplings, and multiple soil structures. Models of a double circuit 132kV transmission line, gas pipelines, soil with different resistivities and variable lightning surges were developed. The effects of pipelines located at various heights above ground and distance of pipeline from the power lines were also studied. Compared to previously published work using PSCAD, it is found that CDEGS has given more accurate results. Several findings which were not possible using PSCAD were observed such as the effect of soil structure on induced voltage and multiple layers soil. This also led to better understanding of the conductive coupling from lightning strikes and fault conditions. The modeling work using CDEGS not only useful for providing more reliable data for further protection and mitigation techniques, but is also very versatile to study the effects of various other important factors affecting the induced voltage on the pipelines.

Corresponding Author:

Zulkurnain Abdul-Malek,
Institute of High Voltage & Current (IVAT), Faculty of Electrical Engineering,
Universiti Teknologi Malaysia (UTM),
81310 UTM Johor Bahru, Johor, Malaysia, (Fax) +(6)07-5578150, Tel +(60)07-5535860
Email: zulkurnain@utm.my

1. INTRODUCTION

The installation of gas pipelines in the vicinity of high voltage overhead transmission lines (OHTLs) is a serious concern due due to interference from the power frequency OHTLs. Electric power transmitted at higher transmission voltages results in the generation of surrounding electromagnetic fields. The fields created by the transmission of power give rise to a stiff competition for land as well as right of ways(ROWs) [1]. Gas pipelines located in the vicinity of OHTLS are susceptible to the electric fields generated by the power lines as by lightning strikes to the lines. Lightning strike on overhead power lines is the principal reason for accidental outages [2]. The probability of a lightning strike terminating on a shield wire or tower top is higher than that of a phase conductor [3, 4]. Nevertheless, transient over-voltages produced during shielding failure are more significant than that of back flash [5, 6]. Currents and voltages are induced along the gas pipelines due to the common conductive path shared by both power line as well as gas pipeline installations [7, 8]. The induced voltage may have undesirable consequences on personnel and livestock, especially when touching the pipeline, as well as pipeline corrosion or damages to the cathodic protection [5, 7, 9, 10].

PSCAD simulation, which is based on the circuit approach, is limited since the conductive coupling is not considered when calculating the induced voltage on the pipeline. The conductive coupling is dependent on the soil type, soil resistivity, and multiple soil structure, all of which cannot be implemented using PSCAD. In view of this schortcoming, this paper proposes the study to be carried out using CDEGS which is electromagnetic based to solve all inadequacies of PSCAD. CDEGS is capable of designing various soil structures with a number of layers. This work further investigates the effects of single lightning stokes on transmission line with back-flashover and the impact of the consequent electromagnetic coupling on gas pipelines. CDEGS combines two powerful software tools, namely, HIFREQ and FFTSES, and solves the problem using more accurate Maxwell equations rather than less accurate fixed circuit elements.

2. COMPUTER MODELS

The transient behaviors of various parts of the problem, such as transmission lines, towers, and pipelines, are modeled in CDEGS. The results of this study were compared to those using PSCAD, which were previously published in [3]. The effects of various factors are also studied.

To obtain the temporal scalar potential and induced voltage, the lightning surge current was decomposed into its frequency domain spectrum using the forward Fast Fourier Transform using FFTSES program. The current distribution in the tower and grounding conductors, the scalar potentials, and the electromagnetic fields, were first computed at selected frequencies using HIFREQ. The time domain scalar potentials and electromagnetic fields were then obtained using the inverse Fast Fourier Transform by using FFTSES again.

2.1. Transmission Line Tower

The transmission line was modeled based on standard twin circuit line geometry. The tower type was a 132 kV steel lattice structure type 23 L series as per nomenclature of TNB. The tower geometry and dimensions are shown in Figure 1. The equivalent surge impedance of the tower is 160 ohms. Steel conductors were used to design the tower in HIFREQ, with a relative resistivity of 12 with respect to copper, and a relative permeability of 250 with respect to free space.

The tower grounding system was a 16m × 16m loop conductor buried at 0.5m depth, which in turn was connected to 8 vertical grounding rods with a depth of 10m. Figure 2 shows the simulated 8-rod tower grounding system in CDEGS indicating the number of segments in each section.

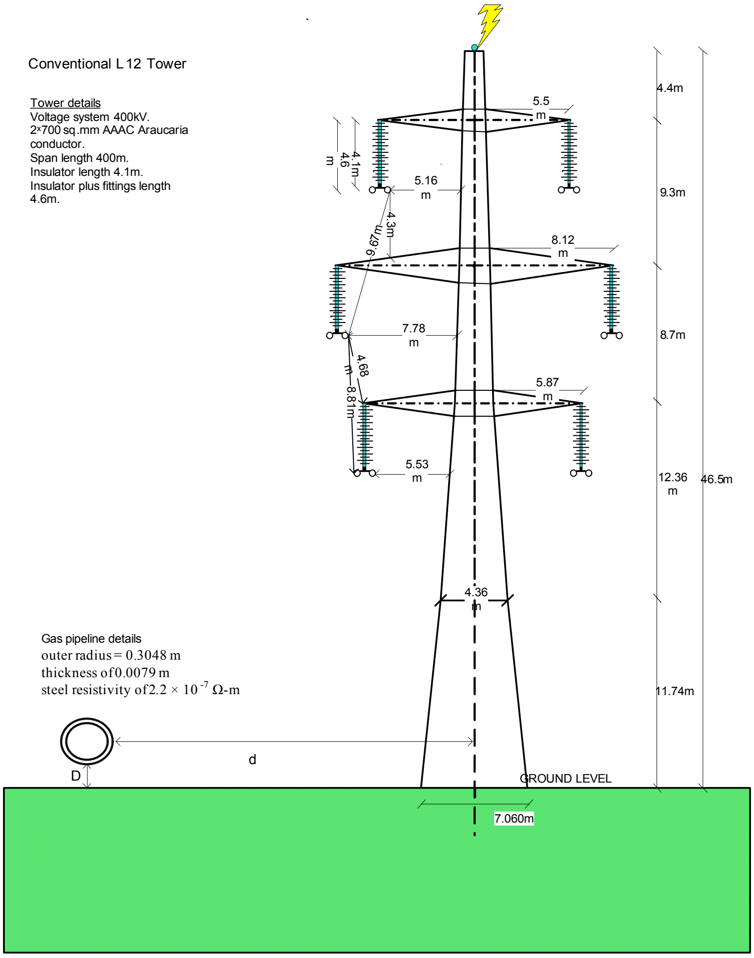

Figure 1. Effects of selecting different switching under dynamic condition

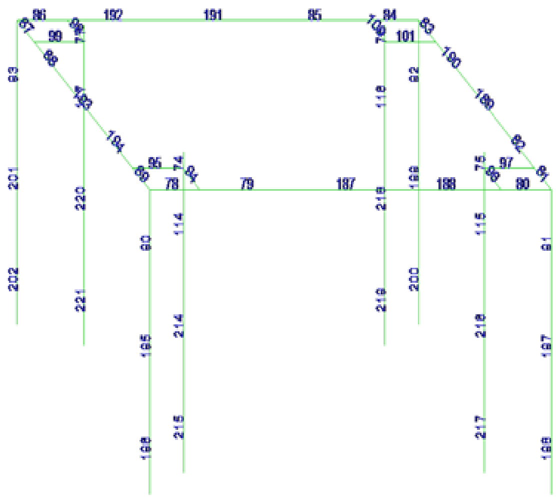

Figure 2. Simulated 8-rod tower grounding system in CDEGS indicating the number of segments in each section

2.2. Pipeline Model

The pipeline is shown in Figure 3. It has an outer radius of 0.3048 metres and a thickness of 0.0079 metres. The pipeline is made of steel having a resistivity of 2.2 × 10-7 Ω-m. The pipeline is 1m above the ground surface. It takes into account the inductive and capacitive coupling. The pipeline steel has a relative resistivity of 17 with respect to copper, and a relative permeability of 270.

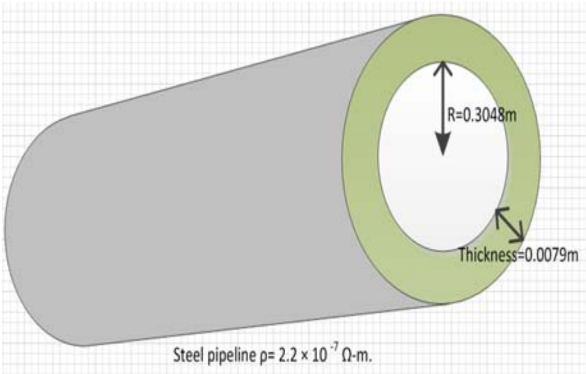

Figure 3. Gas pipeline structure

2.3. Lightning Stroke Current

Statistics showed that lightning characteristics are the same all over the world. Regions are characterized by their ground flash density. Lightning stroke is usually represented by current source of negative polarity. The parameters of a lightning such as crest, front time, maximum current steepness and duration are determined by statistical approach considering the ground flash density at the location [11]. The peak current is statistically related to steepnees or time to crest of the current waveform. The steepness increase as the peak current increases and the front time increase as well. The lightning surge current considered in this study is defined by the following double exponential type function:

$$I(t) = I_m (e^{-\alpha t} - e^{-\beta t}) \tag{1}$$

where Im =30 kA, α= 1.4x10-4 S^{-1}, and β = 6x106 S^{-1}.

The waveform is characterized by a rise time of 0.1 µs, time to half of 50 µs, and total time duration of 300 µs. The modelling of this lightning current by CDEGS is shown in Figure 4. The lightning stroke was assumed to hit the top of a tower, or intercepted by the shield wire at the highest point of the tower.

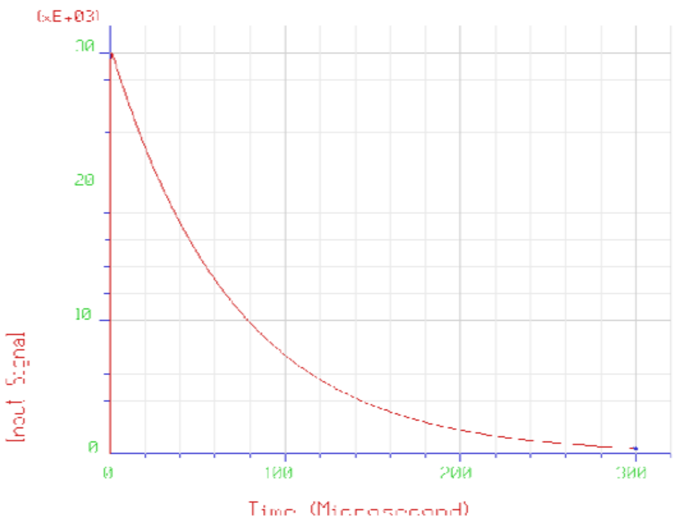

Figure 4. Lightning impulse wave (0.1/50µs) applied at the top of a transmission tower

2.4. Computation Methodology

The method used to obtain the electrical field in time domain is described as follows. By means of Fourier Transform, the scalar potential and electromagnetic field in time domain are given by the following equations:

$$V(t)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}V(\omega)e^{i\omega t}d\omega=\frac{1}{2\pi}\int_{-\infty}^{+\infty}V_0(\omega)I(\omega)e^{i\omega t}d\omega \qquad (2)$$

$$E(t)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}E(\omega)e^{i\omega t}d\omega=\frac{1}{2\pi}\int_{-\infty}^{+\infty}E_0(\omega)I(\omega)e^{i\omega t}d\omega \qquad (3)$$

$$H(t)=\frac{1}{2\pi}\int_{-\infty}^{+\infty}H(\omega)e^{i\omega t}d\omega=\frac{1}{2\pi}\int_{-\infty}^{+\infty}H_0(\omega)I(\omega)e^{i\omega t}d\omega \qquad (4)$$

Where:

$$I(\omega)=\int_{-\infty}^{+\infty} I(t)e^{-i\omega t}dt \qquad (5)$$

is the frequency spectrum of the lightning surge current, and $V_0(\omega)$, $E_0(\omega)$, $H_0(\omega)$are the unmodulated scalar potential, electrical field, and magnetic field in frequency domain, respectively. The unmodulated electromagnetic fields are generated by a unit current energization of the conductor network.

2.5. Soil Characteristics

The soil structure and grounding design of the overhead transmission line are important parameters determing what soil potentials will arise near a pipeline, the lower the structure ground impedance, the lower the lower the local soil potentials. Soil resistivity playes a significant role here. Low soil resistivity means lower structure ground impedance and lower potential differences between the grounding structure and the pipeline. The soil model was selected as a uniform soil. The properties of the air and earth used are shown in Table 1.

Table 1. Soil and air characteristics.

Layer	Resistivity (ohm-meters)	Relative (p.u) permeability	Relative (p.u) permittivity
Air	1E+18	1	1
Earth	100	1	1
Earth	300	1	1
Earth	1000	1	1
Earth	3000	1	1

3. RESULTS AND DISCUSSIONS

The variation of the pipeline induced voltages due to backflashovers had been investigated in conjunction with a variation of key model parameters. In the simulations performed to establish the induced voltages associated with single lightning strike (SLS), the overhead line and pipeline are terminated with surge impedance of the tower abd pipeline respectively. Single stroke current magnitude of 10.7 kA, 20.7 kA, 30.7 kA, 40.7kA, 50.7kA, 60.7 kA, and 110.7kA are injected on the tower top. The resulting voltage wave forms can be used to determine the induced voltage on the gas pipeline.

3.1. Effects of Lightning Current Magnitudes

An increase in the peak lightning current results in a corresponding increase in the induced voltage on the pipeline, as shown in Figure 5. The pipeline was 20 m away from the transmission tower that was strucked by lightning. The induced voltage obtained using PSCAD shows a higher value when compared to that obtained using CDEGS. This the different in values between the two approaches, because PSCAD assumes that the conductors are infinite in length and parallel along the right of way. These two main assumptions lead to insignificant error when the surge current is small, less than 40 kA. This error becomes significant 16 % when the surge current exceeds 90 kA.

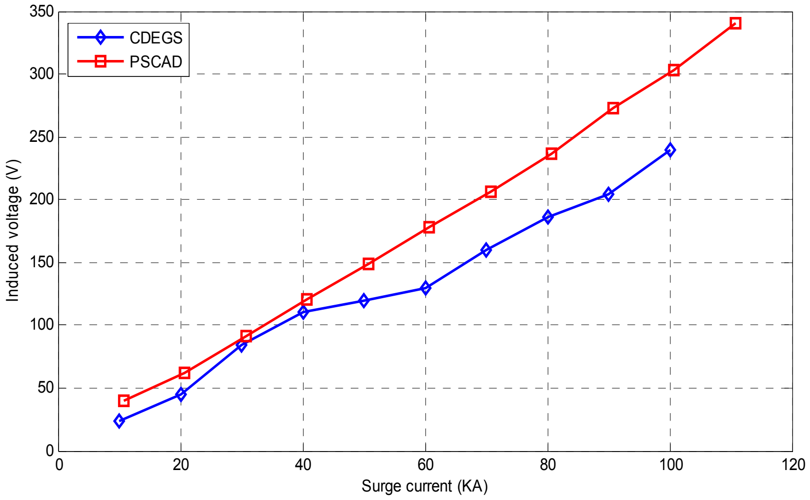

Figure 5. Comparison of computed induced voltages on the pipeline when the peak current is varied at different magnitudes during backflashover using PSCAD and CDEGS

3.2. Effects of Height of Pipe above Ground

A lightning stroke current of 30.7 kA was injected on the shield wire as the pipeline height above the ground surface was adjusted at different heights above the ground. The pipeline was 20 m away from the transmission tower that was strucked by lightning. The pipeline height was varied as 1, 2, 3, 4, and 5 m above the ground surface. In addition, the soil resistivity was also varied as 100, 300, 1000 and 3000 ohm.m. The effects of pipe height above the ground on the induced voltage on the pipeline for various resistivity values are illustrated in Figure 6.

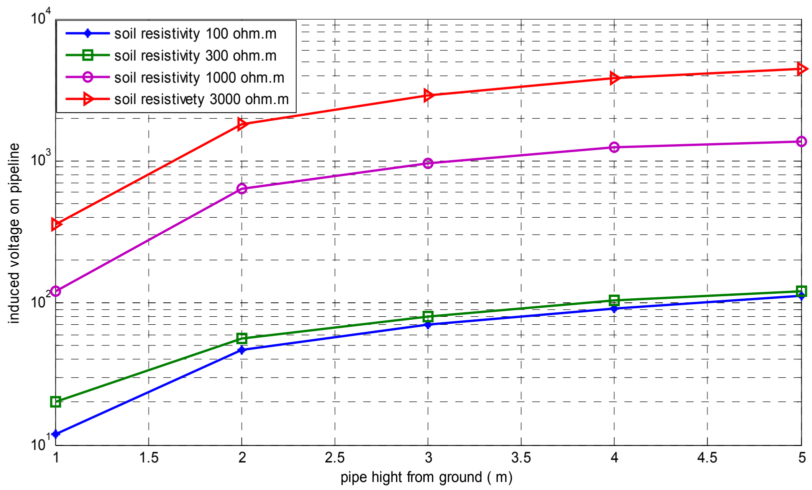

Figure 6. The effect of pipe height above the ground on the induced voltage on the pipeline for various resistivity values (applied current = 30.7 kA)

A sharp increase of the induced voltage was observed when the height was changed from 1 m to 2 m. For height increment from 2 to 5 m, the voltage also increased, but at a slower rate. As expected, the induced voltage also increases as the soil resistivity is increased.

3.3. Effects of Pipeline Distance from Tower

The same lightning stroke current of 30.7 kA was injected on the shield wire. The distance of the pipeline from the tower was altered at d distance of 20 m, 30 m, 50 m, and 50 m. Again, the pipeline was positioned 1 m above the ground.

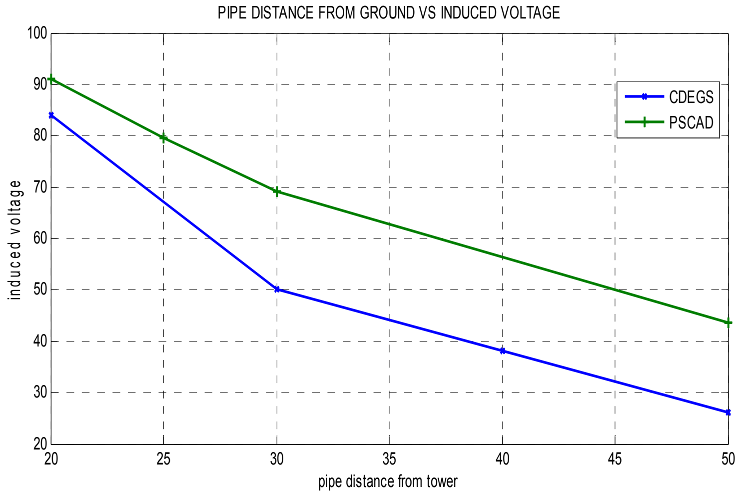

Figure 7. The effect of separation distance between the tower and the pipeline on the computed induced voltage Using PSCAD and CDEGS. A single lightning stroke with a peak current of 30.7kA was used

The effect of separation distance between the tower and the pipeline on the computed induced voltage using PSCAD and CDEGS is depicted in Figure 7. As expected, the induced voltage magnitude reduces when the pipeline was taken further away from the tower.The induced voltage obtained using PSCAD shows a higher value when compared to that obtained using CDEGS. This the different in values between the two approaches, because PSCAD assumes that the conductors are infinite in length and parallel along the right of way. These two main assumptions lead to insignificant error. This error increase as the separation between the pipeline and the tower increase.

3.4. Effects of Soil Resistivity

The effect of soil resistivitydue to the interaction of steady-state electromagnetic fields and pipelines is universally known. In general, an increase in soil resistivity will result in an increase in the induced voltage on the pipeline. The relationship is non-linear in nature. To ascertain this assumption with lightning stuies, various simulations were executed with different soil resistivity being utilized in each model.

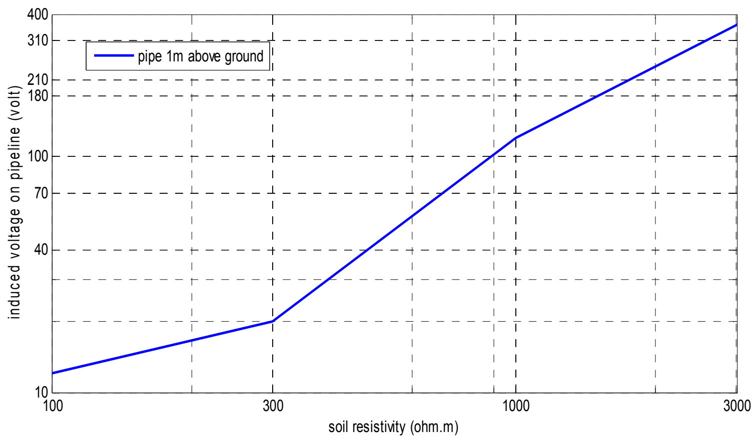

Figure 8. The effect of soil resistivity on the induced voltage on the pipeline. The pipe height is 1 m above ground and the current peak is 30.7 kA.

Figure 8 demonstrates the large disparity of the peak induced voltages on the pipeline associated with soil resistivity values between 100 Ω-m and 3000 Ω-m. A more or less a linear increment of the induced voltage with the log of soil resistivity is observed.

4. CONCLUSION

Provide Pipeline induced voltages due to lightning strikes had been computed using CDEGS and the results were compared with those using PSCAD. Different model parameters were varied to determine the extent of variation in the induced voltage on the pipeline. Results show that PSCAD results are higher than those from CDEGS due to the two main assumptions of PSCAD, which are the pipeline is infinite in length and uniformly parallel to the transmission line. It can be concluded that CDEGS gives more accurate results due to its more accurate simulation models used. It is noted that CDEGS uses a soil model that model a remote earth reference point, while PSCAD considers the whole ground as a finite conducting surface.

The effects of various model parameters on the pipeline induced voltages were also studied. Key findings are a more or less linear increment of induced voltage with the log of soil resistivity, a linear decrease with tower-pipeline separation, a linear increase with pipeline height above ground, and a linear increase of induced voltage with peak lightning impulse current.

ACKNOWLEDGEMENTS

In preparing this paper, the first author was in contact with many people, academicians, researchers and practitioners who contributed immensely towards his understanding and thoughts. The authors are also indebted to the Institute of High Voltage and High Current (IVAT) for providing the full version of CDEGS software with technical support. The authors would also like to thank Ministry of Education and Universiti Teknologi Malaysia for providing the financial support (grant number 10H61).

REFERENCES

[1] Ismail, H.M., *Effect of oil pipelines existing in an HVTL corridor on the electric-field distribution.* Power Delivery, IEEE Transactions on, 2007. 22(4): p. 2466-2472.
[2] Metwally, I. and F. Heidler, *Mitigation of the produced voltages in AC overhead power-lines/pipelines parallelism during power frequency and lightning conditions.* European transactions on electrical power, 2005. 15(4): p. 351-369.
[3] Caulker, D., et al. *Lightning overvoltages on an overhead transmission line during backflashover and shielding failure*. in *Universities Power Engineering Conference (UPEC), 2010 45th International*. 2010. IEEE.
[4] Zeng, T., et al., *Study on Lightning Intruding Overvoltage in Yantan Extension Substation.* TELKOMNIKA Indonesian Journal of Electrical Engineering, 2014. 12(4): p. 2458-2464.
[5] Alqahtani, B. and M. Shwehdi. *Cost Effective Mitigation Study of Electromagnetic Interference by Power Lines on Neighboring Gas Pipeline*. in *CIGRE C4 Colloquium on Lightning and Power System*. 2010.
[6] Ab Rahman, P.N.S., et al., *Misidentification of Type of Lightning Flashes in Malaysia.* TELKOMNIKA Indonesian Journal of Electrical Engineering, 2014. 12(8): p. 5938-5945.
[7] Dawalibi, F. and R.D. Southey, *Analysis of electrical interference from power lines to gas pipelines. II. Parametric analysis.* Power Delivery, IEEE Transactions on, 1990. 5(1): p. 415-421.
[8] Kopsidas, K. and I. Cotton, *Induced voltages on long aerial and buried pipelines due to transmission line transients.* Power Delivery, IEEE Transactions on, 2008. 23(3): p. 1535-1543.
[9] Southey, R., F. Dawalibi, and W. Vukonich, *Recent advances in the mitigation of AC voltages occurring in pipelines located close to electric transmission lines.* Power Delivery, IEEE Transactions on, 1994. 9(2): p. 1090-1097.
[10] Cotton, I., K. Kopsidas, and Y. Zhang, *Comparison of transient and power frequency-induced voltages on a pipeline parallel to an overhead transmission line.* Power Delivery, IEEE Transactions on, 2007. 22(3): p. 1706-1714.
[11] Liu, P., et al. *Modeling lightning performance of transmission systems using pscad*. in *High Voltage Engineering and Application, 2008. ICHVE 2008. International Conference on*. 2008. IEEE.

BIOGRAPHIES OF AUTHORS

Ali is lecturer and the head of control department at College of Electrical and Electronics Technology-Benghazi-Libya. He is Ph.D. student at UTM university. He obtained his Bachelor's degree of electrical engineering from Benghazi University at Libya in 2005. He was work as field engineer at Schlumberger company from 2005 to 2006, and then he moved to Halliburton oil company to work as logging engineer from 2006 to 2009. He joined UTHM university as master student and obtained his M.Sc. degree in electrical engineering in 2011 His research interests are high voltage, transmission line, power towers, induced voltages and lightning.

Zulkurnain Abdul-Malek is an associate professor and Director at UTM Institute of high voltage & high current (IVAT) Universiti Teknologi Malaysia obtained his M.Sc. in Electrical and Electomagnetic Engineering with Industrial Applications (University of Wales Cardiff, Unitd Kingdom 1995). He received his Ph.D. in High Voltage Engineering (Cardiff University, United Kingdom 1999). He is Director in UTM Institute of High Voltage & High Current (IVAT)/UTM High voltage. He is He is Member of Institute of Electrical and Electronics Engineer (MIEEE) and collective Member of The International Conference on Large High Voltage Electric Systems (CIGRE). He is Chairman in Working Group on High Voltage Test Techniques, Malaysia, 2009-present. He is Member in Technical Committee on High Voltage Transmission, Malaysia, 2009-present, Member in Working Group on High Voltage Switchgear, Controlgear and Assemblies, Malaysia, 2002-present.