



The Impact of Fusion Welding in Corrosion Diagnosis of Joint Systems Using Ultrasonic Technique

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ARTICLE INFO	ABSTRACT
<p>Article History: Received 21 December 2021 Received in revised form 15 February 2022 Accepted 13 March 2022 Available online 14 March 2022</p>	<p>Nowadays the ultrasonic guide wave technique is the most accurate method in defect detection. Defect detection in the joined and continues systems make some measurement problems due to the structure and propagation of ultrasonic waves in these systems that must be considered for obtained accurate results. In this paper we analysis the manner and the effect of welded points in joint systems. For this aim we specially considered the grounding grids as a joint system and study the problem of the ultrasonic waves in corrosion diagnosis of this system. The grounding grids are the most important systems that increasing safety of power equipment in substations. The conductors of grounding grids usually connected together by fusion welding or bolts and nuts. But fusion welding make some problems for corrosion diagnosis of grounding grids and also pipelines while using ultrasonic technique. The main problem is incorrect results that obtained due to the interference of ultrasonic waves. This paper presented a new method to eliminating the effect of fusion welding points by placing the ultrasonic transducers in right locations. The influence of the soil is considered. Computer simulation results have shown the effect of this interference in accuracy of the result and effectiveness of the new method.</p>
<p>Keywords: Grounding Grids, Ultrasonic Waves, Piezoelectric, Corrosion Diagnosis, Fusion Welding</p>	

1. INTRODUCTION

Occurrence fault and irregular condition in power systems is inevitable, so in order to reduce victims of this condition such as expensive equipment and employees damages, system instability and etc. some proceeding like grounding grids have been done. Grounding grids flow the fault currents into the earth to protect expensive equipment and employees that work with them. The grounding grids usually buried in 0.5m to 1m in earth. Conductors of grounding grid usually made of copper and copper alloys, steels, aluminums [1]. Chemical reactions in earth, make serious problems for the conductors like corrosion and even sometimes broken which it is affects their operation and reduces the safety of power systems.

In recent years Researchers presented different methods for detecting and locate the corrosion of grounding grids. These methods according to the theory of them divided into:

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- electrical network methods [2], [3]-[6]
- electromagnetic methods [7], [8]-[11]
- electrochemical methods [12], [13]

The basic of the electrical network method is assuming grounding grid like a circuit and measuring the resistance of conductors and accessible ports with flow current into the circuit. According to the operation of the electromagnetic method and their utility about in contrast magnetic field, they are divided into several categories; elliptically, parabolic and hyperbola which for study about modeling base on finite element or boundary integral analysis are effective [14]. In recent years researchers presented a method base on ultrasonic technique with high precision and sensitivity and also very faster than other methods in large scales, for detecting corrosion. In industry use this method for inspection oil and gas pipelines. Many studies have focused on guided wave propagation in structures as means for detection and monitoring of defects and corrosion [17-23]. For connecting conductors in grounding grids usually using fusion welding or pressing methods. It seems that fusion welding makes some problems for ultrasonic guide wave technique for corrosion diagnosis in grounding grid such as; wave Interference, the position of transducers and reducing the detection accuracy.

This paper examined the impact of fusion welding problems in corrosion diagnosis of integrated systems like grounding grids and present a new arrangement for placing the ultrasonic transducers in these systems for minimizing the effect of welding points. First a brief introduction of ultrasonic guide wave propagation in cylinders is given. In the next the influence of welding points in accuracy of detection by ultrasonic waves is discussed.

2. PROPAGATING OF ULTRASONIC WAVES IN CYLINDRICAL SOLIDS

The sound is the most well-known natural phenomena for human beings. The ultrasonic waves are similar to sound waves with a high frequency. They are both travel through a medium. The frequency of ultrasonic waves is normally above 20 kHz. The velocity of sound waves is depended on characterize, density and the compressibility of the medium. Ultrasonic waves can propagating in different types. They are divided into:

- Longitudinal waves (L)
- Shear waves
- Torsional waves (T)
- Flexural waves (F)

The displacement field and stress field of ultrasonic guide waves can be written as [24]:

$$u(x, t) = \hat{u}(x_1, x_2) e^{j(kx_3 - wt)} \quad (1)$$

$$\sigma(x, t) = \hat{\sigma}(x_1, x_2) e^{j(kx_3 - wt)} \quad (2)$$

Where coordinate system (x_1, x_2, x_3) , k is circular wave number, w is circular frequency and x_3 -axis points into the the direction of propagation.

Fig.1 shows the displacement fields of a cylinder carries these three types of modes (L,T,F) for a frequency of 100 kHz. The longitudinal and torsional waves are the most suitable waves for cylindrical structures due to some problems like difficulty to change when different modes presented and irritable shape of waves and propagation of them.

The velocity of longitudinal waves in the materials defined as:

$$c = \sqrt{\frac{\lambda + 2\mu}{\rho}} \quad (3)$$

Where μ, λ are the elastic constants of the material. A wave's group velocity is defined as the velocity at which the overall shape of the wave amplitude propagates through space. The phase velocity of a wave is the rate at which the wave's phase propagates in space. The dispersion curves for a cylindrical aluminum alloy with a radius of 2mm are shown in Fig.2. Red lines represent longitudinal modes, blue lines flexural modes, and black lines torsional modes. As shown in Fig.2, L(0,1) is a good wave at 600kHz since it is the fastest wave at this frequency. As a result, it is one of the reasons why normally longitudinal modes are proposed for SHM.

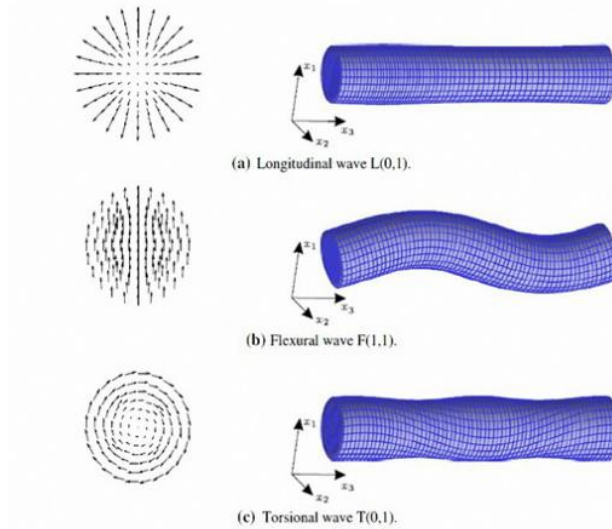


Fig. 1. Displacement fields for different modes of propagation (L,T,F) in a cylindrical structure [24]

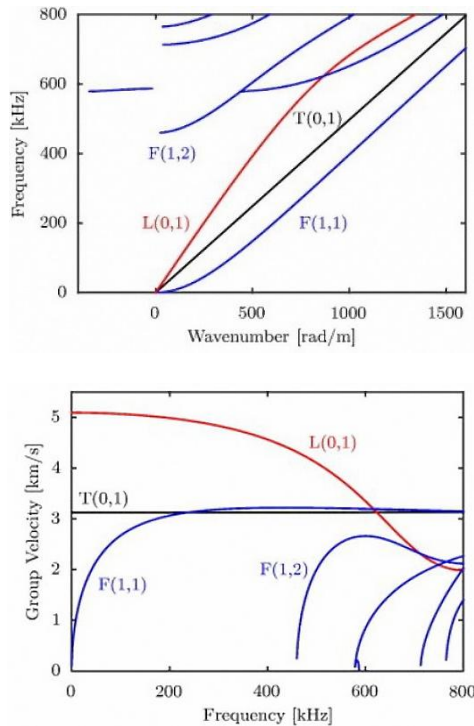


Fig. 2. Dispersion curves for a cylindrical aluminum alloy waveguide with radius of 2mm; (a) frequency versus wavenumber; (b) group velocity versus frequency [25]

3. INFLUENCE OF FUSION WELDING

A grounding grid is formed by many conductors that connected together in equal calculated spacing. As we said, the conductors generally connecting together by fusion welding or bolts and nuts as shown in Fig.3. Fusion welding is a generic term of welding process that relay on melting to join materials of similar composition [16]. Fusion welding has been a key factor in creation of modern civilization. Arc, laser beam, induction, chemical methods, oxyfuel and solid reactant are the different types of fusion welding. Principally an ultrasonic guide wave system

consist of two generally parts such as the software and the hardware parts. The hardware part consist of: Pulse generator, Transmitter circuit, Ultrasonic sensor, Receiver circuit, computer processing. Fig.4 show the elements of the software and hardware parts. The position of the receiver is determined by the structure of the considered medium. So it has an important role detection measurements.in this case we locate the receiver in two places. First at the end of the rod and then near the transmitter. For first case the first echo that appears is the end of the rod echo and after that welded point echo and beginning of the rod echo and second echo. If a fault occur in the entire of the rod the fault echo must be appears between the end and beginning of rods echo. For second one (the receiver is placed with transmitter) again we see the welded point echo and after that the end of the rod echo. Again Similar to the previous model if a fault occur in the entire of the rod the fault echo must be appears between the end and beginning of rods echo. So the most important note is consider the special structure of the medium to place the sensors with the minimum interferences and noises.

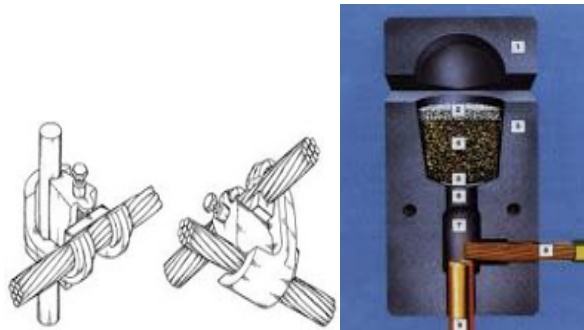


Fig. 3. Two type of connection of conductors of grounding grids; (a) Bolt and nuts; (b) fusion welding

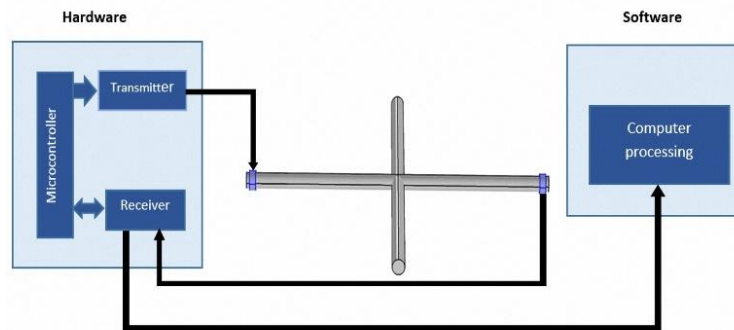


Fig.4. general block diagram of the system

We suppose that a piezoelectric transducer s fixed in the beginning of a conductor rod with two welding points in $1/3$ and $2/3$ of the rod length. When the ultrasonic waves sent to the conductors, the waves are propagating in other connected conductors due to the welding points. In physics, interference is a phenomenon in which two waves superpose to form a resultant wave of greater, lower, or the same amplitude that it is usually refers to the interaction of waves that are correlated or coherent with each other, because they come from the same source with the same frequency. The mode of interference of waves is shown in Fig.5. As we can see when the transmitter sent to ultrasonic waves to the conductor, a part of the waves propagated in the right and left hands of the conductors because of the welding points. According to the fig.5, we consider the path of the waves in three colors. So we named paths as: A blue path, B black path and C the orange path. In Fig.5 ultrasonic waves propagating in different directions in entire of the system. Each welded point make interference .This is because of the system integration and the constant velocity of ultrasonic waves in the used material.

3.1 Simulation model and results

This simulation model examined the influence of fusion welding on corrosion detection with ultrasonic guide wave technique using COMSOL Multiphysics 4.2. There are two situations considered for conductors: (a) without

welding point and (b) with two welding points. The diameter of all conductors is 20mm with length 1m from copper with density 8700 kg/m^3 and speed of sound 4700 m/s . A piezoelectric transducer from leadzirconate-titanate with density 7500 kg/m^3 and speed of sound 4650 m/s used for send longitudinal waves into the conductor. The transducers placed in $Z=0$. A 40kHz sin wave 2.9 V with time step $(0, 0.000001, 0.002)$ inducted to the transducers. The manner of propagating of ultrasonic waves is shown in Fig.6 and Fig.7 shows the incoming ultrasonic waves pressure received by the receiver in time for two different models.

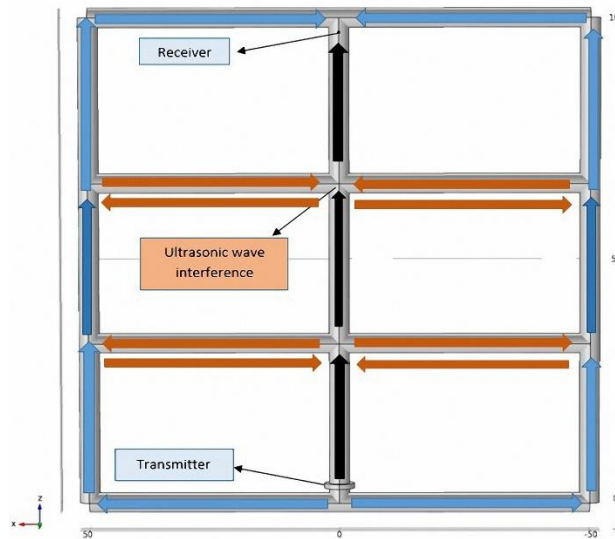


Fig. 5. The manner of the ultrasonic wave propagation in grounding grids with two fusion welding points.

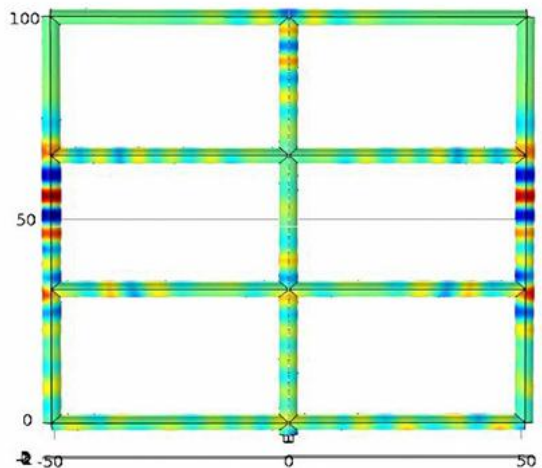
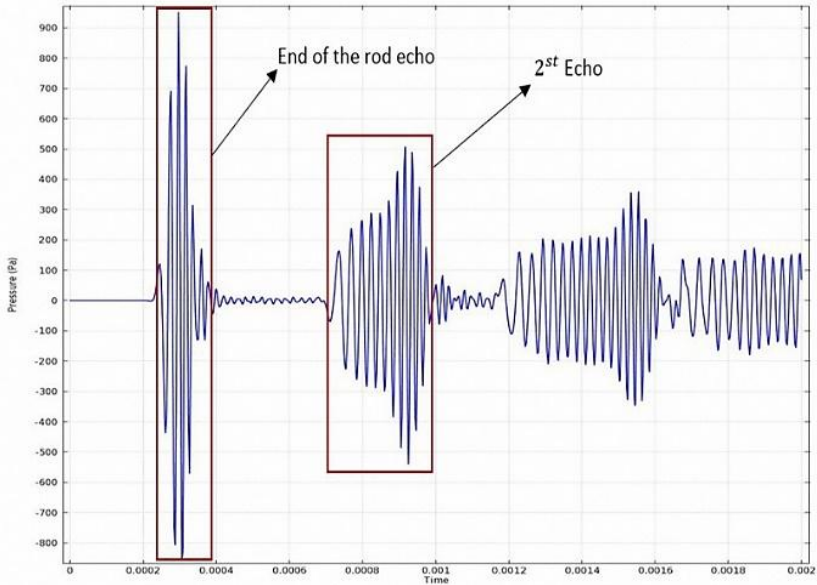


Fig. 6. the manner of propagating of ultrasonic waves in $t = 0.003 \text{ s}$

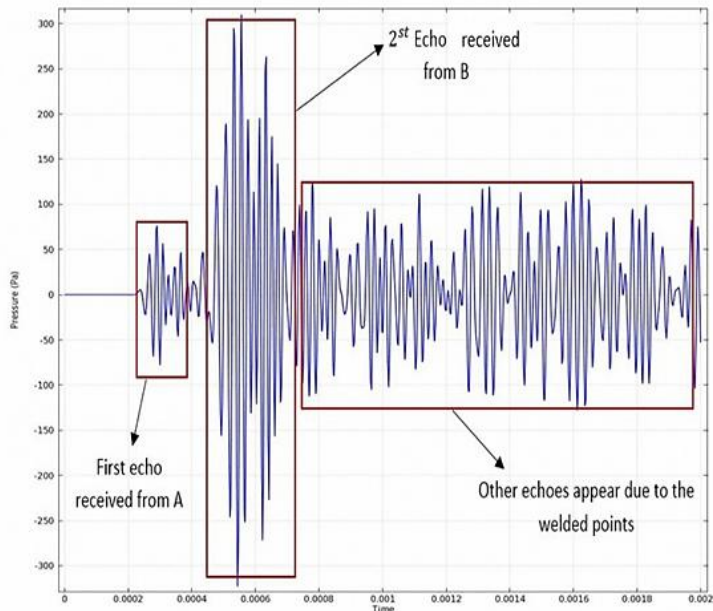
According to the wave curve obtained from receiver we can see that in grids, which have two fusions welded points, the curve of the incoming wave is completely different due to the wave interference. In fact, interference's effects come from ultrasonic waves that propagated from one source, but they take different paths up to the interference point. In the model (a) the end of the rod echo appears by reflected waves from the end of the rod and after this the second echo propagating into the body of the rod by the transmitter.

In defect diagnosis by ultrasonic guide wave technique the fault echo must be clearly appeared between the first and end of the structure echo. If there is a fault occur on the pipe in the model (a) we can see the fault echo between 0.0002s and 0.001s . In the model (b) we have distinctive echoes that reach to the receiver in different paths that have been marked in Fig.7. There is a big problem to the model (b) because it is impossible to detect the defect in presence of other annoying waves that reach to the receiver by other paths and welded points. The phase differences of these

waves can be measured by determining different paths that the wave taken from Source to interference point. When the path difference is a real multiplication of the wave length like $n\lambda$, where n is a natural number, the waves have constructive interference. In other hands, when the path differences are a fractional multiplication of the wave length like $a/b \lambda$, then the waves have been devastating interference. According to these results, we conclude that, for obtaining the accurate results from ultrasonic waves in corrosion diagnosis of grounding grids or other joint systems, there is maximum just one welding point must be there between the receiver and the transmitter. In using ultrasonic guide wave method for detecting corrosion in grounding grids, the position of transducers and receivers must be such a way that fusion welding points have minimum effect on accuracy of detection results.



(a)



(b)

Fig. 7. ultrasonic wave pressure in time for two models; a) without fusion welding b) with fusion welding

4. DISCUSSION

According to these results, we conclude that, for obtaining the accurate results from ultrasonic waves in corrosion diagnosis of grounding grids or other joint systems, there is maximum just one welding point must be there between the receiver and the transmitter or placing the sensors in such a way that any welded point does not affect the results. so in using ultrasonic guide wave method for detecting corrosion in grounding grids and any joint system, welding points must have minimum effect on accuracy of detection results. For this aim we presented a new manner of placing transducers which shown in Fig.9. We placing the transmitter and receiver in the welded point. In this new arrangement of sensors we can monitoring 4 conductors connected to the welded point without any annoying echoes and noises. Fig.8 shows the obtained results for this new method. We send the ultrasonic waves in to the body of 4 adjacent conductors by the welded point and obtained the reflected signal from the positions marked in Fig.9. As we can see there is no interference point between the transmitter and receiver. The locale of possible error echoes is shown in Fig.8. By this new arrangement the main problem of using ultrasonic guide wave for joint system with welded joint like grounding grids is solved and we can monitoring the entire of the grounding grid system with accurate results.

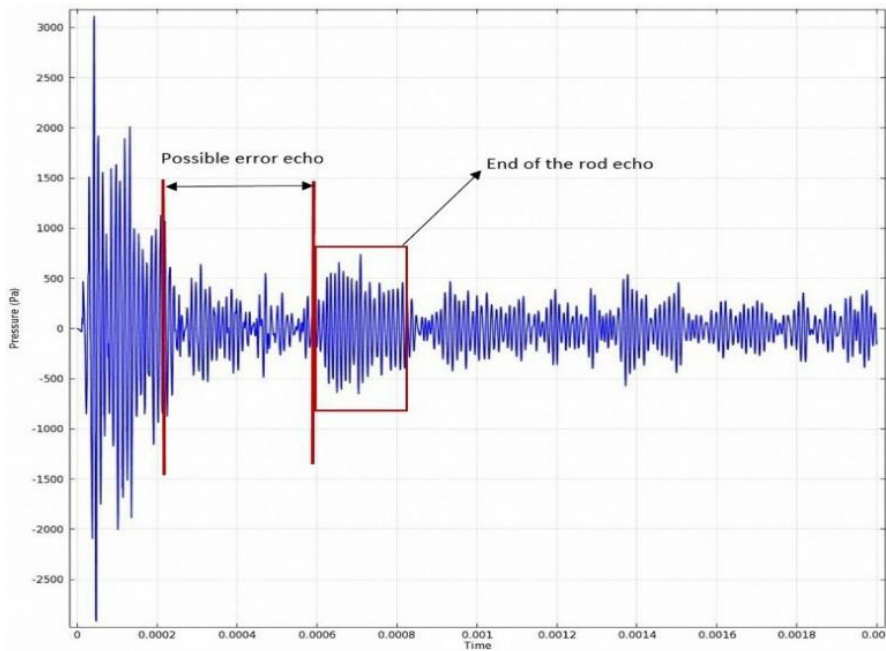


Fig. 8. ultrasonic wave pressure in time for placed sensors in nearby welded point

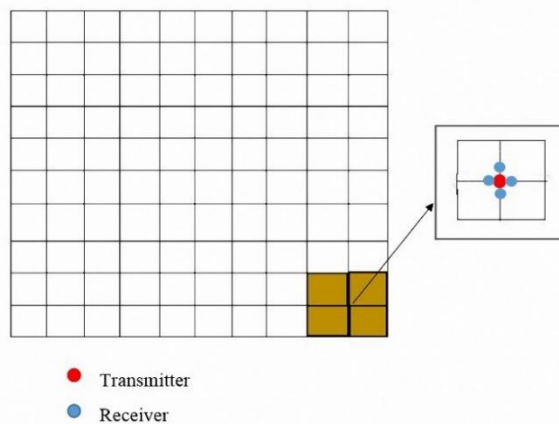


Fig. 9. the manner of placing of ultrasonic sensors

5. CONCLUSION

This paper examined the impact of fusion welding in corrosion diagnosis of continuous systems especially grounding grids and also other integrated systems when the ultrasonic technique used for detect the defects. Simulation results using COMSOL Multiphysics 4.2 shows that, when there are fusion welding points between the transmitter and receiver in an integrated system, the interference phenomena of the ultrasonic waves occur which its effect verify and accuracy of the results. Also this paper presented a new arrangement of placing sensors in grounding grids to minimizing the effect of fusion welding points.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

REFERENCES

- [1] Wang, X., Shi, T., Jiang, Z., Chen, W., Guo, M., Zhang, J., ... & Wang, Y. (2019). Relationship among grain size, texture and mechanical properties of aluminums with different particle distributions. *Materials Science and Engineering: A*. <https://doi.org/10.1016/j.msea.2019.03.034>
- [2] Ackerman, A., Sen, P. K., & Oertli, C. (2013). Designing safe and reliable grounding in AC substations with poor soil resistivity: An interpretation of IEEE std. 80. *IEEE transactions on industry applications*, 49(4), 1883–1889. doi:10.1109/tia.2013.2256092
- [3] Hu, J., Zeng, R., He, J., Sun, W., Yao, J., & Su, Q. (2002). Novel method of corrosion diagnosis for grounding grid. *PowerCon 2000. 2000 International Conference on Power System Technology. Proceedings (Cat. No.00EX409)*. Perth, WA, Australia. doi:10.1109/icpst.2000.898168
- [4] Liu, J., Wang, J.-X., & Wang, S. (2006). A corrosion diagnosis approach for grounding grids based on Tabu search algorithm. *2006 International Conference on Machine Learning and Cybernetics*. Παρουσιάστηκε στο 2006 International Conference on Machine Learning and Cybernetics, Dalian, China. doi:10.1109/icmlc.2006.258565
- [5] Long, X., Dong, M., Xu, W., & Li, Y. (2013). Online monitoring of substation grounding grid conditions using touch and step voltage sensors. *2013 IEEE Power & Energy Society General Meeting*. Vancouver, BC. doi:10.1109/pesmg.2013.6672322
- [6] Xiaoling, Z., & Qingyang, H. (2002). Fault diagnosis of grounding grid of electric power plants and substations. *Proceedings of the CSU-EPSA*, 14, 48–51.
- [7] Zhang, X., & Chen, X. (2000). The technique of the optimization applied in the grounding grid's failure diagnosis. *High voltage engineering*, 26, 64–66.
- [8] Yu, C., Fu, Z., Wu, G., Zhou, L., Zhu, X., & Bao, M. (2017). Configuration detection of substation grounding grid using transient electromagnetic method. *IEEE transactions on industrial electronics* (1982), 64(8), 6475–6483. doi:10.1109/tie.2017.2682033
- [9] Yu, C., Fu, Z., Hou, X., Tai, H.-M., & Su, X. (2015). Break-point diagnosis of grounding grids using transient electromagnetic apparent resistivity imaging. *IEEE transactions on power delivery*, 30(6), 2485–2491. doi:10.1109/tpwr.2015.2403308
- [10] Lawson, V. R. (1988). Problems and detection of line anchor and substation ground grid corrosion. *IEEE transactions on industry applications*, 24(1), 25–32. doi:10.1109/28.87245
- [11] Shang, L., & Liang, W. (2015). Fault diagnosis of substation grounding grid based on the signal distance function. *2015 5th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT)*. Changsha, China. doi:10.1109/drpt.2015.7432529
- [12] Dawalibi, F. (1986). Electromagnetic fields generated by overhead and buried short conductors part 2-ground networks. *IEEE Transactions on Power Delivery*, 1(4), 112–119.
- [13] Zhang, X.-L., Zhao, X.-H., Wang, Y.-G., & Mo, N. (2010). Development of an electrochemical in situ detection sensor for grounding grid corrosion. *Corrosion*, 66(7), 076001–076001–076007. doi:10.5006/1.3462913
- [14] Lei, H. A. N., Shi-Zhe, S. O. N. G., Xiu-Li, Z. H. A. N. G., Yong-Li, L. I., & Zhi-Gang, Q. I. U. (2009).

Development and application of a portable electrochemical device for diagnose of grounding grid corrosion. *Corrosion Science and Protetion Technology*, 21(3), 337–340.

- [15] Lord, W. (1990). Electromagnetic methods of defect detection. International Conference on Magnetism. International Conference on Magnetism, Brighton, UK. doi:10.1109/intmag.1990.734562
- [16] Gu, G., & Zhu, L. (2011). Modeling of rate-dependent hysteresis in piezoelectric actuators using a family of ellipses. *Sensors and Actuators. A, Physical*, 165(2), 303–309. doi:10.1016/j.sna.2010.09.020
- [17] Mudge, P. J. (2001). Teletest® Long Range Ultrasonic Testing Technique-Performance Details.
- [18] Sheard, M. (2001). Field experience of using long-range ultrasonic testing. *Insight*, 43(2), 73–83.
- [19] Alleyne, D. N., & Cawley, P. (1996). The excitation of Lamb waves in pipes using dry-coupled piezoelectric transducers. *Journal of Nondestructive Evaluation*, 15(1), 11–20. doi:10.1007/bf00733822