rods because this tower has a high ground resistance value before the repair.

When each tower is installed with more electrodes, the tower footing resistance, the soil resistivity value, back-flashover level, and insulator voltage in the studied line can be reduced to less than half of their respective previous values. This can be seen in tower 77, where the tower footing resistance reduces to 0.99, the soil resistivity value drops to 6.07 Ω.m, the back-flashover rate decreases to 0.86 flashover rate/km/years, the insulator voltage decline to 0.9 MV when the disturbances occur. Another factor affecting the number of back-flashovers in the lines is the span length; this can be seen in towers 68 and 77.

The soil resistivity value in each tower has increased, but the number of back-flashover disturbances is lower. This is due to the length of the span because the shorter the span, the faster the reflected wave will be; consequently, it can reduce the voltage in the insulator and minimize the chance of flashover occurrence.

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REFERENCES

[1] The Distribution and Load Control Center Sumatera (Sumatera P3B), "Lightning Density," Monthly Report, Sumatera P3B, Indonesia, 2013.

[2] Meteorological and Geophysical of Padang Panjang, "Annual Report," BMKG Padang Panjang, Indonesia, 2017.

[3] N. Malcolm and R. K. Aggarwal, "An analysis of reducing back flashover faults with surge arresters on 69/138 kV double circuit transmission lines due to direct lightning strikes on the shield wires," *12th IET Int. Conf. Dev. Power Syst. Prot. DPSP 2014*, pp. 1–6, 2014.

[4] M. Asadpourahmadchali, M. Niasati, and Y. Alinejad-Beromi, "Improving tower grounding vs. insulation level to obtain the desired back-flashover rate for HV transmission lines," *Int. J. Electr. Power Energy Syst.*, vol. 123, no. February, p. 106171, 2020, doi: 10.1016/j.ijepes.2020.106171.

[5] J. He, X. Wang, Z. Yu, and R. Zeng, "Statistical analysis on lightning performance of transmission lines in several regions of China," *IEEE Trans. Power Deliv.*, vol. 30, no. 3, pp. 1543–1551, 2015, doi: 10.1109/TPWRD.2014.2363122.

[6] R. de la Rosa, G. Enriquez, and J. L. Bonilla, "Contributions to lightning research for transmission line compaction," *IEEE Trans. Power Deliv.*, vol. 3, no. 2, pp. 716–723, 1988, doi: 10.1109/61.4310.

[7] PLN, "Earthing at Substations and Transmission Networks," no. 0053, 2020.

[8] Y. Warmi and K. Michishita, "Lightning trip-out of 150 kV transmission line: A case study," *Int. Rev. Electr. Eng.*, vol. 12, no. 3, pp. 260–266, 2017, doi: 10.15866/iree.v12i3.12233.

[9] Y. Warmi and K. Michishita, "Tower-footing resistance and lightning trip-outs of 150 kV transmission lines in west sumatra in Indonesia," *MATEC Web Conf.*, vol. 215, pp. 4–11, 2018, doi: 10.1051/matecconf/201821501022.

[10] P. Das and A. Baral, "Effect of Tower Footing Resistance on Back Flashover for A Double Circuit Line," *2019 8th Int. Conf. Power Syst. Transit. Towar. Sustain. Smart Flex. Grids, ICPS 2019*, pp. 1–6, 2019, doi: 10.1109/ICPS48983.2019.9067355.

[11] Y. Warmi, "Horn Length Estimation for Decrease of Tripout Rates on 150 kV Transmission Lines in West Sumatra in Indonesia," pp. 1–6, 2018.

[12] Y. Warmi and K. Michishita, "Improvement of Lightning Protection Design of 150 kV Transmission Lines in West Sumatra in Indonesia," *Int. Colloq. Light. Power Syst.*, p. 9, 2017.

[13] Y. Warmi and K. Michishita, "A Study on Lightning Outages on the 150 Kv Transmission Line of Payakumbuh – Koto Panjang in West Sumatra in Indonesia," *19th Int. Symp. High Volt. Eng.*, pp. 23–28, 2015.

[14] Y. Warmi and K. Michishita, "Investigation of lightning tripouts on 150-kV transmission lines in West Sumatra in Indonesia," IEEJ Trans. Electr. Electron. Eng., vol. 11, no. 5, pp. 671–673, 2016, doi: 10.1002/tee.22286.

[15] Y. Warmi, S. Amalia, Z. Antony, and F. R. Yanti, "Experimental Investigation of Insulator Dielectric Strength of Transmission Tower in Rocky Areas," vol. 12, no. 1, pp. 2–8, 2022

[16] Y. Warmi, Zulkarnaini, and Abdul Rajab "Proposal of analysis method to reduce back-flashover rate taking account of tower footing resistance," IJECE vol. 5, no. 1, pp. 94–106, 2023, doi: 10.1591/ ijece.v13i1.

[17] J. He, R. Zeng, S. Chen, S. Li, and W. Wu, "Impulse characteristics of grounding systems of transmission-line towers in the regions with high soil resistivity," *POWERCON 1998 - 1998 Int. Conf. Power Syst. Technol. Proc.*, vol. 1, pp. 156–162, 1998, doi: 10.1109/ICPST.1998.728944.

[18] M. Kizhlo and A. Kanbergs, "Research of the parameter changes of the grounding system," *WNWEC 2009 - 2009 World Non-Grid-Connected Wind Power Energy Conf.*, pp. 8–11, 2009, doi: 10.1109/WNWEC.2009.5335821.

[19] W. M.Telford, L. P. Geldart, and R. E. Sheriff, *Applied Geophisics*, 2nd ed. Cambridge: Cambridge University Press, 1990.

[20] S. Visacro and F. H. Silveira, "The Impact of the Frequency Dependence of Soil Parameters on the Lightning Performance of Transmission Lines," *IEEE Trans. Electromagn. Compat.*, vol. 57, no. 3, pp. 434–441, 2015, doi: 10.1109/TEMC.2014.2384029.

[21] D. Stanchev, "Model study of lightning overvoltages in substation due to back flashover of overhead transmission line 220 kv," *2018 10th Electr. Eng. Fac. Conf. BulEF 2018*, pp. 1–4, 2019, doi: 10.1109/BULEF.2018.8646928.

[22] J. Anderson, "Lightning Performance of Transmission Lines." Electric Power Research Institute, California, pp. 545–597, 1982.

[23] T. S Hutahuruk, *Power System Neutral Earth And Equipment Earth*. Jakarta, Indonesia: Erlangga, 1987.

[24] J. L. Manager and N. B. Member, "Simplified two layer model substation ground grid design methodology," *IEEE Trans. Power Deliv.*, vol. 5, no. 4, pp. 1741–1750, 1990, doi: 10.1109/61.103669.

[25] IEEE Power and Energy Society - Substations Committee, *IEEE Std. 81- Guide for Measuring Earth Resistivity , Ground Impedance , and Earth Surface Potentials of a Grounding System IEEE Power and Energy Society*, vol. 2012, no. December. 2012.

[26] H. B. Dwight, "Calculation of Resistances to Ground," *Trans. Am. Inst. Electr. Eng.*, vol. 55, no. 12, pp. 1319–1328, 1936, doi: 10.1109/T-AIEE.1936.5057209.

[27] Y. L. Chow, M. M. Elsherbiny, and M. M. A. Salama, "Resistance formulas of grounding systems in two-layer earth," *IEEE Trans. Power Deliv.*, vol. 11, no. 3, pp. 1330–1334, 1996, doi: 10.1109/61.517487.

[28] X. Cao, G. Wu, W. Zhou, and R. Li, "New method for calculating ground resistance of grounding grids buried in horizon two-layer soil," *2008 Int. Conf. High Volt. Eng. Appl. ICHVE 2008*, pp. 241–244, 2008, doi: 10.1109/ICHVE.2008.4773918.

[29] M. El Sherbiny, "Simple formulas for calculating the grounding resistance of rodbed buried in non-uniform soil," *Midwest Symp. Circuits Syst.*, vol. 2, no. 1, pp. 1281–1284, 1994, doi: 10.1109/mwscas.1994.519043.

[30] S. Hardi, F. Mirza, F. R. A. Bukit, and Rohana, "Influence of Lightning Characteristics on Back Flashover in Extra High Voltage Transmission Line: A case study," *J. Phys. Conf. Ser.*, vol. 1811, pp. 1–9, 2021, doi: 10.1088/1742-6596/1811/1/012048.

[31] S. Astinfeshan, A. Gholami, and M. Mohajeri, "Analysis of corona effect on lightning performance of HV overhead transmission line using ATP/EMTP," *ICEE 2012 - 20th Iran. Conf. Electr. Eng.*, no. Icee20 12, pp. 485–488, 2012, doi: 10.1109/IranianCEE.2012.6292406.

[32] P. Sarajcev, J. Vasilj, and D. Jakus, "Method for estimating backflashover rates on HV transmission lines based on EMTP-ATP and curve of limiting parameters," *Int. J. Electr. Power Energy Syst.*, vol. 78, pp. 127–137, 2016, doi: 10.1016/j.ijepes.2015.11.088.

[33] Cigré WG C4.501, *Guideline for Numerical Electromagnetic Analysis Method and its Application to Surge Phenomena*, no. June. 2013.