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Electromagnetic interference investigation of two overhead lines with a natural buried gas pipeline: An investigation on the Agri-Horasan Region in Turkey

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SUMMARY

Energy, transportation, and industrial investments increase daily in both developing and developed countries. In Turkey, one of the developing countries, infrastructure investments continue for the energy and transportation required by the increasing population. Turkey's land structure, usage functions of these lands, and high expropriation costs cause parallel and or intersecting routes to be preferred in infrastructure investments such as overhead lines (OHL), metal pipelines, and railway systems. Electromagnetic interference occurs between the transmission line and metal pipeline/railway systems on these routes. This electromagnetic interference induces current and voltage in metal pipelines/railway systems. This induced current and voltage in metal pipelines lead to partial discharges in the dielectric polyethylene coating of the line, which accelerates the pipeline's corrosion. In the present study, electrical interferences between the 400 kV Erzurum III (Horasan)-Agri and 154 kV Horasan–Agri overhead lines and the natural gas pipeline on a similar route are examined along 42.5 km, where the lines are laid in parallel and or intersecting with each other. This electromagnetic interference is investigated for different earth protection conductors on the overhead line by simulating a three-phase short-circuit fault in the 400 kV overhead line. Primarily, the response of 96 mm^2 steel cable, which is widely used in the energy transmission system in Turkey, is examined in terms of coating stress voltage, step voltage, and touch voltage. As an alternative to this conductor, the effect of 93 mm^2 and 200 mm^2 alumoweld (aluminum-clad) steel conductors are chosen since widely used for some other country's transmission lines also obtained according to the same parameters. By examining these alternatives, the advantages and disadvantages of earth protection conductors with similar and larger cross-sections compared to conventional steel conductors are investigated. If the effect of stainless steel and alumoweld protection conductors in close cross-sections on the induced coating stress, step, and touch voltages on the pipeline at the time of failure cases are compared, it is found that the alumoweld conductor performs better at the rates of 21.2%-37.4%. The induced voltage level in the pipeline decreases significantly with the increase in the cross-section of the alumoweld protection conductor. Even if short-circuit faults in high voltage transmission lines are interrupted in a very short time, this may cause cracks and/or holes in the metal pipeline coating. To prevent this phenomenon, which makes the pipeline unguarded to

corrosion, the necessary measures should be taken to reduce electromagnetic interference as much as possible.

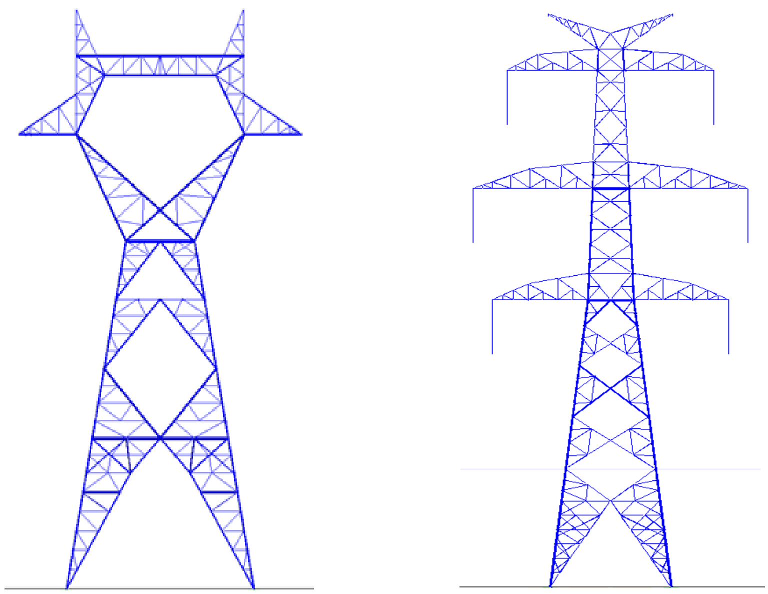
KEYWORDS

Transmission line, pipeline, electromagnetic interference, ground wire, alumoweld.

I. INTRODUCTION

Three different interactions can cause electromagnetic interference between energy transmission lines and pipelines. These are capacitive, inductive, and conductive coupling interactions. Capacitive couplings are observed between aboveground metal pipelines that are electrically insulated from the ground and the nearby OHL. It has been determined that the pipeline height and soil resistivity increase the capacitive interference voltage on the pipeline [1]. The magnitude of the capacitive effect varies according to the voltage value of the OHL's, the distance between the OHL and the pipeline, the OHL operating condition (short-circuit fault or steady-state), the distance at which the OHL and the pipeline are parallel [2].

Inductive interference is observed when a parallel and/or intersecting route between the buried metal pipeline and the OHL. Inductive interference is affected by parameters such as current in OHL, the structure of OHL towers, the distance between phase conductors, OHL operating state (fault or steady-state), distance between OHL and pipeline, intersection angles between these lines, and also fault current [2, 3]. Kim *et al* [2021] examined the effect of overhead lines on the pipeline in the single-circuit tower (phase conductors are horizontally and same height installed) and double-circuit tower (phase conductors are vertically installed) configurations. It is determined that horizontal single-circuit towers create 20% more inductive interference voltage to the pipeline than vertical double-circuit towers [3]. Typical designs of single-circuit (horizontally) and double-circuit (vertically) OHL towers are given in Figures 1(a) and 1(b), respectively. The voltage and current induced by inductive interference on the pipeline can damage the pipeline coating, create safety hazards during maintenance/repair, and disrupt pipeline components such as cathodic protection equipment.



(a) (b)

Figure 1. (a) Single-circuit horizontally OHL tower, (b) Double-circuit vertically OHL tower

Conductive coupling is observed in the buried pipeline during short-circuit faults in the transmission system, operation of switching equipment and lightning strikes. Conductive voltages and currents occur on the coating of the metal pipeline installed close to the lightning or short circuit fault point. The conductive current and, voltage induced in the pipeline by these transient reactions may cause safety risks, damage to the pipeline coating, deformation of the coating with instantaneous reverse currents to be applied by the cathodic protection, and melting of the pipeline metal depending on the location of the short circuit fault [2].

Buried metal pipelines are usually covered with insulating polyethylene material, and the electrical withstand voltage of this coating can be up to 20 kV [4]. During the installation or operation of pipelines, cracks and/or small holes may occur in the coating. When exposed to electromagnetic interference, the corrosion mechanism starts with partial discharges. The rate of this corrosion mechanism can vary with parameters such as humidity and oxygen in the environment, acidity value of the soil, and the distance between the OHL and the pipeline [2].

The most common method to prevent electromagnetic interference from OHL in metal pipelines is cathodic protection. Cathodic protection protects underground metal pipelines and existing metal structures in places such as metal tanks, bridges, submarines, ships, and ports. The purpose of using cathodic protection is to prevent the loss of electrons in the pipeline and the pipeline's metal wall thickness from decreasing and puncturing over time [5]. The main cathodic protection methods are galvanic anode protection and impressed current cathodic protection (ICCP). Cathodic protection with galvanic anode has some advantages such as the economy, low probability of failure, almost no overprotection, and so leakage current does not damage peripheral components in the pipeline. However, ICCP should be preferred in applications requiring high current and voltage where galvanic anode protection cannot provide sufficient power [6, 7]. Cathodic protection may not always be sufficient to protect the pipeline from corrosion. For example, extra precautions should be taken for OHL passing through the pipeline with a low angle or for pipelines installed in a very close parallel with OHL. One of the additional measures is to use a metal conductor connected to the pipeline in critical intersections. Another method would be to place a grounding grid just above the pipeline [8, 9]. Induced touch and step voltages in OHL at the time of short-circuit fault can be eliminated by using ground wire and grounding grid [9].

In this study, electromagnetic interference in a buried metal natural gas pipeline at Horasan-Agri location using the same corridor as 400 kV Erzurum III (Horasan)-Agri and 154 kV Horasan-Agri OHL installed in Turkey is investigated for different earth protection conductors on 400 kV transmission line towers. Earth grounding conductors used in the present study are 96 mm^2 stainless steel, 93 mm^2, and 200 mm^2 alumoweld, respectively. This stainless steel conductor, widely used in Turkey, has higher resistance than alumoweld conductors. The effect of alumoweld protection conductors, which can be used to reduce this resistance, on electromagnetic interference is examined and discussed in terms of coating stress voltage, step voltage, and touch voltage parameters for different conductor types and diameters. This study also aims to examine the variation of the current and voltage parameters induced in the metal pipeline in different tower protection conductors in the case of a three-phase fault in transmission lines.

II. CALCULATION METHOD

The current distribution electromagnetic interference, grounding, and soil structure analysis software (CDEGS) program is used in the calculations made in this study. Two different methods are used in electromagnetic interference calculations. These methods are electromagnetic field theory and circuit approach. Calculations made with electromagnetic field theory give more precise results, but the computer computation time is longer. Calculations made with the circuit approach for pipelines are fast and flexible and can do analysis pipelines using complex routes. CDEGS's Right of Way (ROW) program is used to calculate electromagnetic interference between the OHL and the buried metal pipeline. ROW program makes electromagnetic interference calculations by using the circuit approach. The circuit approach is functional where OHL and buried pipelines share a long route. There are three stages for circuit analysis: circuit parameters calculation, circuit setup, and circuit analysis [10]. To calculate electromagnetic interference, parameters such as pipeline and OHL route, OHL phase conductor and voltage, earth protection conductor, number of phase conductors and their height from the ground, positions of phase conductors and earth protection conductor on the tower, pipeline coating thickness, and resistance, earth resistance, tower foot resistance, and cathodic protection anode are adjusted in the simulation.

The natural gas pipeline is 1.5 m below the ground and 48 inches in diameter. Pipeline coating thickness and resistance are taken as 0.1 cm and 25.000 Ωm^2, respectively, in the simulation of electromagnetic interference. The tower transition resistances of 400 kV and 154 kV are chosen as 15 Ω and 20 Ω, respectively. The 400 kV and 154 kV OHLs have 3x1272 MCM ACSR Pheasant and single 1272 MCM ACSR Pheasant phase conductors, respectively. Electromagnetic interference is investigated in a 42.5 km zone where the 400 kV OHL and the pipeline intersect each other 5 times and follow parallel routes, as seen in Figure 2. Since the OHL and the pipeline move away from each other outside of this examination zone, electromagnetic interference between them is found to be negligible.

(a) (b)

Figure 2. 400 kV OHL and nature gas pipeline (a) general view with 1:25 km scale (b) examined 42.5 km section

ROWCAD simulation region and critical zone of the Horasan-Agri pipeline with 400 kV and 154 kV OHLs are shown in Figure 3

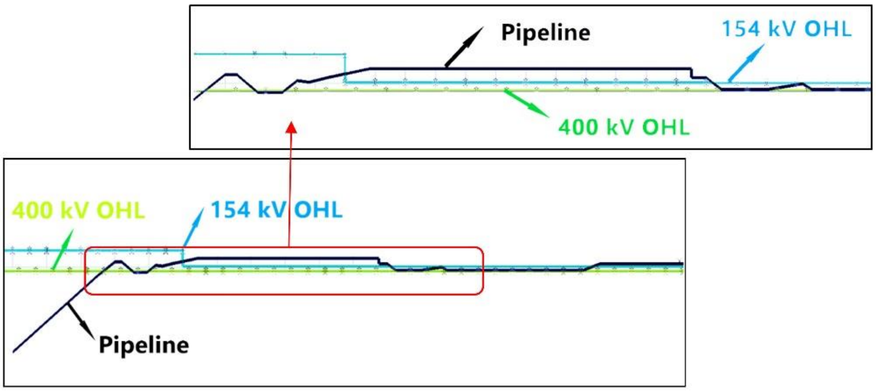


Figure 3. ROWCAD simulation region and critical zone of the 42.5 km route

III. RESULTS and DISCUSSIONS

Changing the earth protection conductor for the steady-state condition in the 400 kV Erzurum III (Horasan)-Agri overhead line is not caused a significant difference in the section current, touch voltage and, leakage current density. The section current, touch voltage and, leakage current density parameters have maximum amplitudes of 30.70 A, 3.83 V, and 12.33 A/m^2, respectively, when 96 mm^2 stainless steel is selected as the protection conductor. Since the safety limit value of the voltage induced in the pipeline in GB6830-86, GB540054-1995, and IEC61201 standards is 60 V, 50 V, and 33 V, respectively, the voltage induced in the pipeline at steady-state is within the safety limits for steady-state operation [11]. In addition, since the maximum value of the leakage current density is below 20 A/m^2, where electromagnetic interference begins to cause corrosion, the steady-state condition of the transmission line does not cause any corrosion.

The coating stress voltage, step voltage and, touch voltage parameters in the natural gas pipeline are calculated with CDGES when there is a 3-phase fault in the 400 kV Erzurum III (Horasan)-Agri overhead line for chosen three different types of earth protection conductors. While the induced voltage in the pipeline coating is 224.20 V for 96 mm^2 stainless steel conductors, this parameter decreases to 140.26 V and 68.09 V for 96 mm^2 and 200 mm^2 alumoweld conductors, respectively, as seen in Figure 4.

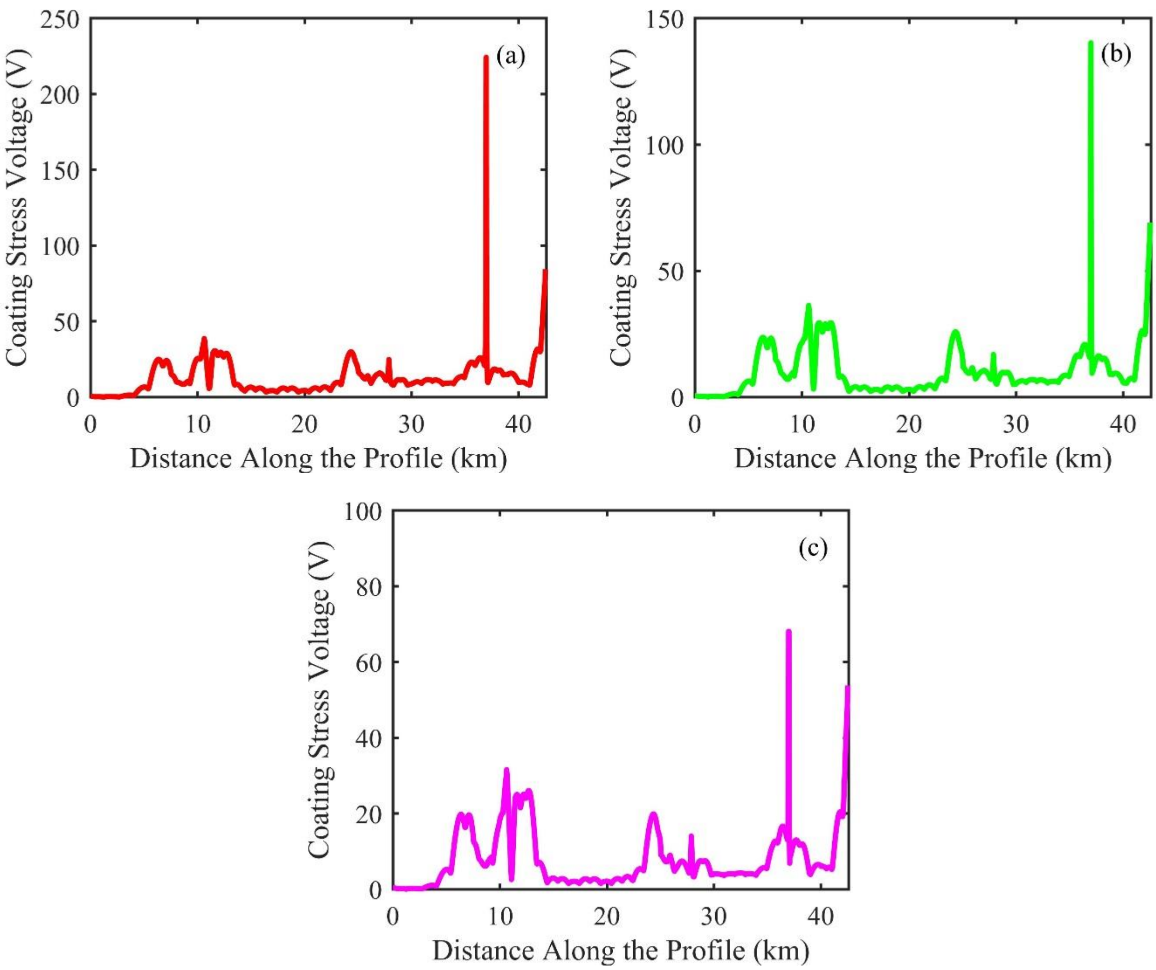


Figure 4. Coating stress voltage in case of 3-phase fault using (a) 96 mm^2 steel, (b) 93 mm^2 alumoweld, and (c) 200 mm^2 alumoweld protection conductor

Step voltages for different earth protection conductors under the same conditions with the three-phase fault in the transmission line are shown in Figure 5. While this voltage value is 6.43 V in steel conductors, it is found to be below 5 V in alumoweld conductors.

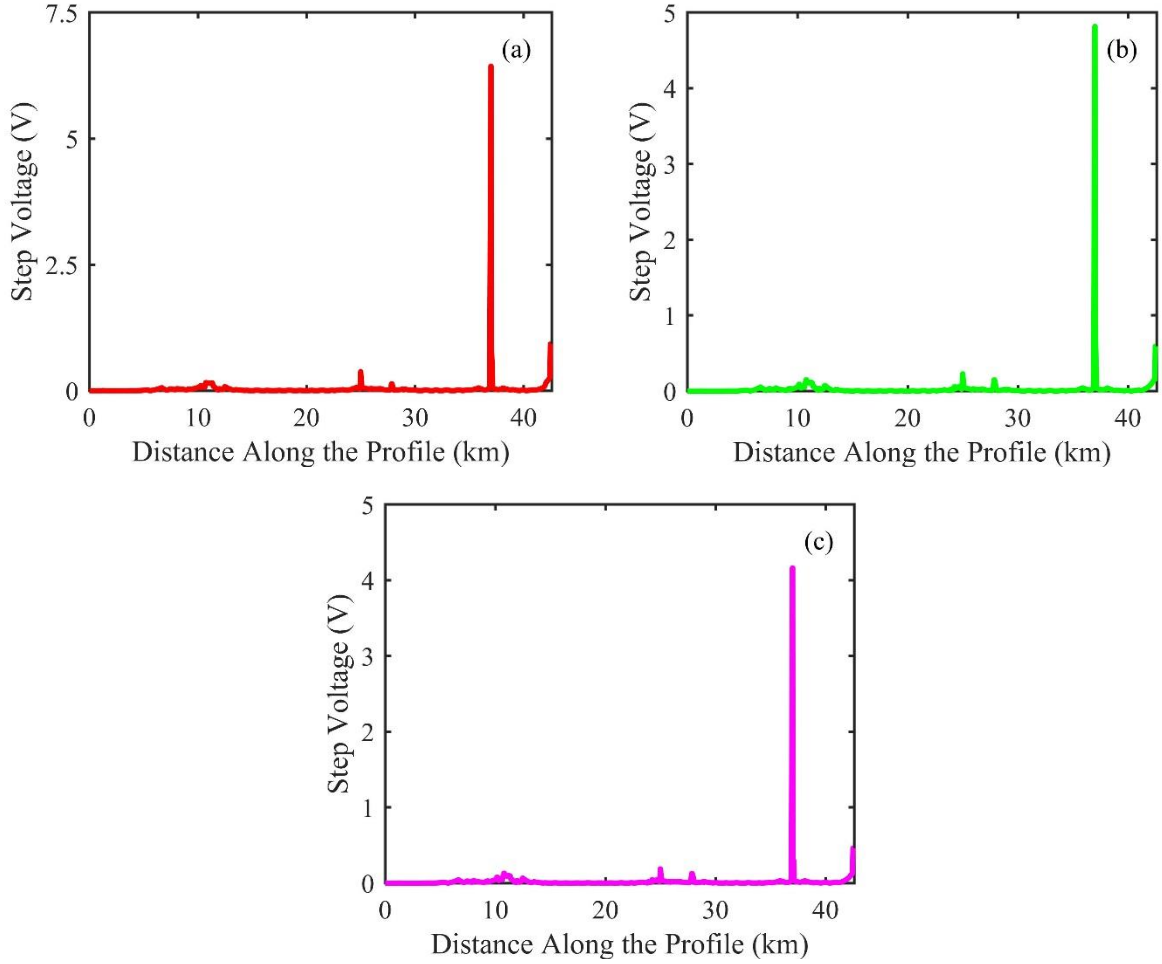
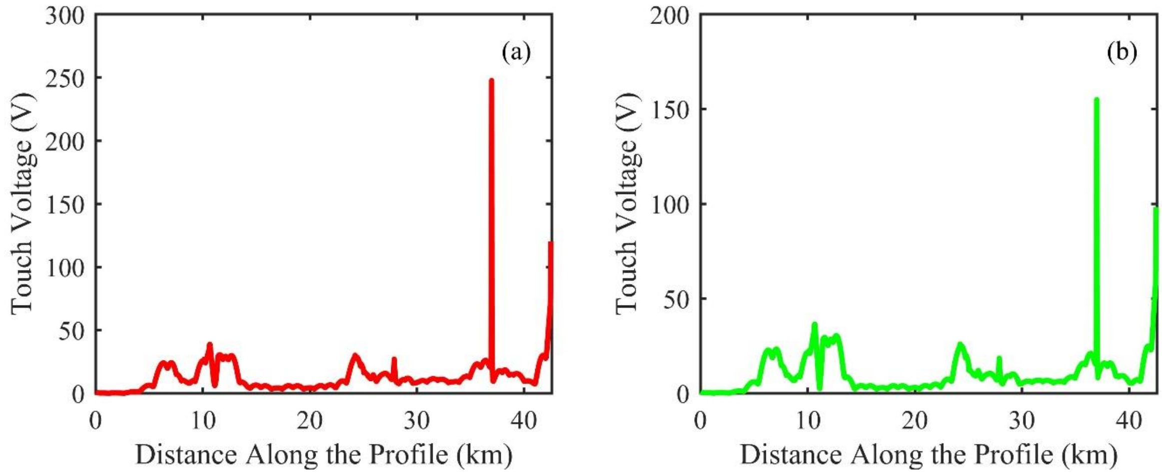


Figure 5. Step voltage in case of 3-phase fault using (a) 96 mm^2 steel, (b) 93 mm^2 alumoweld, and (c) 200 mm^2 alumoweld protection conductor

For the same conditions, the worst performance in terms of touch voltage is observed in 96 mm^2 stainless steel conductors. Touch voltage decreases by 37% and 52% in 93 mm^2 and 200 mm^2 alumoweld conductors, respectively, compared to steel conductors, as seen in Figure 6. Reducing the touch voltage induced in the pipeline at the time of failure in the transmission line by using alternative protection conductors ensures that the employees in the maintenance/repair processes work in a safer environment.



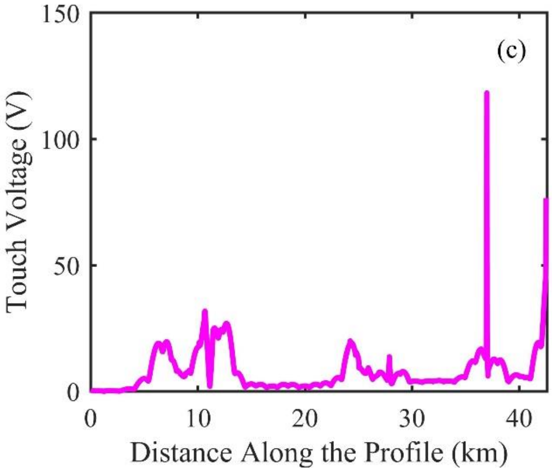


Figure 6. Touch voltage in case of 3-phase fault using (a) 96 mm^2 steel, (b) 93 mm^2 alumoweld, and (c) 200 mm^2 alumoweld protection conductor

A comparative analysis of the coating stress, step, and touch voltages induced on the pipeline for three different earth protection conductors when a three-phase fault occurs in the 400 kV Erzurum III(Horasan)-Agri OHL are given in Table 1.

Table 1. The overall effect of the different earth protection conductor

Type of Earth Protection Conductor	**Coating Stress Voltage (V)**	**Step Voltage (V)**	**Touch Voltage (V)**
96 mm^2 Stainless Steel	224.20	6.43	247.57
93 mm^2 Alumoweld	140.26 (37.4%)	4.81 (21.2%)	154.96 (37.4%)
200 mm^2 Alumoweld	68.09 (69.6%)	4.16 (35.3%)	118.21 (52.2%)

IV. CONCLUSIONS

This study examines the electromagnetic interference between the 400 kV transmission line and the natural gas pipeline following the same route in the Horasan-Agri region of Turkey for different earth protection conductors. The main outcomes of the present study can be summarized as follows,

- The stress voltage in the pipeline coating decreases by 37% and 68% for 93 mm^2 and 200 mm^2 alumoweld conductors, respectively, compared to the steel conductor when there is a 3-phase fault in the 400 kV transmission line.
- Step voltage decreases at the same fault condition by 21.2% and 35.3%, respectively. The step voltage is well below the safety limit in the standards for all three types of protective conductors.
- Although 96 mm^2 steel and 93 mm^2 alumoweld conductors are in very close cross-sections, the alumoweld protection conductor performs much better in terms of all three electrical parameters.
- When alumoweld conductors of different cross-sections are compared to each other, the voltages induced in the pipeline decrease significantly with the increase in the cross-section of the conductor.
- Since alumoweld protection conductors have higher conductivity than steel, fault current easily flows to earth at high amplitude. This reduces the induced voltages on the pipeline, thus preventing the deterioration of the pipeline's coating and increasing its service life as well.
- Future works will be an investigation of the effect of size of pipelines and also different types of fault cases such as mostly facing line-to-ground short circuit effects.

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