CIGRE-630 **2023 CIGRE Canada Conference & Exhibition**
Vancouver, BC, Sept.25 – 28, 2023

EMI Interaction of HV AC Lines with Railway Infrastructure

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SUMMARY

Transmission lines are a major source of Electromagnetic Fields (EMFs). When planning power transmission lines, it is important that engineers have a good understanding of EMFs so they can be considered during the project life cycle and their effects mitigated where possible. In recent years, Electromagnetic Interference (EMI) with infrastructure such as railways, telecommunication equipment, buried pipelines and boundary fences have been of great interest in the literature. The effects on such easily accessible metallic structures are a real and serious problem which can place the public, workers and infrastructure integrity at risk. When a long-term or short-term induced Alternating Current (AC) voltage exists on a metallic object in close proximity to the transmission line, it can be dangerous and potentially life-threatening for anyone touching that metal object. The impressed voltage can also trigger accelerated corrosion of the metal object. In addition, the effects of EMI on safety critical equipment such as railway signalling and communications can have safety and operational reliability consequences and, therefore, requires careful management.

The focus of this paper is the impact of transmission lines EMI on rail networks. It provides background on EMI from energized transmission lines and the relevant standards defining threshold levels for induced voltages for personnel safety and controlling the impact of extraneously induced power frequency voltages on railway safety critical system operations. The process of identifying and managing the risks of induced interference through a project lifecycle are described and modelling approaches to quantify the hazard exemplified. The EMI impacts are illustrated with the help of real-life case studies of assessment of EMI from HVAC transmission lines on railways that share an interface, such as a common right-of-way corridor, with the transmission lines. The case studies are geared towards assessing the impacts of EMI on personnel safety and infrastructure integrity and designing mitigation techniques to ensure a safe environment for members of public and workers at all times and the assessment of extraneous voltages impressed on railway safety critical systems. Case studies cover steady state operation and fault state events on the transmission network; impacts of seasonal variation in soil resistivity where ground is subject to freezing; possible mitigation techniques and the performance of various mitigation techniques.

KEYWORDS
Electromagnetic Interference, AC Interference, Induced Voltage, Inductive Coupling, Conductive Coupling, Transmission Lines, Railway Safety, Power Grid.

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1. INTRODUCTION

There are four coupling modes by which voltages are induced in railway tracks: (1) Capacitive Electrostatic Coupling: caused by the electrostatic field (which is proportional to the voltage level of the line) surrounding the energized conductor; (2) Inductive Electromagnetic Coupling: produced by the electromagnetic field (which is proportional to the current flow of the line) emanating from the line conductors; (3) Radiative Coupling: typically caused by corona activities on high voltage powerlines; (4) Conductive Coupling: takes place during fault conditions when very high current radiates from ground electrodes such as the power line tower footings and substation ground grids in earth. This high fault current often raises the electric potential of the earth near the railway track to thousands of volts with respect to remote earth. The collective effect of the three modes is called AC interference. The induction effect is mainly associated with the flow of current in power line conductors. Any metallic object in close proximity to current carrying power lines will have current induced in it due to interaction with the electromagnetic field generated by the power lines.

Typical objects affected by induction along the transmission line routes are pipelines, railway tracks, metallic fences or other transmission lines that come into close proximity of the main transmission line. Of particular significance in the context of this paper is the induction effect on railway networks. EMI on railways from AC transmission networks is of interest in several mainstream industry standards and assessment guidelines [1][2][4][6]. This paper discusses the effects of EMI arising from the colocation of AC transmission lines with railway tracks particularly from the point of view of personnel safety and interference caused to the low voltage signalling track circuits. The EMI issue is illustrated with the help of case studies drawn from recently completed EMI projects in UK and Canada by the authors.

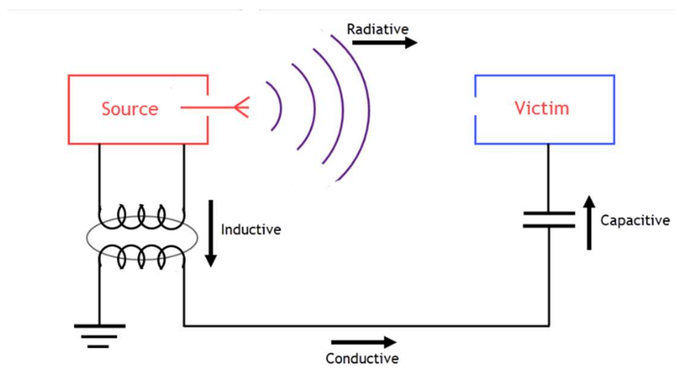

Figure 1 – Coupling mechanisms between powerlines and nearby metallic objects.

2. STATEMENT OF PROBLEM

The net impressed voltage on a railway as a result of EMI may put at risk the safety of any personnel carrying out work on the rail track or cause maloperation of safety critical systems such as railway signalling. Factors affecting the net impressed voltage are the magnitude of the current flowing in the power line, the ballast resistivity, the resistivity of the soil on which rail track is laid and the degree of parallelism and mutual separation between the railway and transmission line. The impressed voltage can trigger accelerated corrosion of the metal object. In carrying out recent studies, the authors discovered an important gap in the published literature. While there are sufficient guidelines on the acceptable limits for induced voltages from the viewpoint of personnel safety, very little guidance exists in available literature on the limits imposed by tolerability of track connected signalling elements which are essentially low voltage devices. It was found that track-connected equipment (especially the signalling surge arresters) can be unreasonably stressed under the influence of induced voltages from nearby AC transmission lines. The present standards governing manufacturing and testing of such devices do not provide guidance on compatibility of surge protective devices based on induced voltages from extraneous sources. One of the case studies presented here attempts to quantify the stresses the signalling arresters might be routinely exposed to under fault conditions on nearby transmission lines and paves the way to look into the EMI impact in further detail in future research to help power engineers establish the EMI compatibility criteria for signalling arresters.

3. RISK ASSESSMENT & HAZARD ANALYSIS

All projects perform risk assessments when undertaking infrastructure upgrade works, however their scope often does not encompass EMI, with interference issues only being identified when they manifest themselves upon project completion. Failure to identify and mitigate sources of EMI can not only lead to financial loss, but significant reputational damage and potentially dangerous situations.

Due to the distributed nature of both the power grid and railway infrastructure, identification and management of interfaces is critical in ensuring EMI is controlled. Key to the process is the concept of the HazID (Hazard Identification) workshop, which serves to identify risks associated with systems or actions (either planned or unplanned) that fall within the whole life cycle of the project, including the scope of design, construction or operation of the project. In doing so, the HazID will generate project-specific requirements for consideration and management.

For any identified hazards, effective mitigation measures shall be decided upon such that they can be eliminated by way of design changes or mitigated to levels deemed acceptable and managed. The identified hazards and associated mitigation strategies are then cascaded to the relevant design teams to aid the development of the designs and ensure requirements are met.

With respect to railway systems, interference manifests itself in several ways via various coupling mechanisms namely, capacitive, inductive, radiated EM fields and galvanic (conductive). Figure 2 provides an overview of the Powerline Sources, coupling mechanism and their potential system level impacts on operational railways.

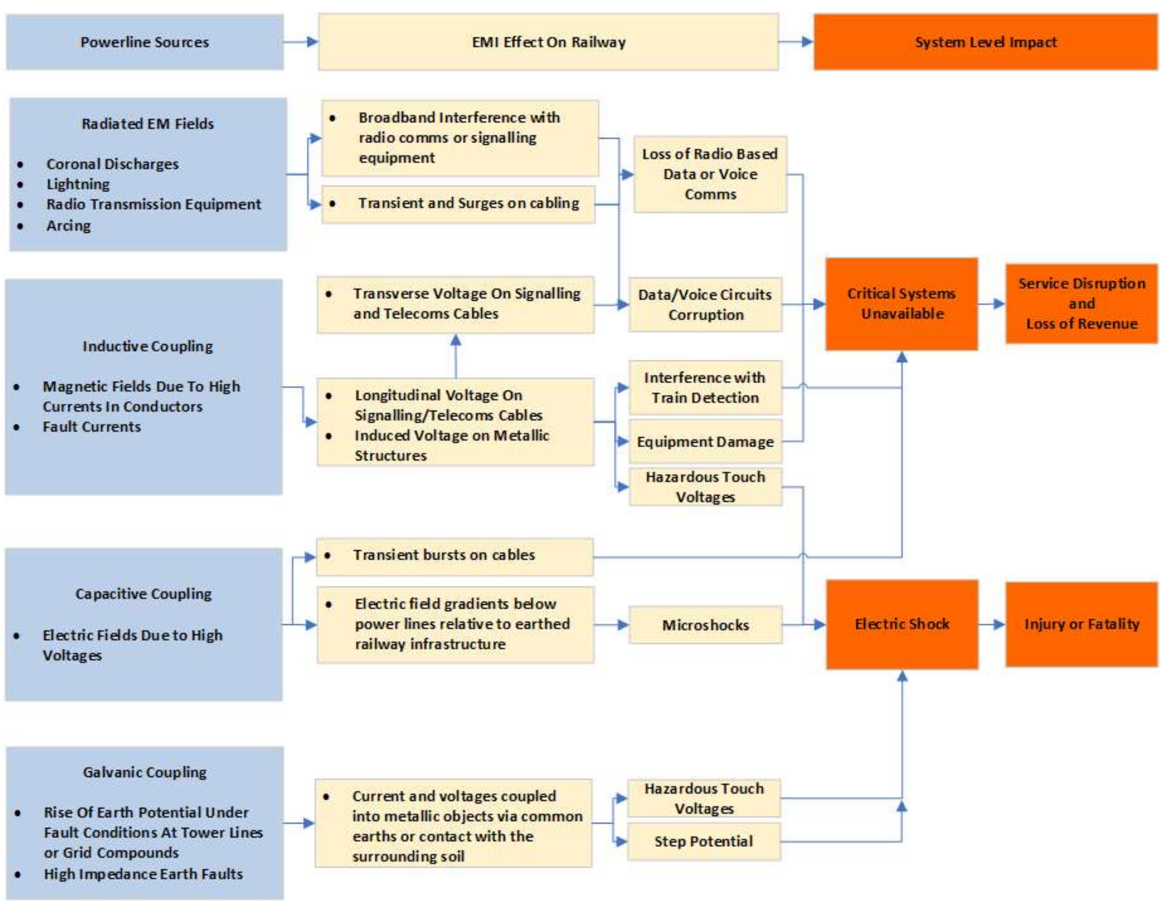

Figure 2 – Powerline sources of interference and impacts on railway systems.

There are a wide variety of standards and processes which give a best practice approach to the identification and management of hazards including:

- Europe - The Common Safety Method (CSM) [9], EN50126 [10] and EN50128 [11]
- USA - The Hazard Analysis Guide for Transit Projects [12]
- Canada - The Canadian Method for Risk Evaluation and Assessment for Railway Systems [13]

The hazard identification process can be summarised as shown in Figure 3.

Figure 3 – Generic HazID process

It is important that the hazards are reassessed throughout the project to capture any new interfaces or changes to the proposed design and that all stakeholders are involved in their identification and agreed resolution. Monitoring and tracking the generated requirements and their subsequent closure is best achieved by producing an EMI Control Plan which captures the HazID output and sets easily identifiable tasks which can be added to the broader set of project requirements in tools such as DOORS (Dynamic Object-Oriented Requirements System).

4. CASE STUDY 1: HIGH SPEED 2 AND GRID TRANSMISSION LINES IN THE UK

High Speed 2 (HS2) is a new 360 km/h railway in the UK connecting London to Birmingham and Manchester to deliver high capacity and faster journey times [5]. A systematic integrated electrical modelling programme has been undertaken by the project to support the progressive electromagnetic compatibility (EMC) and earthing and bonding / grounding assurance activities. The modelling de-risks the design by providing a quantified demonstration of system compliance within a "digital twin" of the relevant power and rail systems. A wide-ranging sensitivity analysis of this baseline model was carried out to ensure the predictions were bounding for the manifold assessment criteria. Localised refinements of the system-wide base model were made at significant interfaces to allow the electrical coupling between HS2 and third-party infrastructure to be quantified. These interfaces included locations at which National Grid (NG) high voltage (HV) transmission lines run parallel to the HS2 route for significant distances at close proximity.

An electromagnetic compatibility (EMC) desktop line of route survey was undertaken to identify potential susceptors and sources of EMI along the HS2 route as part of the consultation stage of the project. This assessment applied simple criteria to identify locations at which coupling of HV transmission lines to HS2 infrastructure would need to be assessed. Eight interfaces with 400 kV NG lines were identified with horizontal separations ranging up to 50 m and lengths of parallelism from 0.6 km to 4.1 km.

For each of these interfaces a multiconductor transmission line (MTL) model of the HV grid lines and receptor conductors in the HS2 rail systems was implemented in a MATLAB based toolkit as shown in Figure 4. The model represents all the mutual capacitances and inductances between the conductors in the cross-section of the transmission line, an exact solution of the Carson/Pollaczek ground return through the earth and distributed earth conductance of receptor conductors were appropriate. Auxiliary calculations based on earthing standard EN 50522 [6] were used to determine earth leakage resistances for intentionally and fortuitously earthed assets such as fences and rails and to estimate suitable termination impedances to be applied at the ends of the interface. Other assets considered included railway assets such as floating telecommunication and signalling cables and earthed fibre armours, cable sheaths and bonding conductors. Simulations were run for fault and steady-state conditions of the HV transmission lines. At this stage of the evaluation pessimistic assumptions for the electrical parameters of the grid (fault level, steady state load, disconnection times, phase imbalance) at each location were made were based on publicly available information and standards from NG [7][8].

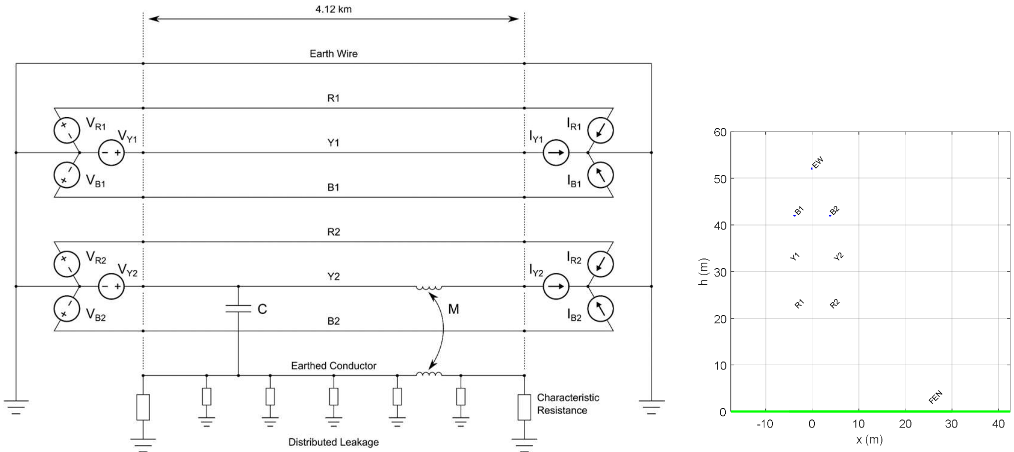

Figure 4 – Case Study 1: MTL model for NG 400 kV line interface with a HS2 conductor

For each interface the maximum induced voltage into the relevant HS2 conductors under steady-state and fault conditions was determined. Figure 5 shows some typical results for the touch voltage on a continuous metallic fence that is fortuitously earthed through its posts.

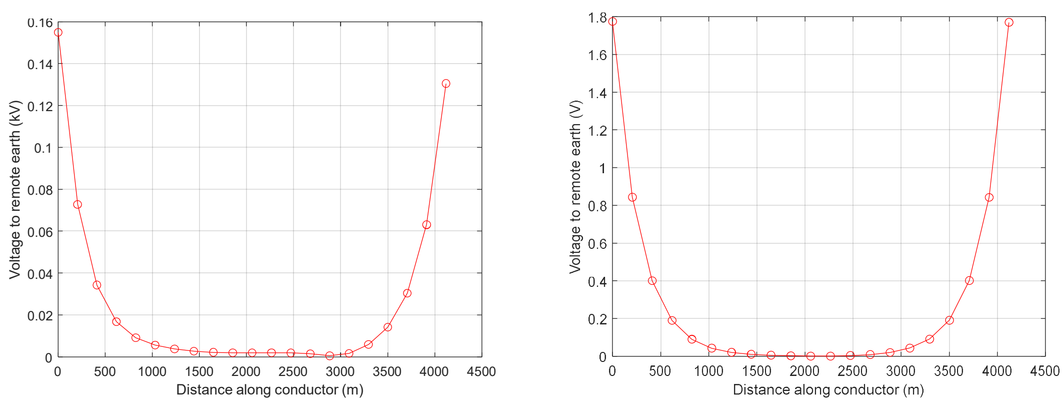

Figure 5 – Case Study 1: Typical induced voltage on a continuous earthed fence under fault (left) and in steady-state (right)

For the HS2 railway in which the 25 kV AC traction system and other assets and systems are bonded to a common earth to form an overall meshed network, the dominant standard that defines touch voltage safety limits for the protection against electric shock arising from the high voltage traction system is EN 50122-1 [1]. The application of the EN 50122-1 safety limits for touch voltage were also applied to voltages induced into lineside railway signalling and telecommunications cables. In addition to the induced voltage from NG, there will be an induced voltage into HS2 infrastructure from its own railway traction power system. The values for this traction component at each interface were obtained from the dynamic touch voltage "digital twin" modelling of the HS2 electrification system. For the initial evaluation the traction and NG induced voltages were pessimistically assumed to add in phase and the assessment criteria applied to the cumulative induced voltages.

The results of the modelling were used to drive a formal hazard assessment process looking at the risk of hazardous touch voltages on HS2 assets including railway traction return conductors, signalling and telecommunications cables, cable sheaths and armours, train detection system and fence lines. The assessment included consideration of construction and maintenance phase hazards, such as induction into the HS2 overhead contact lines during construction. The initial modelling study showed that many identified hazards were compliant with the relevant touch voltages standards and provided the necessary assurance evidence to eliminate them from further consideration. Where this was not the case the modelling provided design criteria for HS2 (such as maximum telecommunication circuit lengths at an interface) to ensure the hazard was adequately mitigated. The assessment also identified interfaces where more detailed analysis using location specific information from National Grid needed to be undertaken to determine if specific mitigation measures were needed.

5. CASE STUDY 2: COLOCATION OF 60 KV TRANSMISSION LINES WITH UNELECTRIFIED RAILWAYS IN CANADA

This case study is for a 60 kV double circuit transmission line running in close proximity to non-electrified railway tracks. Figure 6 – Case Study 2: Model shows the system considered for the study. The 60 kV transmission line network consists of several tap offs to feed load stations from the main double circuit lines that are supplied by two transmission stations at two ends as shown in Figure 6. The main fault current contributors are the two stations at either ends of the 60 kV lines labelled Source 1 and Source 2. A few spans of the line also carry underbuilt 25 kV distribution circuit complete with multi-grounded neutral. Transmission line is unshielded, and the structures do not have grounding except at locations where the underbuilt distribution neutral is to be grounded.

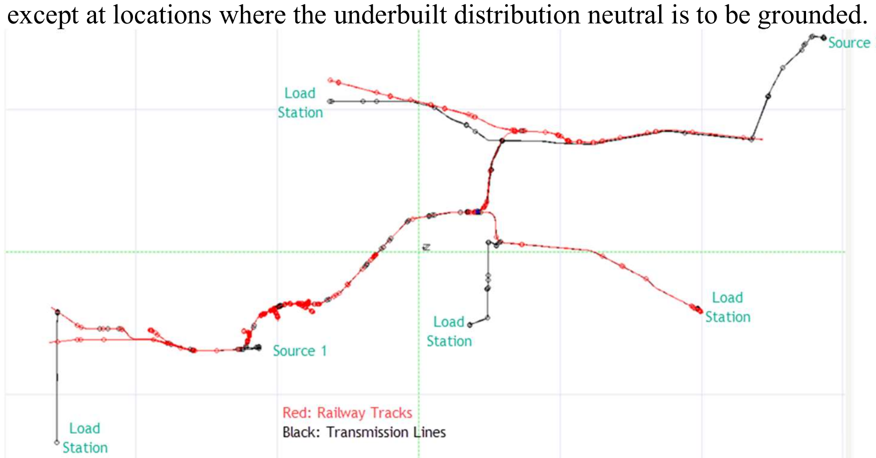

Figure 6 – Case Study 2: Model

The rail tracks also have several branches and bypasses to accommodate temporary parking of locomotives and enable two-way railway traffic simultaneously. The rail network has several controlled vehicle crossings complete with automatic signalling system at each location. The signalling system employs following equipment that is relevant for the subject of this study: i) insulating rail joints; ii) signalling shunt elements between the two tracks; iii) signalling circuit surge arresters; iv) metallic signalling bungalows located by the track side at each crossing location.

The analysis attempts to estimate net impressed voltage (will be referred to as simply 'induced voltage' going forward) on railway tracks as a result of all three modes of interreferences (electromagnetically induced, electrostatically impressed and galvanically conducted) from the adjacent transmission line. Both steady state and fault state conditions of the transmission lines are considered in the study. The induced voltage is studied further to analyse impact on personnel safety from shock hazards, signalling system operation and integrity, and corrosion issues due to leakage currents to earth. Sensitivity study is then conducted to study the effect of shunting of two rail tracks caused by presence of metallic locomotive at selected location along the rail tracks. The parameters of concern for assessment under this case study were rail to ground and rail to rail induced voltages for personnel safety and impact on signalling surge arresters.

Figure 7 shows some of the study results collected for a section of the complete railway tracks considered in the study. While the rail-rail voltages were relatively low, the fault state induced voltages from rail-ground exceeded touch safety limit calculated using IEEE std. 80-2013 methodology. The hazardous area was largely limited in vicinity of the faulted transmission line structure indicating that the galvanic component of EMI was dominant. The induced voltage was found to exceed slightly over the limit some distance away from faulted structure indicating dominance of electromagnetically induced component as one moves away from the faulted transmission structure. It was noted that since the railway signalling circuits bring the induced rail voltages into signalling bungalows present by the side of tracks, the operators could be exposed to a hand-to-hand touch voltage situation in case of inadvertent or deliberate contact with rail connected equipment and metal body of the signalling bungalows and therefore hand to hand touch voltage limit is used here. As mitigation measure, additional insulating rail junctions were proposed on either side of transmission structures to limit the exposed length of railway tracks. However, this did not have an impact on galvanically transferred voltage. Grounding the railway tracks was not an option as this would significantly alter the signalling system operation. As a last resort, the identified signalling bungalows were prescribed safe work operating procedures such as temporary grounding of railway signalling circuits for maintenance operation and/or treating the signalling circuits as live objects at all times.

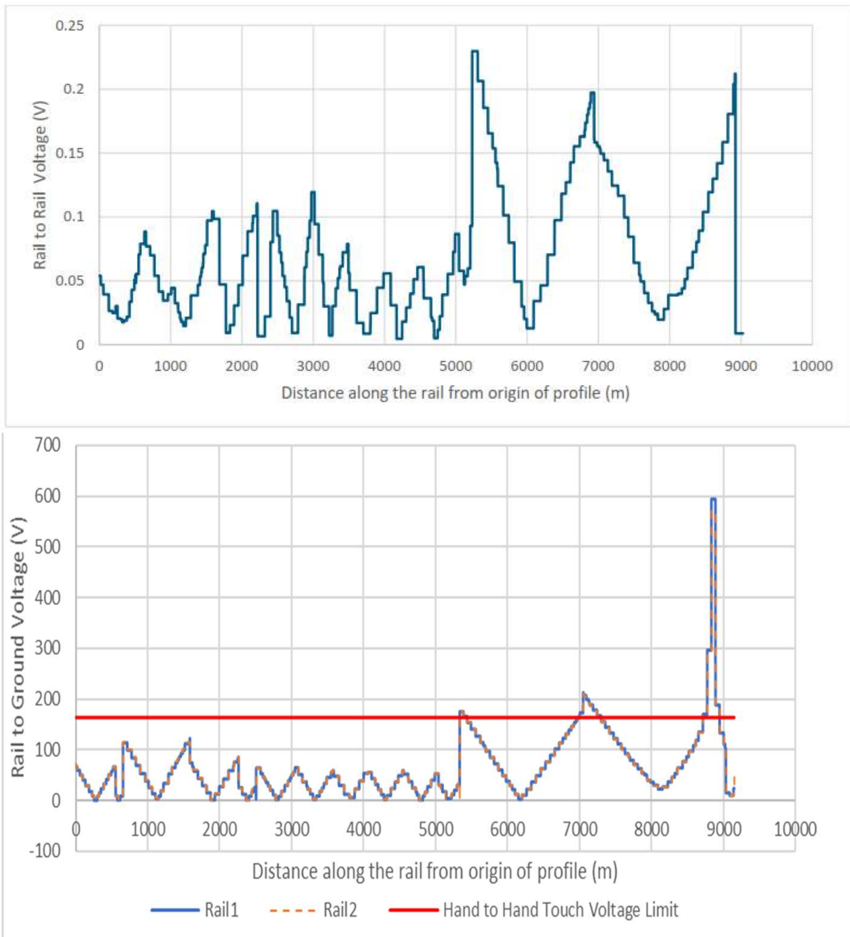

Figure 7 – Case Study 2: Rail to rail voltage during steady state (top) and rail to ground voltage in fault-state (bottom) power line operation.

The signalling circuit protective surge arresters did not have a readily available short term overvoltage exposure withstand capability or thermal conduction energy limit. Upon discussion with the arrester manufacturer, it was concluded the current set of industry standards for railway industry in North America (mainly AREMA[1]) do not cover compatibility of signalling arresters with short term AC power frequency over voltage exposure from extraneous sources. For the particular case study being discussed in this paper, it was established in consultation with the arrester manufacturer, that the arrester behaviour under short term overvoltage exposure will depend on the overvoltage magnitude, duration and short circuit strength of the induced voltage that would eventually translate into thermal energy the arresters will have to withstand in case they start conducting. Future research is warranted including controlled laboratory tests to establish the energy ratings of signalling arresters and comment on compatibility with extraneously induced short term power frequency AC voltages. For the concerned case study, calculations were made to this effect and results indicated that the maximum energy to be dissipated by arresters could reach as high as 54 KJ with open-circuit voltages across arresters reaching to about 600 V RMS.

[1] American Railway Engineering and Maintenance-of-Way Association

Figure 8 shows results of fault state induced voltage (for the same case presented in Figure 2) if a metallic locomotive was to be present and shunting the insulating joints near the faulted transmission structure. Shunting is assumed not across the insulating joints on the pair of tracks but also between the two tracks. It can be seen that the induced voltage distribution can be significantly changed in presence of a locomotive and places where rail to ground voltage was lower without locomotive could now see much elevated voltage. This is expected as shunting causes effectively a longer section of tracks to be exposed to induction than the case without shunting.

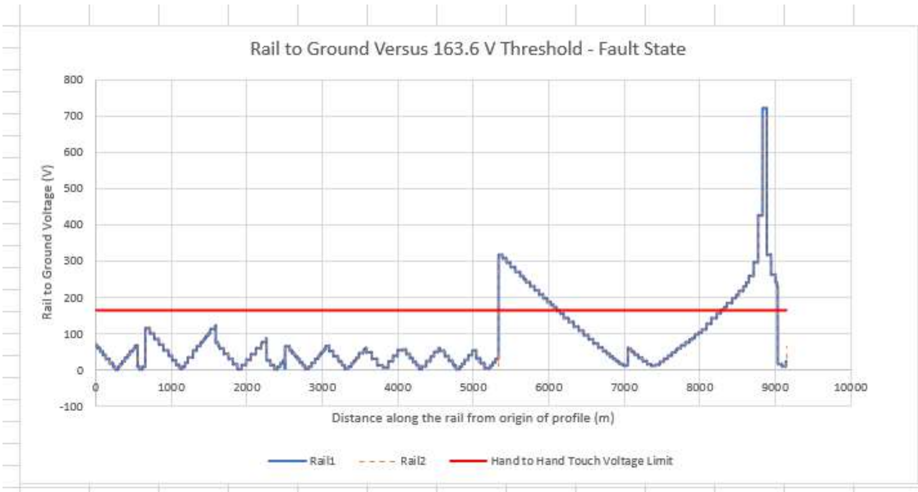

Figure 8 – Case Study 2: Rail to ground voltage during fault state with locomotive shunting a pair of insulating joints.

6. CONCLUSIONS

This paper attempts to present the nature of EMI impacts on railway infrastructure arising as a result of colocation of railway tracks with AC transmission lines. The following important conclusions can be drawn from the preceding discussions:

- Applying a systematic approach involving early hazard identification enables a work program to be developed that efficiently mitigates the hazards.
- EMI between power lines and railways could jeopardize the proper operation of the signalling and protection system of railways. Furthermore, it can produce unsafe touch and step voltages.
- While there are sufficient guidelines on the acceptable limits for induced voltages from viewpoint of personnel safety and signalling system operation, very little guidance exists in available literature on the acceptable limits imposed by tolerability of track connected signalling elements to sustain short term power frequency voltage induced by collocated transmission lines.
- The case studies show induced voltages could well exceed small signalling arrester capabilities and further research is warranted to establish acceptability criteria from perspective of compatibility with short term power frequency voltage induced in rail tracks by extraneous sources.

Performing an accurate interference study in a complex right-of-way including railways is an important step in assessing the personnel safety hazards and determine ability to safely withstand or bypass the induced voltages to earth by signalling arresters.

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