CONTROLLING RAIL POTENTIAL ON DC SUPPLIED RAIL TRACTION SYSTEMS

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ABSTRACT

Most of the modern DC electrified mass transit systems use a totally floating earth as their grounding strategy. A well known problem related with totally floating systems is that the touch potentials can be dangerously high. In order to reduce the voltages on rails, several devices exist. Most of these devices allow a direct connection to earth when a certain voltage threshold is exceeded. In this paper, working principals of these devices are given and the effect of certain parameters related with these devices on the minimum achievable touch potentials is investigated.

I. INTRODUCTION

In most of the older traction power systems, the rails were not insulated from the ground, and direct connections between the negative busses of substations and the earth were established. Such systems are called directly connected earth systems [1]. The return current passes through mother earth as well as rails in such traction systems. A particular problem that is related with this strategy is the increase in stray currents, which results in energy loss, and more importantly, corrosion in surrounding utilities [2,3].

After observing the adverse effects of corrosion near mass transit systems, most of the modern railways started to insulate the negative return system including rails and negative busses of substations such that the whole system is “floating”. Such systems are called totally floating earth systems. Actually, most of the DC traction rail systems in continental Europe are totally floating systems [4]. The problem with this strategy, on the other hand, is the increase in rail voltages (sometimes to dangerous levels). Therefore special precautions must be taken when running rails are used as the return current conductor and insulated from the ground. This is usually done by placing electronic devices (usually called as rail potential control devices (RPCD)) [1,5]. Settings of these devices, however, have to be done with great care as there are often limits on the minimum possible touch potential that can be achieved for a given system depending on these settings. In this paper, we discuss the existence of such limits and the effect of several parameters on the rail voltages observed on a test system by the help of simulation. In particular, the effects of grounding of the rail potential control devices and the threshold voltage levels used in these devices are investigated.

The simulation program used for research is introduced in Section 2, and the model of grounding scheme used in simulations is given in Section 3. Section 4 describes the test system used to do comparisons and Section 5 briefly shows the working mechanism of rail potential control devices. In Section 6 and 7, the existence of the limits on rail potentials and the effect of the quality of RPCD grounding on these limits are discussed by the help of simulations, respectively. Finally, Section 8 is the concluding section where the results and recommendations are provided.

II. SIMULATION PROGRAM

A DC fed rail mass transit system power network solution involves solving of numerous non-linear equations. Iterative solution of sparse matrices whose size depend on length of line and selected parameters for examination is required in such calculations. This can only be achieved by help of simulation programs.

A multi – line, multi – train simulator called SimuX [6,7] is used to do analysis presented in this paper. SimuX enables users to simulate DC fed rail systems in a user-friendly environment taking into account the regenerative braking and under-voltage behavior of the vehicles.

All kinds of details including the characteristics of trains and transformers, gradients, curves, passenger stations, properties of power lines and rails, section insulation points, jumpers and depots can be entered to the simulation program to obtain a realistic simulation.

The program has already been used in the comparison of energy loses in using 750 V DC and 1500 V DC power supply systems [8] and in the analysis of effects of upgrading the rolling stock on the power supply system [9].

III.MODELLING RAIL VOLTAGES

Usually stray currents and rail voltages are modelled together in a traction rail simulation program. Stray currents occur as a result of the conductance between the running rail and the earth. For loosely insulated systems (such as directly connected earth systems) the conductance between the rail and the ground could be in the range of 1 – 10 S/km, whereas this value can be as low as 0.003 S/km for highly insulated systems (such as floating earth and diode earth systems). For simplicity, rail-ground conductivity is taken as 0.01 S/km throughout this paper.

A way of representing the conductivity between the rail and the ground is dividing the track into smaller segments called as cells, and for each cell representing the conductivity by a resistance connected at a single point [10] and [11]. Figure 1 illustrates a simple model that can be used in simulating stray currents and rail voltages for a single train running on a single track between two substations. Here, R_{RG} represents the resistance between the rail and ground, R_{NG} is the resistance between the negative bus of the substation and the ground, R_r is the resistance of a rail cell, and R_{L1} and R_{L2} represent resistance of the catenary line. The length of each cell is given by L. The smaller values of L result in better approximations in the simulation. We note that as the train moves along the track the model changes accordingly.

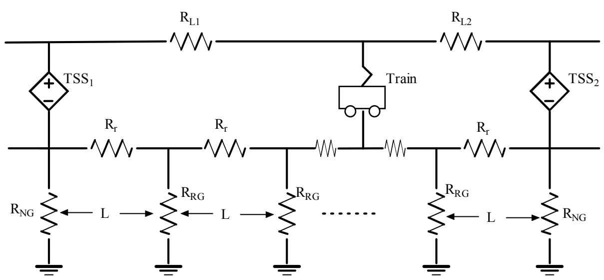


Figure 1: A simple model that can be used for computer simulations of stray currents.

IV. TEST SYSTEM

In order to be able to view the effects of different settings to touch potentials a simple system is constructed as can be seen in Figure 2.

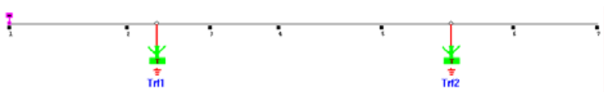


Figure 2: Simulation setup for the basic tests

Here, we consider the case where a single train runs on a single track, powered by two substations with 750 V DC nominal voltage. The length of the track is 6 km, and 7 passenger stations are placed unevenly along the track as given in Table 1. The locations of the power substations are selected as 1500m and 4500m, respectively. It is assumed that there is a 70 kmph speed limit throughout the line. The change of elevation of the track can be seen in Figure 3.

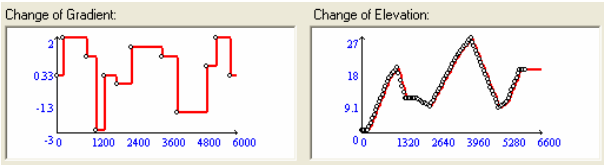


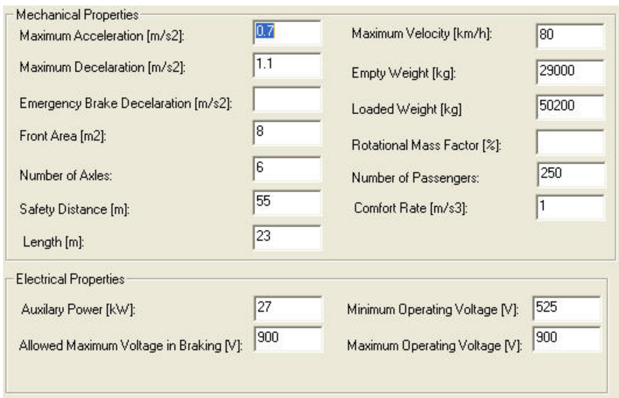
Figure 3: Change of elevation in the test track

Station No:	Location:
1	5 m
2	1200 m
3	2050 m
4	2750 m
5	3800 m
6	5140 m
7	5990 m

Table 1: Locations of passenger stations

The resistance on the catenary system is taken as 1.5 10^{-5} Ω/m and the rail resistance is assumed to be 2.06 10^{-5} Ω/m.

Main mechanical and electrical characteristics of the vehicle used in simulations are given in Table 2.



Mechanical Properties

Maximum Acceleration [m/s2]:	0.7	Maximum Velocity [km/h]:	80
Maximum Decelaration [m/s2]:	1.1	Empty Weight [kg]:	29000
Emergency Brake Decelaration [m/s2]:		Loaded Weight [kg]	50200
Front Area [m2]:	8	Rotational Mass Factor [%]:	
Number of Axles:	6	Number of Passengers:	250
Safety Distance [m]:	55	Comfort Rate [m/s3]:	1
Length [m]:	23		

Electrical Properties

Auxilary Power [kW]:	27	Minimum Operating Voltage [V]:	525
Allowed Maximum Voltage in Braking [V]:	900	Maximum Operating Voltage [V]:	900

Table 2: Vehicle characteristics

Tractive effort produced by one vehicle versus speed diagram can be seen in Figure 4. We remark that this characteristic is dependent on the line voltage and the simulation program used takes these changes into consideration.

It is possible to show that the maximum rail voltages on this sample track usually occurs near the first passenger station (PS1) just after the train accelerates to leave the station. The change of train acceleration and rail voltage at the PS1 are shown in Figure 5.

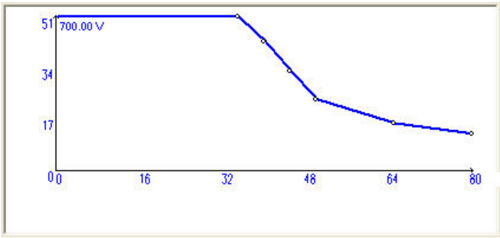


Figure 4. Tractive Effort (kN) – Speed (km/h)

As can be seen from this figure, the rail voltage steadily increases as the train accelerates with a constant acceleration rate 0.7 m/s^2. A peak value of 75.1 V is reached when the train starts to reduce acceleration. This might be considered as a dangerous voltage for human safety and therefore required to be eliminated. A way of reducing the rail voltages is through the rail potential control devices as discussed in the next section.

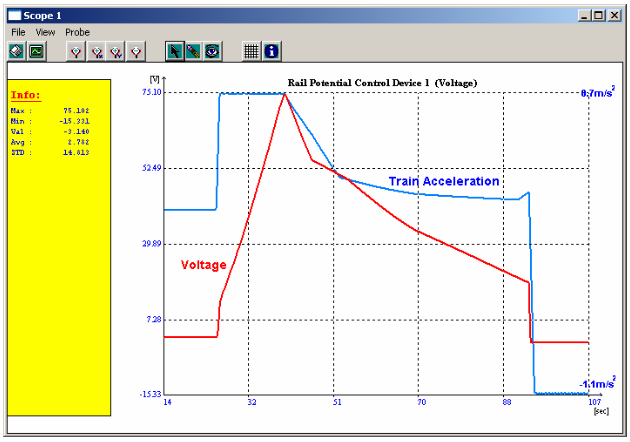


Figure 5: Change of train acceleration and rail voltage on the first passenger station without the use of RPCDs.

V. RAIL POTENTIAL CONTROL DEVICES

On a totally floating system, the potential difference between the rail and the ground needs to be restricted especially in safety critical places such as depots and passenger stations, to ensure the safety of the personnel and public. This is usually achieved by the help of Rail Potential Control Devices (RPCD) [2]. An illustration of an RPCD is shown in Figure 6. Here, a control unit constantly monitors the potential difference and the flowing current between the rail (or negative bus) and the ground. The switch is open under normal operating conditions (floating earth). When a predefined threshold voltage (V_r) is exceeded the switch is closed to allow current to flow through ground and limit the rail voltage. RPCD is said to be in ON position when this happens. The control unit opens the switch back to its normal position only after the current flowing through the circuit is below a given threshold (I_r) and a certain time limit (minimum ON time, T_{ON}) passed. Usually direct connection to earth is not possible and therefore a small resistance (R_G) is assumed to exist between RPCD and the ground. We would like to remark that in real world applications usually RPCD is switched on after a certain voltage-time characteristics observed. However, for the sake of simplicity in analysis we assume that a switch on occurs when the threshold is exceeded at least for 250 ms.

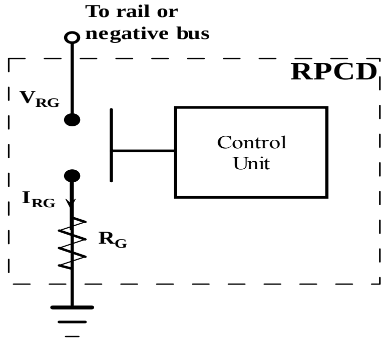


Figure 6: Rail Potential Control Device (RPCD)

In order to illustrate the working mechanism of RPCDs, an RPCD is placed in each of the passenger stations and negative bus of the power substations. In order to simplify the analysis, the current and time thresholds are set to I_r=100 A, and T_{ON}=2 second in the following discussions.

After assuming a very good earthing by choosing R_G = 0.1Ω and setting the voltage threshold to V_r = 65 V, the changes in train acceleration (a_T), and voltage (V_{RG}) and current (I_{RG}) of the rail potential control device located at the first passenger station (RPCD1) is recorded as can be seen in Figure 7. Here, we observe that RPCD1 is switched on immediately after the rail voltage (V_{RG}) exceeds the threshold (V_r = 65 V) such that high currents are allowed to pass through the device (around 38 sec). This causes the rail voltage to drop down to V_{RG} = 47 V. We note that as in the totally floating case of Figure 5, the rail voltage continues to increase until the train starts to reduce acceleration. However, it never exceeds the threshold value of 65V. It should also be noted that the RPCD stays in its ON state, until the current I_{RG} drops below I_r=100A at around 94 seconds.

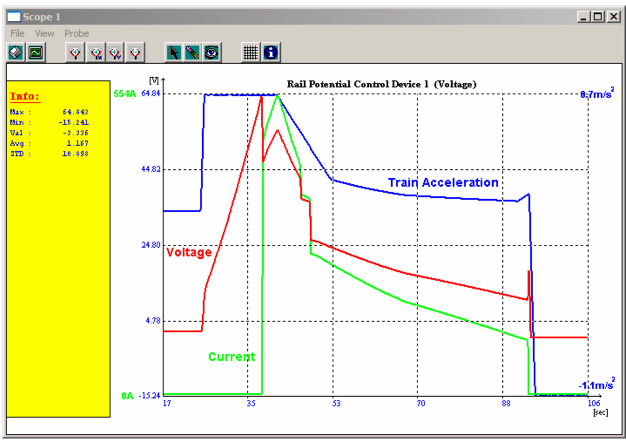


Figure 7: Change of voltage and current on RPCD1 and the acceleration graphics of the train.

VI. RAIL VOLTAGE LIMIT (V_{RL})

In the previous section we have shown that it is actually possible to reduce the rail voltages of a DC traction power system using a totally floating earth scheme by the help of RPCDs. A natural question that may come into mind at this stage is whether it is always possible to reduce the rail voltages to any given threshold value for a given system, and if the answer is no, what are the limits.

Figure 8 shows the train acceleration (a_T), and voltage (V_{RG}) and current (I_{RG}) of RPCD1 when the voltage threshold is set to V_r = 40 V. From this figure, we can observe that again as soon as the rail voltage exceeds the threshold at 32 seconds the RPCD is switched ON and the voltage drops to 30 V. However, since the train continues to accelerate the rail voltage increases from 30 V to V_{max}=53.56V until the train reduces acceleration. Therefore the RPCD cannot restrict the rail voltage at the required level of 40V.

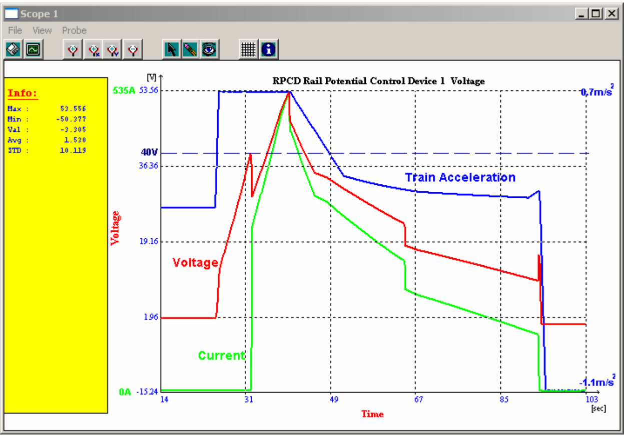


Figure 8: Change of voltage and current on RPCD1 and the acceleration graphics of the train for V_r = 40 V.

Actually it is possible to obtain the maximum voltage observed on rails at the first passenger station (V_{max}) as a function of the voltage threshold (V_r) of all RPCDs used on the track (Figure 9). When this function is examined we see that setting the voltage threshold (V_r) less than 55V does not make sense. We say that 55V is the *rail voltage limit* (V_{RL}) for this setup. It is also possible to observe that setting the threshold (V_r) less than the rail voltage limit increases the overall stray currents since high currents are allowed to pass through RPCDs for a longer period of time, resulting in higher corrosion rates.

VII. GROUNDING OF RPCDs AND ITS EFFECTS ON RAIL VOLTAGE LIMIT

Obviously rail voltage limit depends on many parameters including the topology of the line, the maximum distance between power substations, the electrical properties of rails, the use of regenerative energy, jumpers and section insulators throughout the line. We will focus on the effect of RPCD grounding on rail voltage limit in this section.

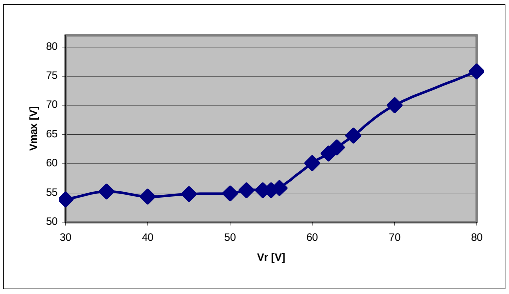


Figure 9: Maximum rail voltage vs voltage threshold of RPCDs (Vr) for R_G = 0.1Ω.

Normally high currents (returning current) flow through rails when a train accelerates and draws current from a power substation or a nearby decelerating train that produces regenerative power. These currents induce a voltage difference between the rail and the ground. So as to reduce this voltage difference, an alternative path for the returning current is created by RPCDs so that the current flows through mother earth to reach the negative bus of power substations. The resistance on this alternative path is mainly determined by the rail to ground resistance (R_G) of RPCDs, which is closely related with how well the grounding is done.

The less this grounding resistance the more currents that flow through the alternative path and hence the less the voltage difference is. For instance the maximum voltage (V_{max}) as a function of the voltage threshold (V_r) of all RPCDs is given in Figure 10, when R_G=0.08Ω. Here we see that the rail voltage limit is reduced around V_{RL}=47V. Actually, maximum rail voltages for different settings of V_r and R_G are given in Figure 11.

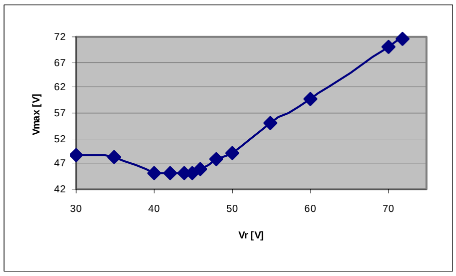


Figure 10: Maximum rail voltage vs voltage threshold of RPCDs (Vr) for R_G = 0.08Ω.

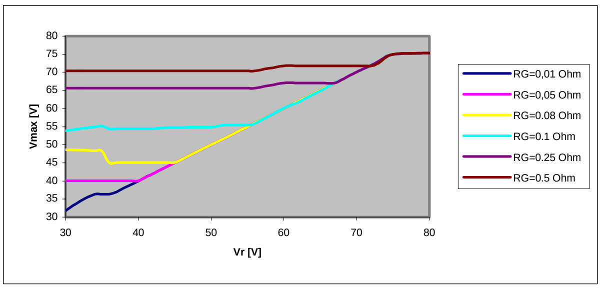


Figure 11: Maximum rail voltages for different settings of V_r and R_G.

The rail voltage limit as a function of rail to ground resistance for the test system we consider is given in Figure 12. Note that better grounding (lower values of R_G) results in lower rail voltage limits, even though the relation is nonlinear. From these graphics, we can state that rail to ground resistance should be less than 0.5Ω for RPCDs to become effective. This is achieved only by employing an extremely good grounding installation. Therefore the installation and maintenance of grounding in mass transit systems is extremely important and can save lives.

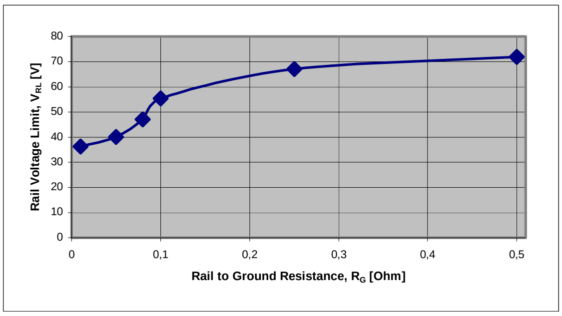


Figure 12: Rail voltage limit (V_{RL}) vs rail to ground resistance (R_G) for the test case considered.

VIII. CONCLUSION

In this brief note we have discussed how to reduce the rail voltages on a DC power traction power system that uses a totally floating earth scheme. In particular, it is shown that RPCDs can provide an efficient mechanism to control the touch potentials. In order RPCDs to be used efficiently, however, their settings have to be done correctly.

Usually there are lower limits on voltage thresholds (V_r) of RPCDs. Setting the thresholds lower than these limits would not decrease the rail voltages and only increase the stray currents.

Grounding of RPCDs plays an important role in determination of rail voltage limits and therefore has to be done very carefully.

Possible future research includes examination of stray currents at different settings of RPCDs and the effects of regenerative braking on rail voltages and stray currents.

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