When d.c traction systems meet HF disturbances:

The best of both worlds?

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***Abstract*— Traditionally d.c. traction systems rely on insulated running rails used for traction return current, use unscreened cabling, and do not utilize a proper earthing strategy, due to fear for stray currents. This leads to systems which are very vulnerable to disturbances due to traction harmonics, or HF phenomena such as lightning, which quite often lead to availability problems. As railway systems are legacy systems, a change over to a modern earthing philosophy, which is needed in order to reach EMC, is quite often very difficult to implement. For a green field metro line in Doha, Qatar, however it was possible to develop and implement an earthing philosophy taking care of HF disturbances and of stray currents at the same time.**

***Index Terms*— d.c. traction systems, stray currents, earthing philosophy, HF disturbances**

I. INTRODUCTION

Historically in d.c. traction systems running rails are insulated with respect to earth, in order to avoid stray currents. Also line side cabling used for telecommunication and signaling purposes has no cable screen, in order to avoid traction return current flowing along cable screens. This is a historical choice, which leads to a poor HF immunity of the system, lightning for instance quite often leads to severe damage. Also due to increased switching frequencies in traction converters in rolling stock, induced harmonic voltages in lineside cabling are becoming more problematic. In existing railway systems however it is very difficult to implement a new earthing strategy.

II. PROJECT OVERVIEW

In Doha, Qatar, a four line metro network is being built at the moment. Part of the green line is above ground, and therefore vulnerable to lighting. This part is joined with at grade and tunnel sections. Within this part "Al Riffa" station, see Fig 1. is present. Due to the large amount of cabling and pipelines present in the close vicinity of the line, very strict requirements apply with respect to stray currents. Apart from reaching EMC, safety for human beings is of course also very important. The entire section above ground is 3 km long, and supported by 72 pylons, see Fig. 2. The system will use a third rail for traction power supply.

Fig. 1. Al Riffa station, artist impression

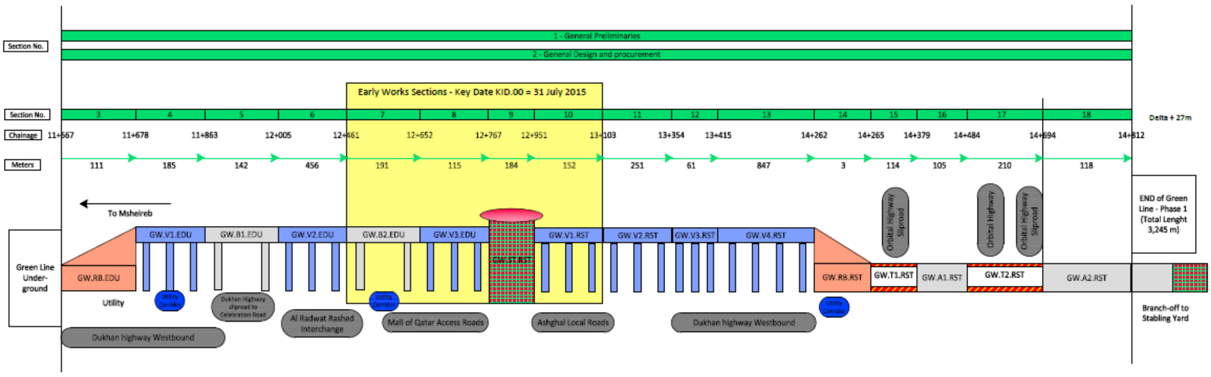

Fig. 2. Schematic overview of Green Line Doha Metro elevated section

It should also be taken into account that the soil resistivity (Qatar is a lime desert) is relatively high approximately 100 Ω.m – 1000 Ω.m. Due to the fact that in the station two power supply stations are present (general and traction) fed from a HV station (33 kV) close by (500 m) the one phase to earth short-circuit current is 31,5 kA, with a maximum switch-off time of 3 s, see [4]. This poses severe demands on the earthing system of the station, as the requirements of [5] have to be met.

III. BASIC SYSTEM DESIGN

A. Overview

The basic system design consists of five main parts:

- Traction current return system;
- Stray current collection system;
- Overall integrated earthing system;
- Cabinets, cabling and wiring;
- Lightning protection system.

B. Traction current return system

The traction return current circuit consists of the four running rails. Rail insulation is specified as 100 Ω.km under dry conditions, 10 Ω.km under wet conditions. For stray current analyses the latter value has to be used. Cross-connections are present every 600 m, audio frequency track circuits are used, so no impedance boxes are present.

C. Stray current collection system

In order to meet the demands of [6] & [7] a Stray Current Collection System (SCCS) has been designed. The system consists of a concrete slab under the running rails. Within the slab 8 rebars ∅ 16 mm are present, close to the running rails. Every 30 – 40 m a cross-connection is present. At cross-connections the rebars are connected to a Stray Current Collection Cable (SCCC), a 120 mm^2 Al cable, present on both sides. In traction power feeding station, the SCCC can be connected to the minus bar. The SCCS is insulated from the supporting civil structure by a 5 mm layer of HDPE, see Fig. 3.

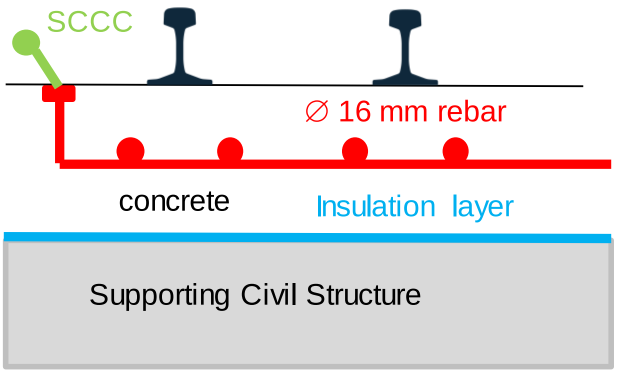

Fig. 3. Stray current collection system, single track

D. Overall integrated earthing system

It should be noted that due to civil structural constraints large amounts of electrically conductive rebars are present. Therefore it was decided to use these in the earthing system design. As a minimum 6 rebars ∅ 16 mm are welded and accessible for earthing purposes in the entire construction (both in horizontal spans and in pylons as well as a 5 m x 5 m mesh in all floors of the station building), goal is a maximum use of the civil structural assets available. The foundations of the pylons as well as of the station, with added meshes and steering rings are used as connection to “Mother Earth”. For earthing calculations the theory as developed by [8] has been used. Along the entire system two 120 mm^2 Cu earthing conductors are foreseen, connected to the reinforcement every 30 – 50 m. Main goal of these earthing conductors is to provide a physical earthing facility for objects, as well as reducing common mode currents on cable screens. For at grade sections, parallel bare Cu conductors buried in the soil will be used. For the tunnel sections the civil structure itself “Ufer Ground” is used.

As the 33 kV feeding station “Al Riffa” is only 500 m away from the traction power supply room and station power supply room at “Al Riffa” station building, the one phase to earth fault currents are high, notably 31,5 kA. Originally it was foreseen to use three one phase feeding cables, with the cable screens grounded at one end. This would lead to a situation where the entire fault current has to return to its source through earth, leading to high step and touch voltages. Therefore an alternative approach was used, the feeding 33 kV cables are surrounded by 120 mm^2 Cu cables (red dots), connecting the earthing system at KAHRAMAA side with the one at the railway side, see Fig. 4. The strong inductive coupling between the feeding cable and the return cabling will lead to a reduced current towards the earthing network at the railway side, thereby reducing step and touch voltages.

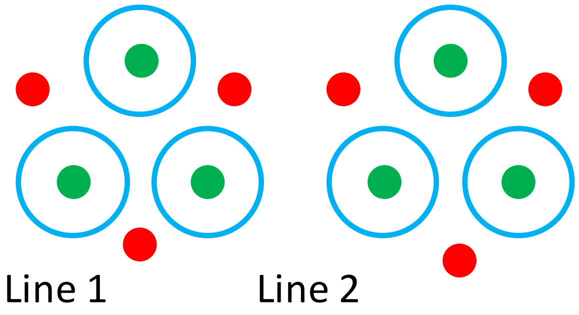

Fig. 4. Connection of power supply to KAHRAMAA @ 33 kV

E. Cabinets, cabling and wiring

Historically in d.c. railways cable screens are avoided for two reasons:

- Stray currents can lead to overheating of cable screens;
- Two consecutive cable earth faults towards the cable screen can lead to a wrong side failure.

However as mentioned earlier, this avoidance of proper earthing and shielding leads to a poor HF performance of the system. Nowadays earth fault detection devices are available, and can be used in combination with a proper signaling design to avoid wrong side failures. Problems with stray currents can be avoided by using a "hard" earthing of the cable screen at the station location and a "soft" earthing at the line side, an example can be found in Fig. 5. The capacitors block d.c. stray currents, while at the same time allow disturbing HF currents to flow. Thus the basic philosophy of [1] can still be used.

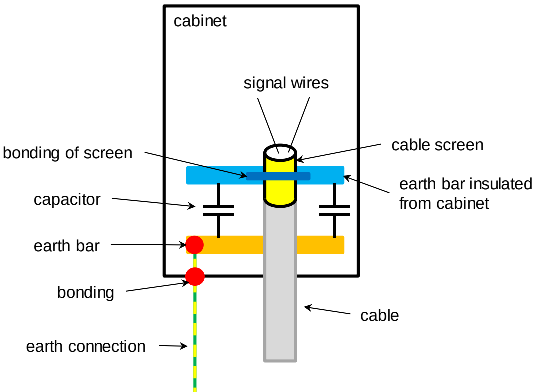

Fig. 5. Line side cabinet, using "soft" earthing

Of course the capacitors must meet the demands of transients caused by lightning, short circuits or traction harmonics. Analysis has shown that polypropylene types, 3 μF, 200 kHz, 1 kV, 100 V/μs can be used. Dimensions are small enough to fit in normal line side cabinets. For cabling a transfer impedance Zt_{DM} of 2.5 x 10-7 Ω/m @ 50 Hz is required.

F. Lightning protection system

Architectural ambitions imposed on the project limit the design of the lightning protection system. At the pylons, as well as at the station, no downward conductors as required by [9] are allowed. Also apart from the station building roof, no air termination network is allowed. Instead of using external downward conductors, the reinforcement present in the pylons and in the station building is used as downward conductor. Is has been proven that this method is more effective than the use of conventional downward conductors [10]. For the elevated sections, the handrailing on the sides can be used as air termination network, as they are connected galvanically to the reinforcement. However, this will only work in the absence of a vehicle. In case a vehicle is present the metal vehicle body will act as air termination network, which will lead to a high transient voltage on the running rails. Therefore it is foreseen to connect a Voltage Limiting Device, Type F (VLD-F [5]) between the running rails and the reinforcement of the civil structure at each pylon location. This will allow the lighting current to flow from the vehicle body through the running rails, the pylon, towards "Mother Earth". As VLD-F's normally remain a short circuit after a lightning strike, a monitoring system is foreseen. In case a VLD-F becomes conductive, this will be noted for immediate repair, in order to avoid problems with stray currents.

IV. SYSTEM PERFORMANCE

A. General

In order to check the performance of the system as presented above a large number of simulations has been performed, using simulation tools as SimspoG [11] and STARTRACK [12], here only a few typical results will be given. In Fig. 6 the current and voltage distribution for a one phase to earth fault @ 33 kV in the station is given. A section length of 32,5 m has been used. It can be seen that 87,5 % of the short circuit current of 31,5 kA returns through the intended cables, and 12,5 % through "Mother Earth". Maximum voltage at the station location is 270 V, here 900 A flows to the earthing system. The remaining 3 kA flows to earth at the pylons and the tunnel sections. Note the relatively high current to the earthing system at the station location, caused by the low earthing resistance due to a large building. Also the influence of the low earthing resistance of the tunnel sections on the right hand side can be seen quite clearly. Given the fact that the maximum Ground Potential Rise (GPR) is only 270 V, the voltage which can be bridged by human beings is much less, so the situation is safe for human beings.

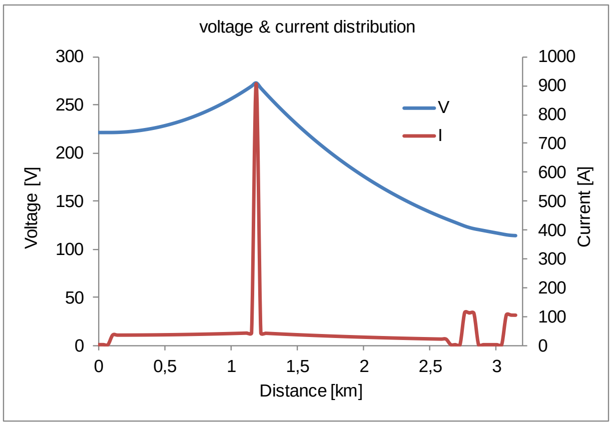

Fig. 6. Voltage and current distribution, short circuit at the station location

In Fig. 7 the current distribution for d.c. traction return currents is given. A current of 1 kA is injected in the return circuit at KM 3.0. Only the traction power supply station in "Al Riffa" station is in operation, which is a worst case scenario. In Fig. 7 we can see this current flowing back to the source at KM 1.3, causing a current of 8 – 10 A in the SCCS. This leads to a current of 0,5 – 2.0 A in the civil structure, causing a current of much less than 1 A in the soil. This leads to a voltage between the earthing system of the railway system and the surrounding soil of approximately 200 mV, see Fig. 8. Therefore for services such as pipelines and cabling, at a few meters distance, the requirements of [6] are met. An overview of the complete earthing design can be found in Figure 9.

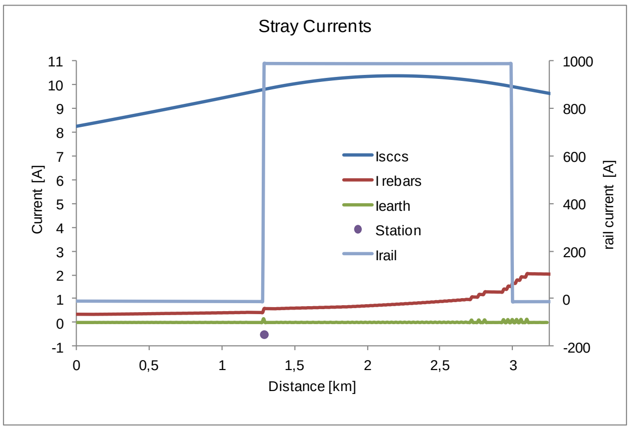

Fig. 7. Traction return currents, stray currents

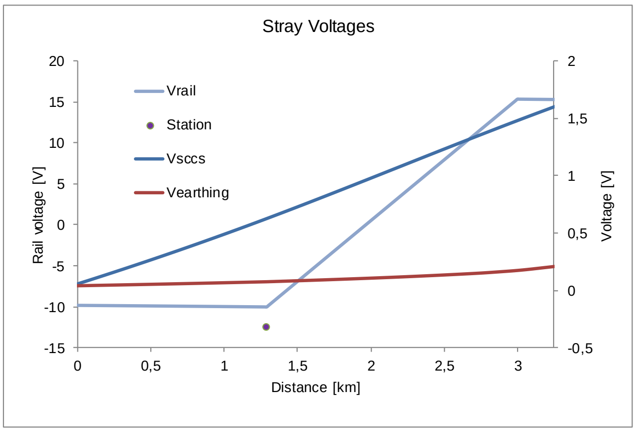

Fig. 8. Voltage distribution caused by stray currents

At the moment the metro system is still being constructed, so no measurements are available, however a measurement campaign is foreseen in the future to check on the system performance.

Note that in the civils structure 6 rebars are used for earthing purposes, while 8 rebars are used in the SCCS.

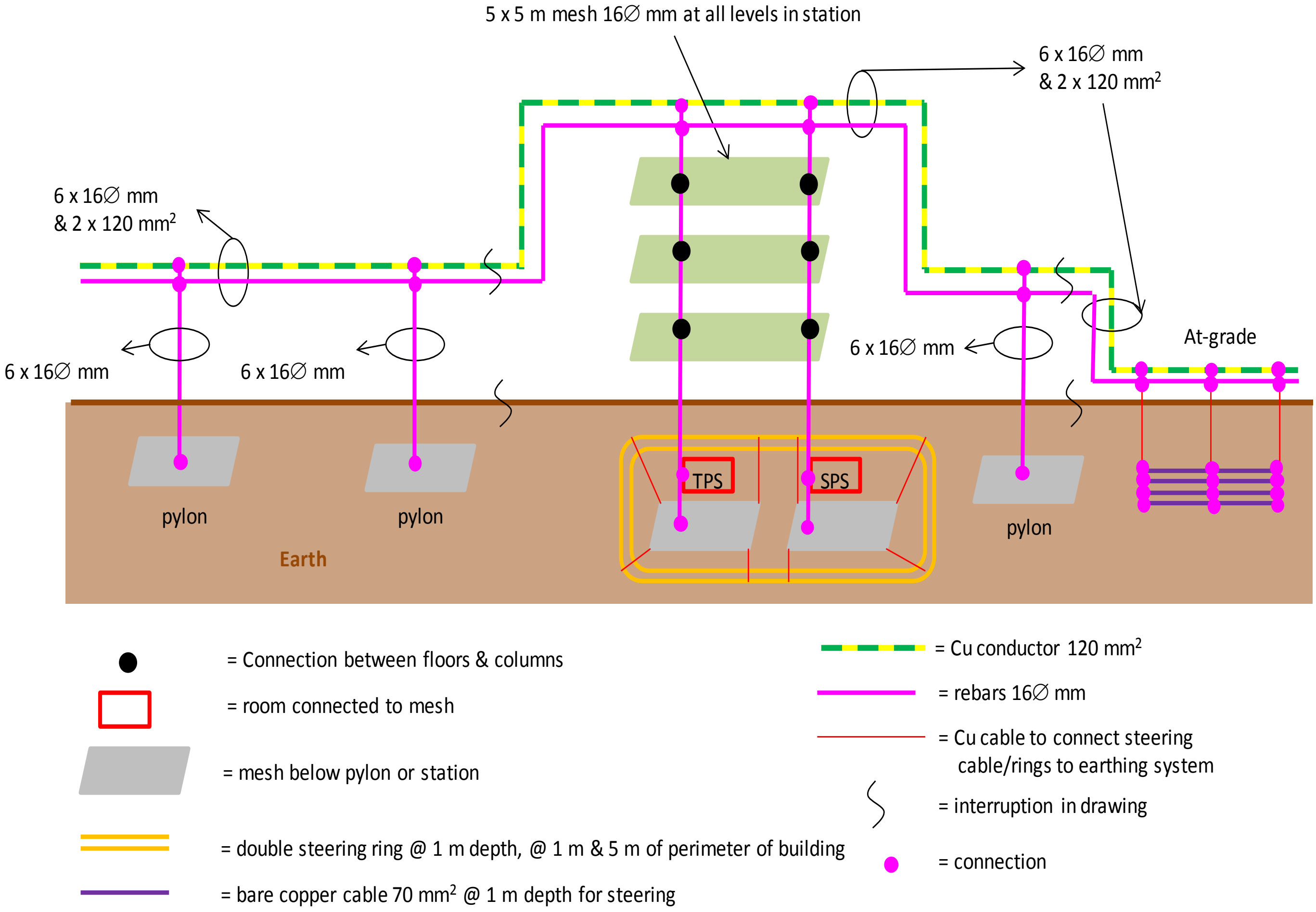

Fig. 9. Overview of earthing system design

V. CONCLUSIONS

Although historically d.c. railway systems do not use a proper earthing strategy, and have poor EMC properties, due to fear of stray currents, it has proven to be possible to develop an earthing philosophy along the lines of [1], while at the same time avoiding problems due to stray currents. The combination of an overall integrated earthing system, in combination with measures for cabinets, cabling and wiring as well as a lightning protection system, leads to an earthing system design with good EMC properties, which strongly resembles integrated designs used for a.c. railways with a proven performance over the last 15 years [13]. Main conclusion is that also for d.c. traction systems it is possible to reach EMC, also for HF phenomena by applying a proper earthing, screening and bonding philosophy.

VI. RECOMMENDATIONS

It is recommended to use a proper earthing, screening and bonding philosophy for d.c. railway systems, and to throw overboard all historical fears related to stray currents and wrong side failures. This will lead to a more reliable system, which requires less maintenance. Of course within a green field project like Doha Metro, Qatar, this is more easy to implement than in a legacy system. However using a step wise approach, and a well-controlled rollout, it is possible, and the benefits clearly outweigh the costs.

VII. ACKNOWLEDGEMENTS

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