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Electric safety assessment in conductive ERS: grounded vs. ungrounded systems

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Summary

Conductive Electric Road Systems (ERS) rely on a physical connection between the vehicles and the infrastructure for the power transfer. This connection implies that, unless an isolating device such as an isolated DC/DC power converter is used, the vehicle and the ERS supply are part of the same electric domain. Depending on the relative impedance to earth, ERS can be classified as grounded (one of the ERS power supply poles is tightly connected to earth) or floating (both poles have a high impedance to earth), and these two types have different safety implications in case of an insulation fault happening either on the infrastructure or the vehicle side. This paper constitutes a first attempt to model and assess the electric safety aspects of ERS with a floating power supply, and compare them with those identified for the grounded alternative.

1 Research Questions

Unlike inductive dynamic charging in which the energy transfer between the infrastructure side (ERS supply) and the vehicle happens through coupled magnetic field, thus providing intrinsic galvanic isolation, conductive ERS need a physical connection between the ERS supply and the vehicle.

Whether to use an ERS power supply referred to earth (grounded) or not is an important design decision that requires careful attention. A grounded supply, where one of the two poles has a low impedance connection to earth, by e.g. having the negative supply rail permanently connected to earth, allows to ensure that, when not energised, all parts of the infrastructure that can be potentially touched by a nearby pedestrian stay at a safe potential relative to earth. However, unless an isolating device such as an isolated DC/DC power converter is used, the vehicle and the ERS supply are part of the same galvanic domain. In principle, this does not pose a safety hazard per-se, but in case of an insulation fault in the vehicle, the chassis and the body of the vehicle could be energised to the nominal voltage of the ERS posing a safety hazard to a bi-standing pedestrian if he/she touches the vehicle.

In an ERS power supply not referenced to earth, also called a floating supply, both poles are galvanically isolated from earth. Hence, even if no additional galvanic isolation exists between the ERS infrastructure and the vehicle, two faults are needed in order to energise the chassis to a dangerous potential: one on the infrastructure side and one on the vehicle side. From this point of view, a floating supply is inherently safer than a grounded supply. Nevertheless, depending on the actual physical implementation of the system, it is not always easy to warrantee galvanic isolation due to the extensive size (usually several kilometres long) and the open environment in which these systems operate. Moreover, there might be additional challenges associated with a floating supply, for example, when handling fault situations when several vehicles are connected to the same ERS section. Figure 1 shows both a grounded and a floating supply ERS schematic.

This paper constitutes a first attempt to model and assess the electric safety aspects of ERS with a floating power supply, and compare them with those identified for the grounded alternative.

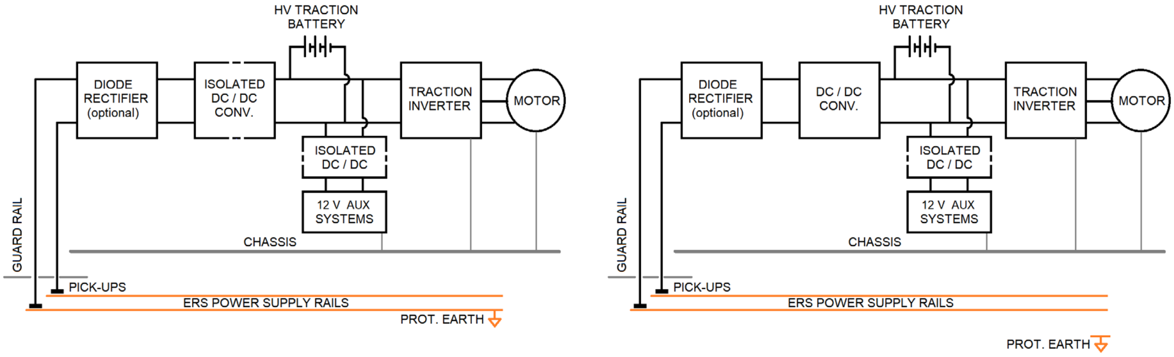

Figure 1: Grounded ERS power supply with isolation on the vehicle (left) and floating ERS power supply without isolation on the vehicle.

2 Methodology

The first step consists on identifying the most challenging ERS implementation alternatives, regarding not only the power supply relation to earth, but also the equipment on-board the vehicle. In all cases, the length of the segments is set to 100 m, allowing several vehicles to be connected to the ERS simultaneously.

For ERS with a grounded supply, two alternatives are considered:

- with an isolated DC/DC converter installed on-board the vehicle in order to provide galvanic isolation between the vehicle and the infrastructure
- without galvanic isolation between the vehicle and the infrastructure

For ERS with floating supply, only the case without galvanic isolation on-board the vehicle is considered, since the infrastructure is already isolated from earth.

For each of the three cases identified, an electric model of the ERS and the vehicle(s) is used in order to analyse the behaviour of the system under different conditions, both in normal and faulty operation. The model is implemented in LT-Spice as shown in Fig. 2.

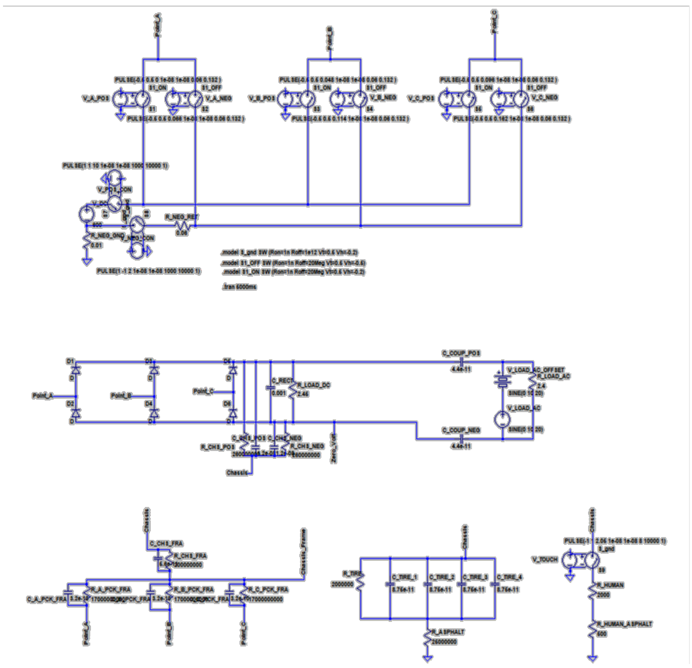

Figure 2: LT-Spice model of an ERS with a grounded power supply

In order to assess the safety level of the system some conditions are defined:

- an electric safety hazard occurs when those parts of an electric vehicle that are exposed to contact for pedestrians outside the vehicle become energised to a potentially dangerous voltage referred to earth
- the system must be designed so that a single insulation fault, be it on the infrastructure or the vehicles side, does not create a safety hazard
- at any time, the maximum allowed touch current between any vehicle's exposed parts (usually electrically connected to the chassis) and earth, assuming that the human body is modelled with a 2.5 kOhm equivalent resistance, must be below 500 mA RMS, considering a moving average window over 100 ms

3 Results

3.1 ERS with a grounded power supply

For ERS with a grounded power supply, an insulation fault on the infrastructure side will likely result on very high currents (in the worst case a short-circuit) which will prevent the system from operating at all, regardless of the condition of the vehicles.

On the other hand, the consequences of a fault on one of the vehicles connected to it depend on whether there exists galvanic isolation between the vehicle and the ERS or not. In the first case, the galvanic isolation barrier prevents the fault from affecting either the ERS or the rest of the vehicles connected to it. A single fault in a vehicle with e.g. an isolated DC/DC converter interface to the infrastructure will not result in a direct safety hazard, although it should be identified and repaired before a second fault occurs. Moreover, faults occurring in different vehicles connected to the same ERS do not add up. Thus, in order to create a direct safety hazard two insulation faults must happen on the same vehicle.

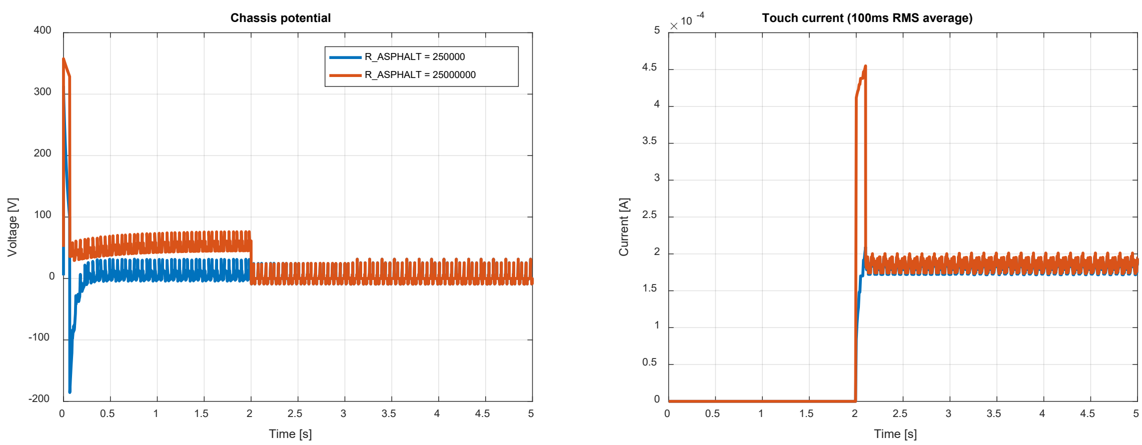

Figure 3: Chassis potential and touch current after one insulation fault on the vehicle side with a grounded ERS power supply and galvanic insulation between the vehicle and the infrastructure. The fault happens after 2s and the touch event after 2.1s.

If no galvanic isolation is present on-board the vehicles, a single fault in a vehicle could energise the chassis to a dangerous potential and create a safety hazard to nearby pedestrians, which is against the conditions defined in the previous section. However, the fault will only affect that particular vehicle and not the other vehicles connected to the same ERS.

3.2 ERS with a floating power supply

For ERS with floating supply, no galvanic isolation is provided on-board the vehicles.

A fault on the infrastructure side will immediately create a “reference” to earth, leaving us in the same situation as in the case previously discussed (grounded supply with no galvanic isolation provided). In this case, a single fault on the vehicle side (besides the already existing fault on the infrastructure) will directly create a hazardous situation.

On the other hand, since the impedance between vehicles’ chassis and both earth and the ERS supply is high (i.e. the chassis is floating with respect to both earth, via the rubber tires, and the ERS supply, via the existing insulation on the electrical equipment) a single fault on a vehicle will not cause a direct hazard. Furthermore, a fault on two different vehicles could only pose a hazard if a nearby pedestrian touches both vehicles at the same time.

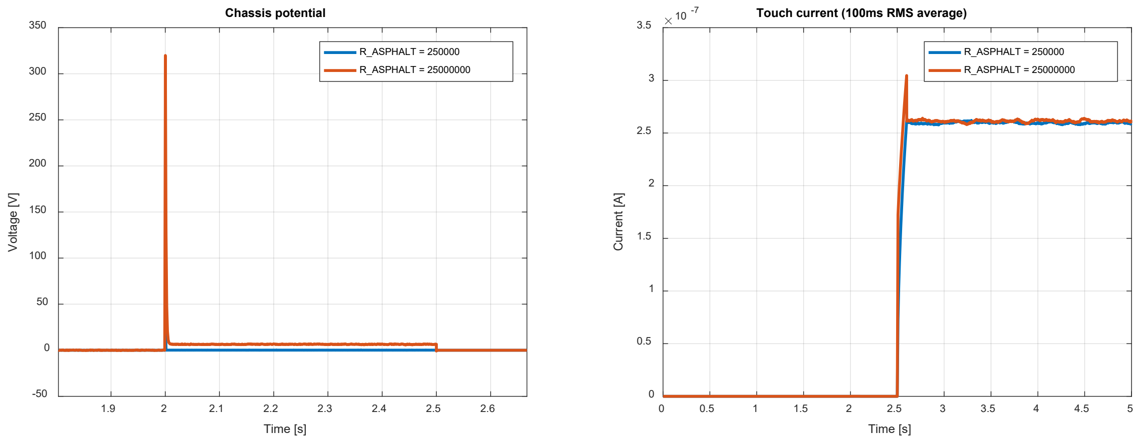

Figure 4: Chassis potential and touch current after one insulation fault on the vehicle side with a floating ERS power supply and no galvanic insulation between the vehicle and the infrastructure. The fault happens after 2s and the touch event after 2.1s.

However, there are a few challenges that remain to be investigated in an ERS with a floating supply and no galvanic isolation interface between vehicles and infrastructure:

- The practical implementation of such a system might be complicated. Ensuring galvanic insulation between the ERS power supply and earth seems difficult in a system that extends over several kilometres, that is installed outdoors and exposed to adverse climate conditions, salt for de-icing and potentially severe mechanical stresses if vehicles can drive over it.
- If there is no galvanic isolation between the vehicles and the ERS, that means that all the vehicles connected to the same ERS segment are also galvanically connected to one another. For this reason, faults occurring in one of the vehicles may affect all other vehicles in the same ERS segment to a greater extent. Even if these faults do not pose a safety hazard, they could impair the normal system functioning, thus making the system unfeasible in real life applications.

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Authors

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