EMC Simulation of Cable Interference in E-cars

Length and placement of the cables in electric vehicles (EV) can lead to serious problems regarding the electromagnetic compatibility (EMC). This article presents three geometry simulation models of the basic components in an E-car (frequency-voltage converter, cables, electric motor and high-voltage power source), so as to obtain the optimum length of the cables and receive suitable EMC.

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Simulations have been made, for estimating the cables' interference both in and outside the car, in cases of shielded and unshielded cables, as well as for defining the absorption rate of the cable shielding and the chassis. The analysis takes place in the frequency range 30MHz-1GHz, where special emphasis is put on the motor cable. The different geometries are modelled and simulated with the software product MEFiSTo-2D Classic. The EMC behaviour of an E-vehicle can be improved, based on the simulation results.

The technological development, together with the fuel depletion, lead to replacement of conventional cars and internal combustion engines with E-cars and electric motors. Electrical drive systems are integrated into today's passenger cars either to reduce the fuel consumption -hybrid electric vehicles (HEV), or to create a full electric vehicle (.V) with zero emission [6].

The electric drive system in an E-vehicle consists of four basic components: high-voltage power source (usually a Li-ion battery) which provides power supply; frequency-voltage converter (more common as AC controller), with implemented pulse width modulation (PWM), which realises the speed control; electric motor -usually alternating current (AC), for propulsion; shielded or unshielded high-voltage cables for connection.

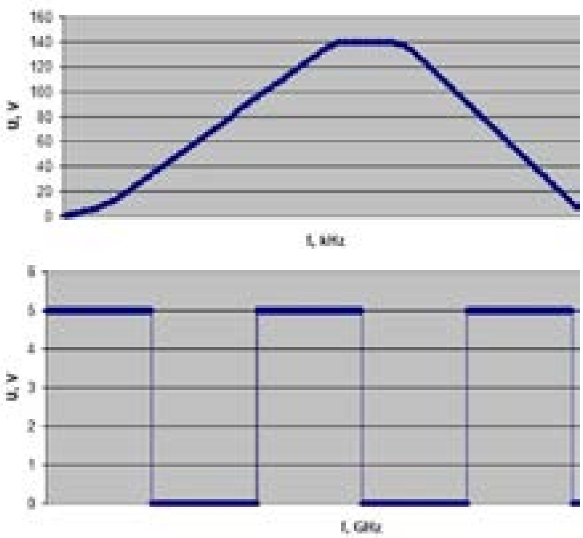
Disadvantages of E-mobility vehicles are relatively high price, small amount of energy storage, low speed of charging, short distance passed per charge, but scientific research in this field aim to improve these characteristics. Apart from these aspects, there are strict electromagnetic compatibility (EMC) requirements, which have to be considered [5]. Each of the main components of an EV acts as a source or path of electromagnetic interference (EMI), but some of them could lead to substantial incompatibility problems [4]. This is the reason why accurate equivalent circuits [1] and simulation models [2] have to be done for proper and detailed analyzing.

In this article are given the results of cable interference simulation, carried in three E-car geometry models. At other conditions being equal, the basic components of an electric drive system are relocated in the different geometries. Recreation of form and amplitude of the signal passing through the high-voltage cables is done, for estimation of cables' noise interference in and outside the car in cases of shielded and unshielded cables, so as to define the common absorption of the E-car in the frequency range 30 MHz-1 GHz. This way is established the best geometry placement, with optimum length of cables and could be reduced the price of used cable shielding.

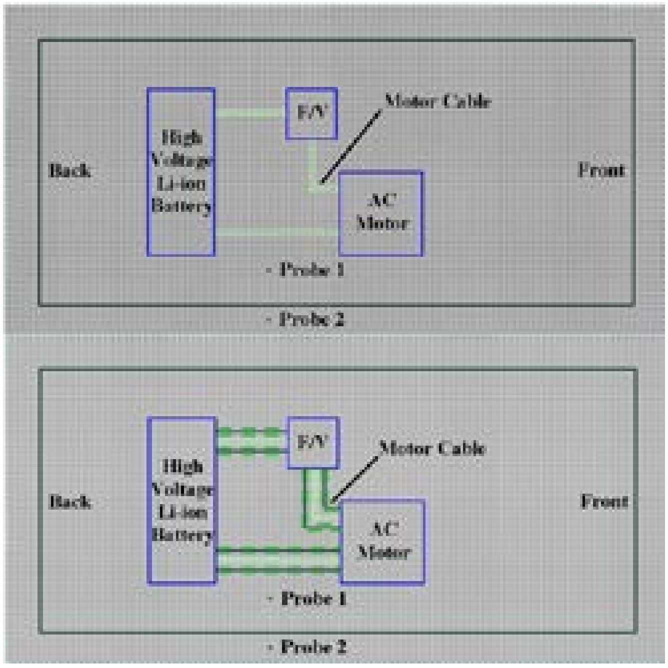
Simulation & Modeling Issues

The frequency-voltage converter is known to be the main source of EMI within an E-vehicle because of its' high speed switching transistors, which create electromagnetic noise disturbance and higher harmonics. These high frequency interference is emitted mostly through its' outgoing lines, which act as transmitting antennas. Special emphasis is put on the Motor cable, which connects the F/V converter with the AC motor, but noises are propagated over the HV-bus to the battery as well. In order to receive good EMI levels of the high-voltage cables is used multi-layer cable shielding structure, with implemented absorption material particles (Nickel Zinc Ferrite), which dissipate the EMI into heat energy [3]

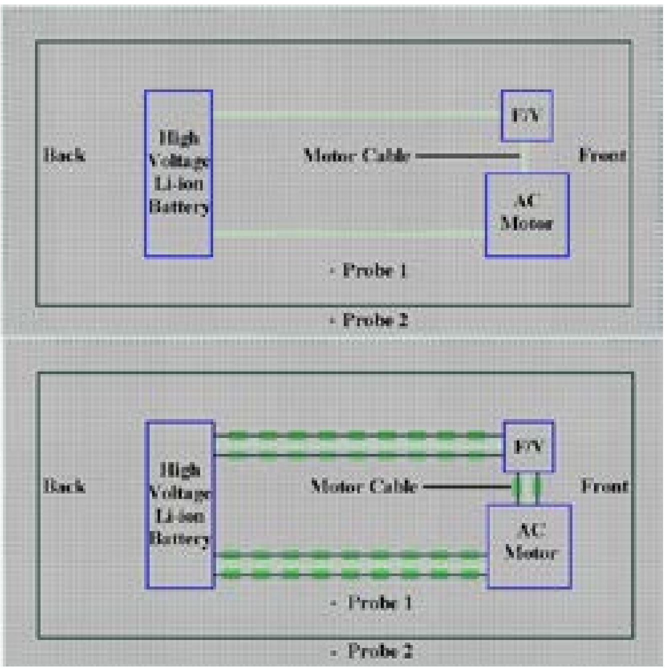
The software product used for the EMC cable interference simulation is MEFiSTo 2D Classic (Multi-purpose Electromagnetic Field Simulation Tool). For the aims of the simulation is recreated the form and amplitude of the signal passing through the high-voltage cables. What is taken into account is the low-frequency high-voltage PWM signal (50-150 kHz, 140 V, used for the torque control of the AC motor) and high-frequency low-voltage CAN (Controller Area Network) signal (in GHz, 5 V, used for communication between the controllers in the electric drive system) Figure 1.



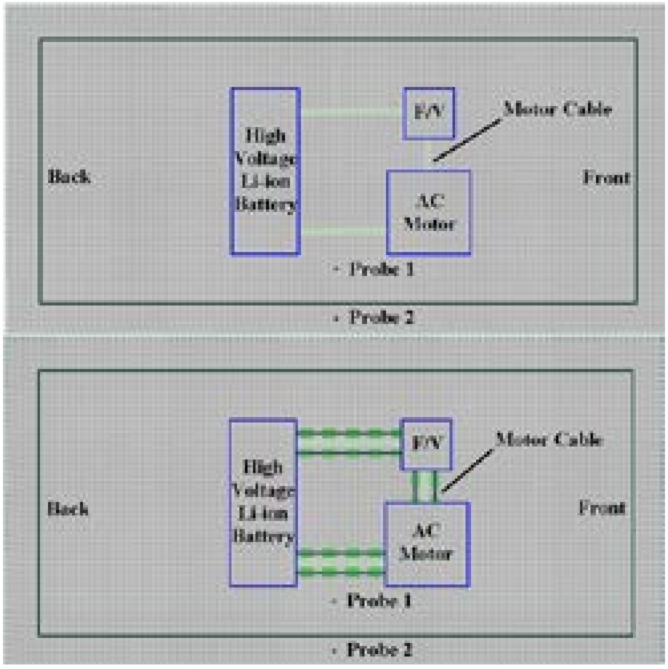
The first geometry simulation model is similar to the placement of the main components in the electric drive system of Ford Fusion Hybrid Figure 2. At the upper part is shown the model without used cable shielding for the connecting cables. The black rectangle between the two probes simulates the chassis absorption, the blue lines -the reflection surface of the metal boxes of the main components in the drive system. At the lower part is shown the model with used three-layer cable shielding structure (absorption material, metal, absorption material).



The second geometry represents the case of transferring a conventional internal combustion engine car into an E-vehicle Figure 3. The F/V converter and the AC motor are situated under the hood at the front of the car and the high voltage battery is placed in the trunk at the back.



The third geometry suggests placement of the electric drive system at the bottom of the car under the passenger seats Figure 4. This way not only the cables are kept as short as possible, but is provided good stability of the vehicle on the road.



According to the EMC standards, at the one side of the E-car in each of the simulation models are put two probes (internal -Probe 1 and external -Probe 2), for defining the interference levels in the frequency range 30 MHz-1 GHz, with a pitch of 30 MHz. Since the program estimates the amplitude of current noise interference, the result values from the text reports of the probes are converted into dB:

$$G_{dB} = 20\log_{10}\left(\frac{A_2}{A_1}\right),\ dB\,\frac{\mu A}{m} \qquad (1)$$

where A_2 is amplitude level, A_1 - reflected amplitude level, G_{dB} - gain in dB. For each of the simulation models are made the following calculations:

Cable shielding absorption - $CableS_A$:

$$CableS_A = Probe1_N - Probe1_S,\ dB \qquad (2)$$

where $Probe_N$ is probe in a model with no used cable shielding, $Probe_S$ - probe in a model with used cable shielding

Chassis absorption - $Chassis_A$:

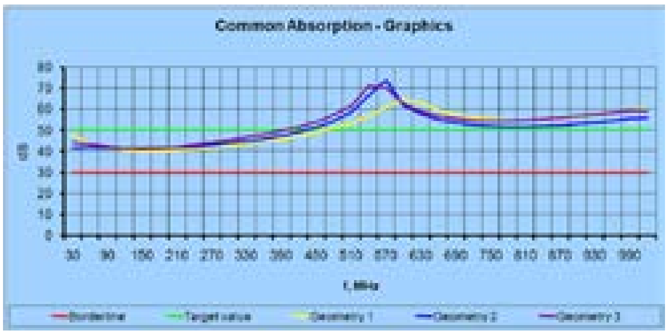
$$Chassis_A = Probe1_S - Probe2_N = Probe1_S - Probe2_S,\ dB \qquad (3)$$

Common absorption - Common:

$$Common_A = CableS_A + Chassis_A,\ dB \qquad (4)$$

Results & Conclusion

The common absorption graphics of the three geometry simulation models, in the frequency range 30 MHz-1 GHz, is shown in Figure 5. So as to meet the EMC requirement limits of cable noise disturbance, the common absorption rate of the E-vehicle is recommended to be around 50 dB and should not drop below 30 dB. The simulation experiments and the calculations show that on average, for the whole frequency range, the different geometries show different common absorption results: first geometry -51,82 dB; second geometry 50,78 dB; third geometry -52,82 dB. Since in all models is used the same chassis and cable shielding with equal absorption rate, these values prove the different levels of cable EMI. As far as EMC is concerned, the second geometry showed worst results, due to significant emission of excessive long cables, while third geometry obtained the best cable EMI levels.



Based on the simulation results, the used cable shielding can be verified and optimized in terms of cost and flexibility (by reducing the quantity on Ni Zn Fe particles in the absorption material), while still covering the appropriate emission limits for the good EMI behaviour of the whole system.

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