Current ripple simulation of the electric system in an electric bus

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An electric system simulation model is a powerful design tool to predict problems and reduce the need of prototypes when developing hybrid and electric vehicles.

Climate change is a major threat to the planet. A way to reduce emissions in the transport sector is to build electric and hybrid vehicles. Volvo Buses have been doing this successfully for some time now. An example is the electric bus on line 55 in Gothenburg.

All kinds of electric and hybrid vehicles have some sort of electric system with power electronic converters. This is because a battery is a direct current source that needs to convert power to some sort of electric machine requiring alternating current. When converting power using a power electronic converter, current ripple can occur. For Volvo Buses this current ripple causes problems in the buses' electric systems. For example can the lifetime expectancy for capacitors be greatly reduced due to current ripple. This occurs because some subsystems in the electric system are not designed for current ripple produced by other subsystems. Figure 1 shows an overview of the electric system in Volvo's electric bus.

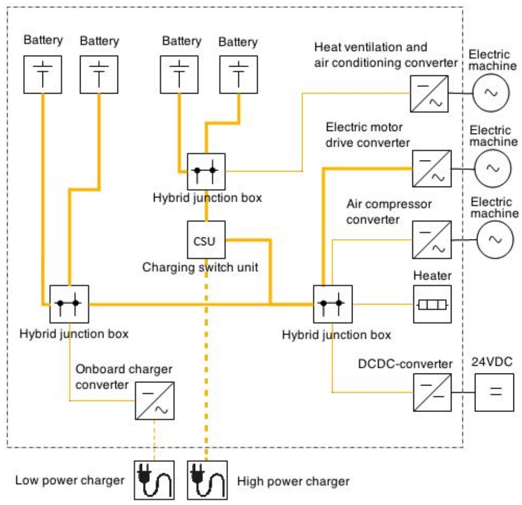

Figure 1. *The high voltage electric system of Volvo's electric bus. The black dotted square surrounds the DC-side (DC - direct current) of the electric system which is included in the simulation models.*

During the development process for an electric or hybrid bus it is useful to evaluate the current ripple. With a simulation software one can simulate the current ripple in an electric system of an electric or hybrid bus. Simulations gives a greater understanding of how current ripple affect the system and how to reduce it. It is valuable for existing vehicles and also for new vehicles during a development process.

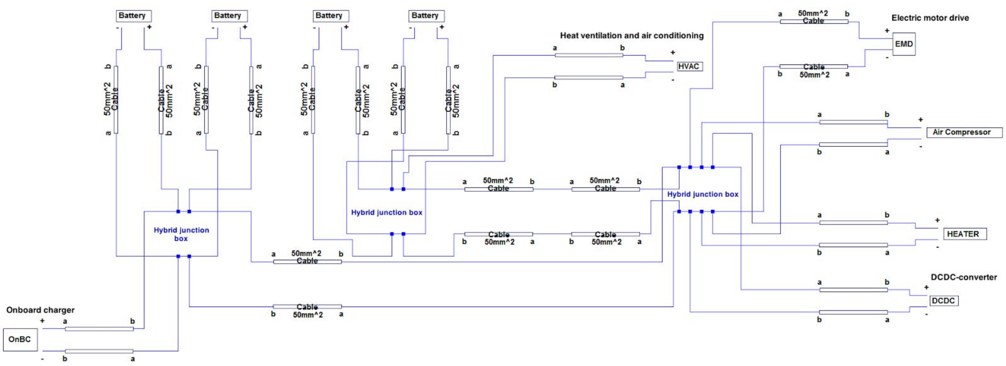

Figure 2. *The simulation model of the DC-side of the high voltage electric system for Volvo's electric bus.*

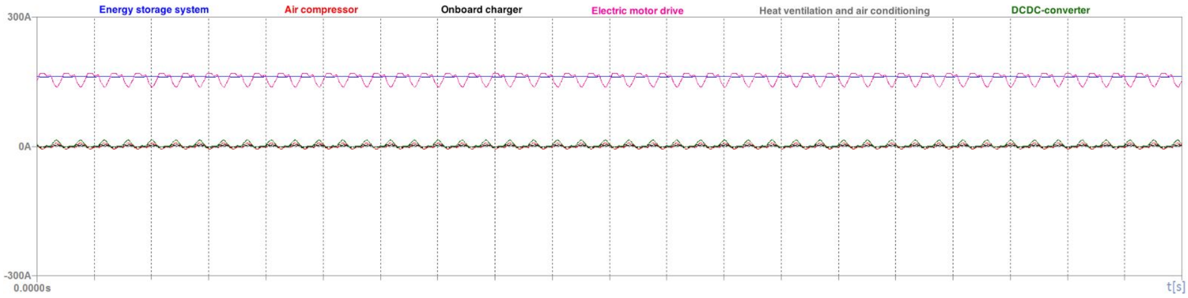

Figure 3. *Simulation of current ripple in the hybrid bus with the active subsystem the electric motor drive. Current plotted between $\pm$ 300A over time. The pink is the electric motor drive. The dark green is the DCDC- converter. The black is the onboard charger. The gray is the Heat ventilation and air conditioning. The red is the Air compressor. The blue is the Energy storage system.*

A component library for Volvo Buses electric systems has been established. The idea is to use the library as a Lego-brick solution to put together different subsystems to whole electric systems. One simulation model for a hybrid, and one simulation model for an electric bus was built. Figure 2 shows the simulation model of the electric system of Volvo's electric bus. The solution enables building of different subsystems and foresee how current ripple will affect new electric systems.

Simulations to verify the models against the measurements shows that the simulation models are very sensitive to alterations of certain component values. A small alteration of for instance a DC-link capacitor value in a subsystem causes a great impact on the simulated current ripple.

Figure 3 shows simulations and Figure 4 shows measurements. The aim is a simulated fault margin of $\pm 10-20\%$ compared to measurements. As a conclusion the aimed for fault margin is not reached due to a number of uncertain component values. When comparing results from Figure 3 and Figure 4 using a fast fourier transform the fault margin is 28%.

In the future it is very important to use more exact component values for an increased model accuracy.

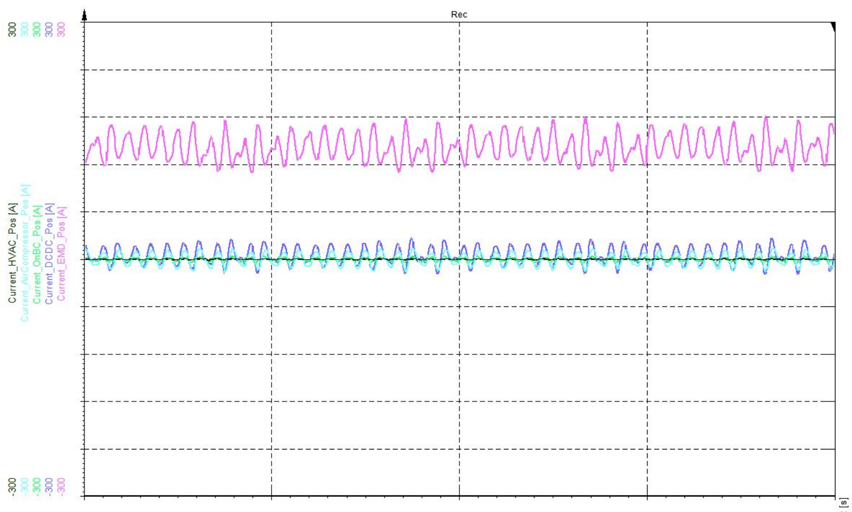

Figure 4. *Measurement of the current ripple in the hybrid bus with the subsystem electric motor drive (EMD) active. Current plotted between $\pm$ 300A over time. The pink is the EMD. The purple is the DCDC- converter. The green is the onboard charger. The dark green is the Heat ventilation and air conditioning. The turquoise is the Air compressor.*