Real-time simulation of combined engine and electrical equipment model in Simulink RT

7. Real-time simulation of combined engine and electrical equipment model in Simulink RT

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7.1 Introduction

This chapter presents steps towards real-time simulation of a combined engine and electrical equipment model in Simulink Real-Time (RT). This is a continuation of earlier work of Digital-twinning the engine research platform in VEBIC [1]. In this research, the goal was to build a digital twin of the engine research platform in VEBIC. When moving towards a digital twin, one of the first essential steps was to have a real-time capable model of the research platform. Real-time simulation capability was necessary for running the model and its real-world counterpart in parallel. The parallel simulations are needed to establish the model ability to emulate the real operation in the engine laboratory.

7.2 Modelling the hybrid power generation system

Earlier modelling work covered the validation of a GT-Power model of a 4-cylinder common rail medium speed diesel engine (W4L20) and electrical equipment consisting of an induction machine, a frequency converter and a battery in Simulink. The real-time capability of the electrical component models has already been established [1]. In this section, the engine model's conversion to real-time and the coupling between the engine and electrical equipment models are covered.

7.2.1 Fast Running Model of the 4L20 engine

For real-time capable simulations, the execution time of the 4L20 GT-Power model was required to be decreased. The selected route to cover faster simulation time for the engine model was selected to be Fast Running Model (FRM). Reason for this decision was that the FRM conversion process was relatively simple and some

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details could be kept in the model. Furthermore, real-time capability could be yet achieved with this format [2]. In addition, the map-based approach in Mean Value (MV) modelling, which was earlier considered [1], would have required more measurement data that was available at this point. Basically, the reduction process from detailed engine model to FRM covers the first the steps of MV conversion. Thus, the simplifications of FRM process should be carried out first to see whether the model's simulation time is reduced to an acceptable level or additional simplifications are still needed. Throughout the process, the manuals provided in the GT-ISE software were followed and the conversion steps and their order were performed as recommended [3].

7.2.1.1 Conversion from detailed engine model to FRM

The FRM converter tool in the software was used and subsystems, which were pre-defined from the flow-components, were merged and simplified in terms of either speed or accuracy. All created subsystems, i.e., exhaust manifold, exhaust pipes, intake manifold, compressor outlet pipes (including CAC) and intake pipes, were simplified in terms of accuracy respectively. Afterwards, the exhaust manifold was simplified in terms of speed to further decrease the simulation time of the model. Since combustion profile was already used in the detailed model, simplifications for combustion or cylinders were not required during FRM conversion process. Calibration was embedded in the step-by-step reduction process and performed after merging the volumes when needed. Depending on whether the pressure lost or temperature wanted to be calibrated, the optimization parameter was selected to be either the subsystem's orifice diameter or heat transfer multiplier respectively. The calibration was performed for a single case which was the highest load point. The optimized value resulted in the calibration was used for all load points. In Figure 1, the FRM is presented after the conversion process has been carried out.

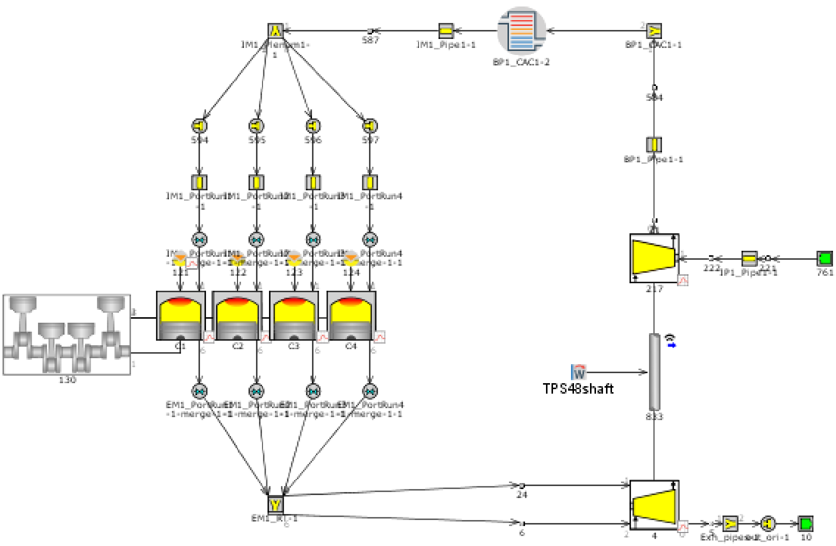

Figure 1. The FRM of the 4L20 engine.

7.2.1.2 Validation and real-time capability

After the model was converted into the FRM, the simulation results were compared to the results with the detailed engine model. The parameters observed were the parameters used previously in the detailed 4L20 model validation, i.e., BMEP, BTE, maximum cylinder pressure and exhaust temperature before turbine [1]. Simulation results of both models are presented in Figure 2.

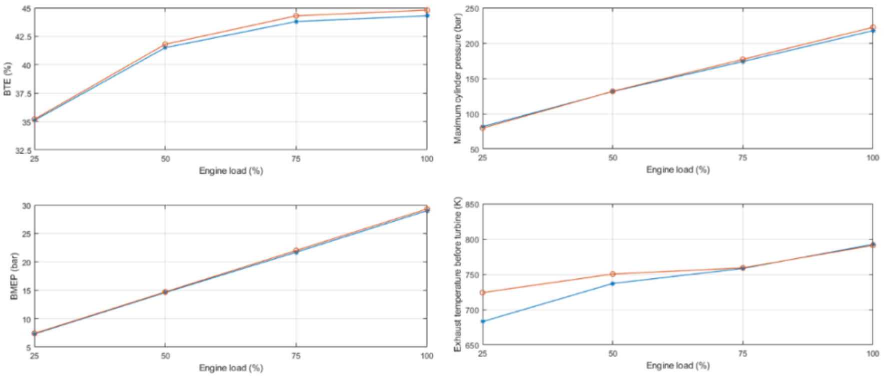

Figure 2. Simulation results of detailed 4L20 engine model (blue) and FRM (orange).

It was expected that, during the simplifications and reduction process, increasing the simulation speed would cause the accuracy of the results somewhat deteriorate. It was aimed that the errors between the simulation results of FRM and detailed model would remain inside ± 5 %. When the results presented in Figure 2 were observed more closely, it was noticed that the exhaust temperature before turbine at 25 % load point was outside of the desired error range. Since calibration was performed only for the highest load point, it can cause larger errors for the lower load. Thus, it should be noted that a closer, case dependent and multi-objective calibration could produce more accurate results. However, in this case, the case-dependent calibration method was not a suitable option, as case-dependent inputs had to be replaced before real-time simulations. The model was accepted with this limitation for the intended use.

After the FRM conversion, the real-time capability of the model was observed. The last step to implement the model to real-time simulations and to be connected in Simulink, was to change the license type into GT-SUITE-RT. Simultaneously, the FRM accelerator tool in the software was used to implement settings that would decrease the simulation time. Some small modifications were performed to enable the model work as before the change. In addition, some case-dependent values were replaced by functions or tables in order to smooth the coupling with Simulink. The real-time factor, which presents the model's real-time capability, was approximately 0.35. This was sufficient since the model should be able to performance in real time with planned implementation already with average factor of 0.5-0.6 [4].

7.2.2 Combining the engine and electrical equipment model in Simulink

After model's real-time readiness was confirmed, the links between the two software were created. Inputs for the FRM were decided based on the inputs used earlier in the engine model and the available signals from engine laboratory's data acquisition system that could be used in parallel simulations. These input parameters for the engine model were reference engine speed, ambient temperature and pressure. One limitation was injected fuel mass that was earlier used as input for the engine model. This parameter was not continuously measured from the engine and therefore could not be used as an input for the model. Nevertheless, since reference load was used as control signal in the engine laboratory it was decided to be used in the FRM as well. A brake power controller was added to the model and used as input instead of injected fuel mass. This did not have major effects on the simulation results. The biggest difference was in BMEP with 50-100% load points where the relative error was approximately -1.4 %. The main output from the engine model to the electric equipment models in Simulink was brake torque which was used as input to the electric machine. In addition, BMEP, cylinder pressure, burned mass fraction of fuel at CA50 (CA, crank angle) and exhaust temperature at turbine inlet were used to observe the engine model performance.

In Simulink, the engine model was imported using the GT-SUITE specific library and in particular the block GT-SUITE-RT. In that way, the engine model was represented as an s-function. The combined model in Simulink is presented in Figure 3.

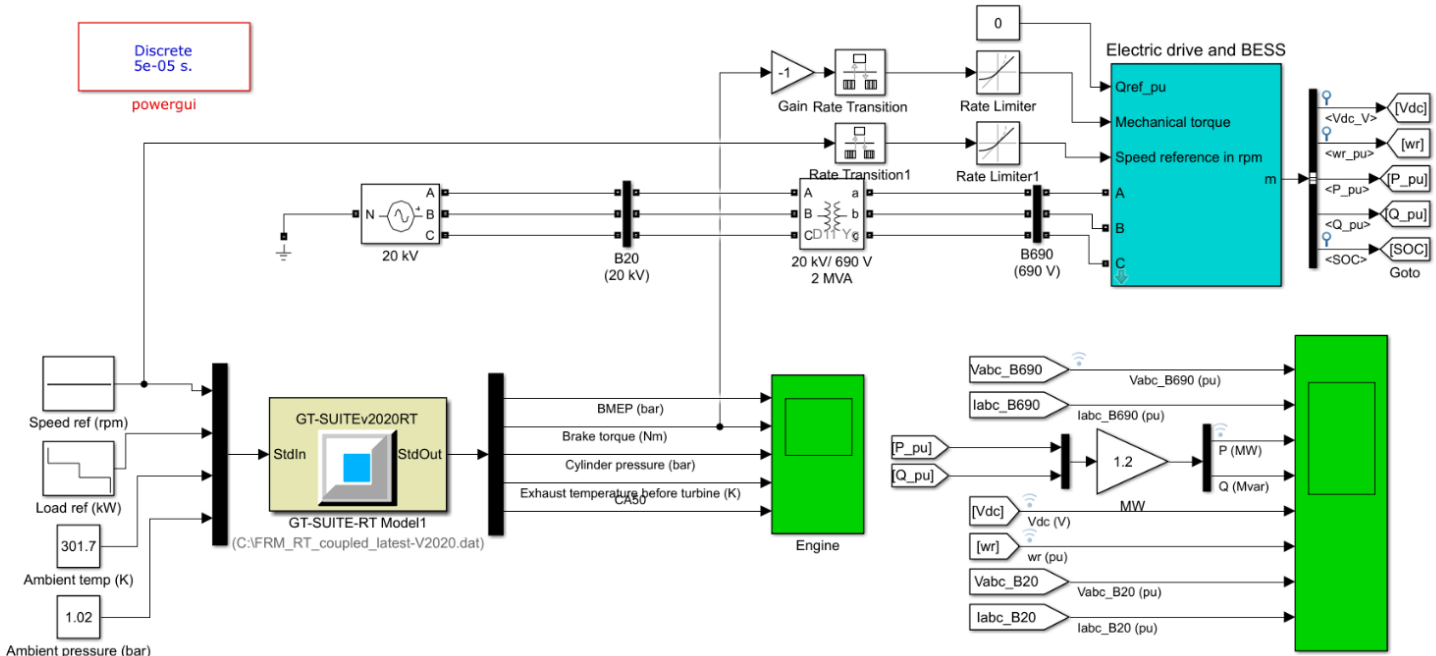

Figure 3. The combined engine and electrical equipment model in Simulink.

7.3 Simulation of the combined engine and electrical equipment model in Simulink

After the engine model was imported to Simulink, the whole model could be simulated. The model was simulated for 200 seconds in order to demonstrate its functionality. Four load points were included in the simulation by using load reference (kW) as input. The other constant inputs were the engine speed reference (rpm), ambient temperature (K) and ambient pressure (bar). As stated earlier, the outputs from the engine model included in Simulink were BMEP (bar), cylinder pressure (bar), brake torque (Nm) and exhaust temperature before turbine (K). The brake torque (Nm) was an input to the electric machine. The speed reference (rpm) was also an input to the speed controller. In addition, the reactive power reference was an input to the frequency converter. Table 1 presents the inputs to the engine model and how they vary with time for the simulation case presented here.

Table 1. Events during the simulation.

Time (s)	Speed reference (rpm)	Load reference (kW)	Ambient temperature (K)	Ambient pressure (bar)
0	1000	848.2	301.7	1.02
50	1000	637.7	301.7	1.02
100	1000	426.6	301.7	1.02
150	1000	213.9	301.7	1.02

The simulation results are presented in Figure 4 and Figure 5. Figure 4 shows the outputs from the engine and Figure 5 the outputs from the electrical equipment. The outputs from the electrical equipment were chosen from a point located after the frequency converter and before the 690 V / 20 kV transformer. For this case, four outputs were chosen: the active power output (kW), the power factor cos (φ), the 690 V bus RMS currents (A) and the grid frequency (Hz). The electrical outputs were validated against measurement data and the engine outputs were the same as the outputs for the FRM when simulated in GT-SUITE.

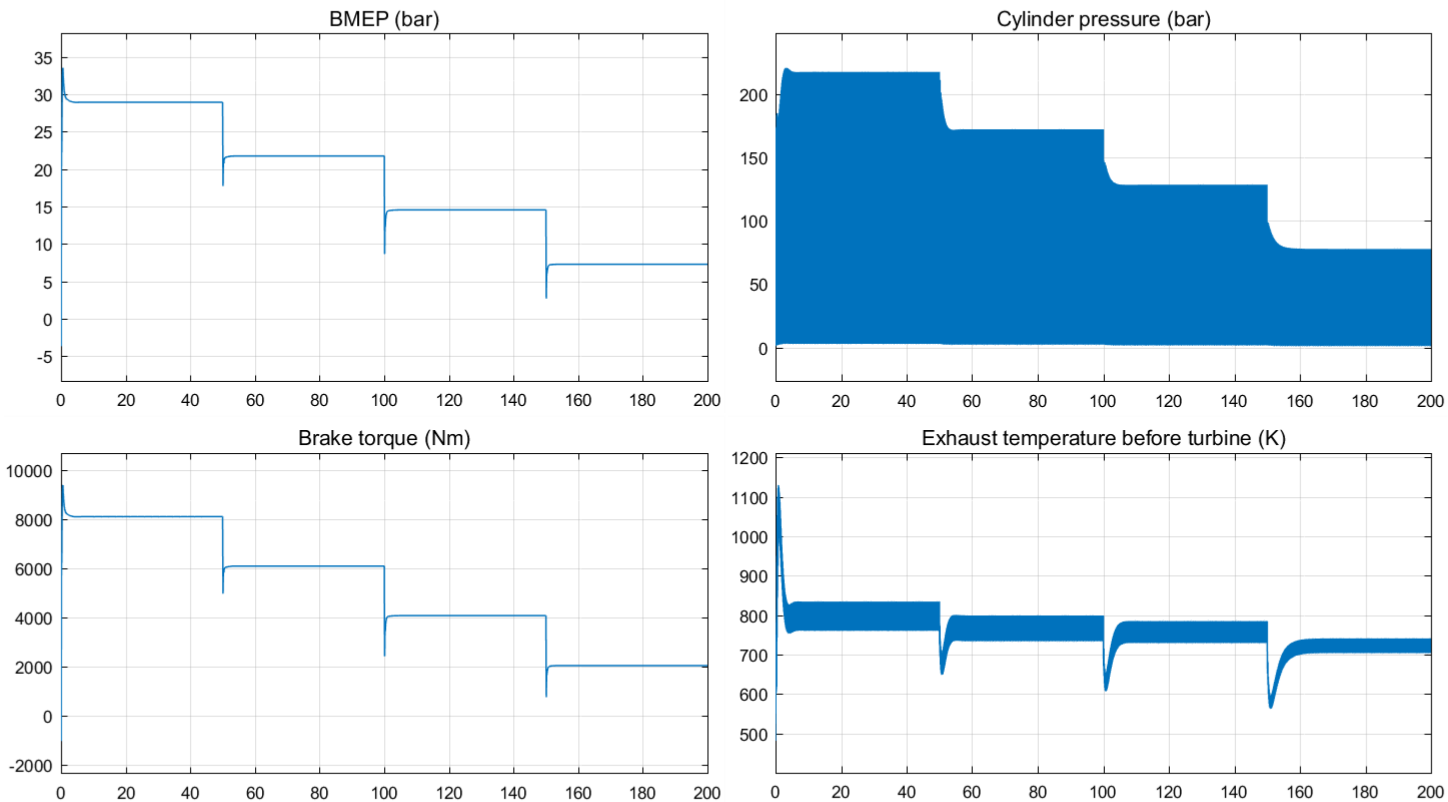

Figure 4. The engine measurement outputs in Simulink.

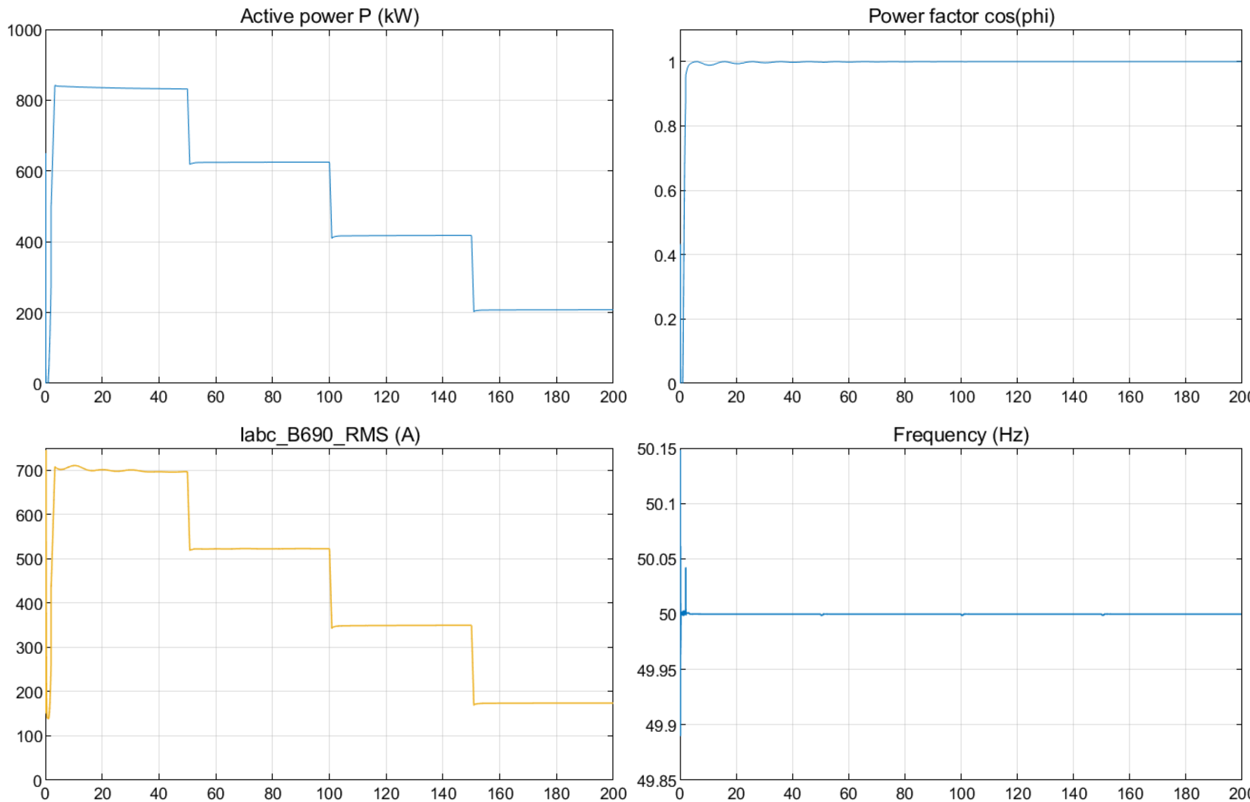

Figure 5. The electrical equipment measurement outputs in Simulink.

7.4 Real-time simulation and future work

Subsequently, when the combined model had been successfully simulated on the development computer, next step was to convert it into a real-time application and run it on the target PC using Simulink Real-Time. However, the GT-SUITE-RT block caused several problems in the compiling phase. After an extensive investigation, it was possible to compile the GT-SUITE-RT block and obtain a real-time application for the combined model. The electrical equipment model was already earlier proved to be real-time capable. The engine model was proved to be real-time capable, but it required a large sample time, which was not optimal for the output accuracy. Figure 6 shows the engine model outputs when running on the target PC as a real-time application, with a sample time of 1 s. As it can be seen, the average task execution time (TET) for this model on the specific computer used was 0.807 s, and the large sample time caused the cylinder pressure output to fail.

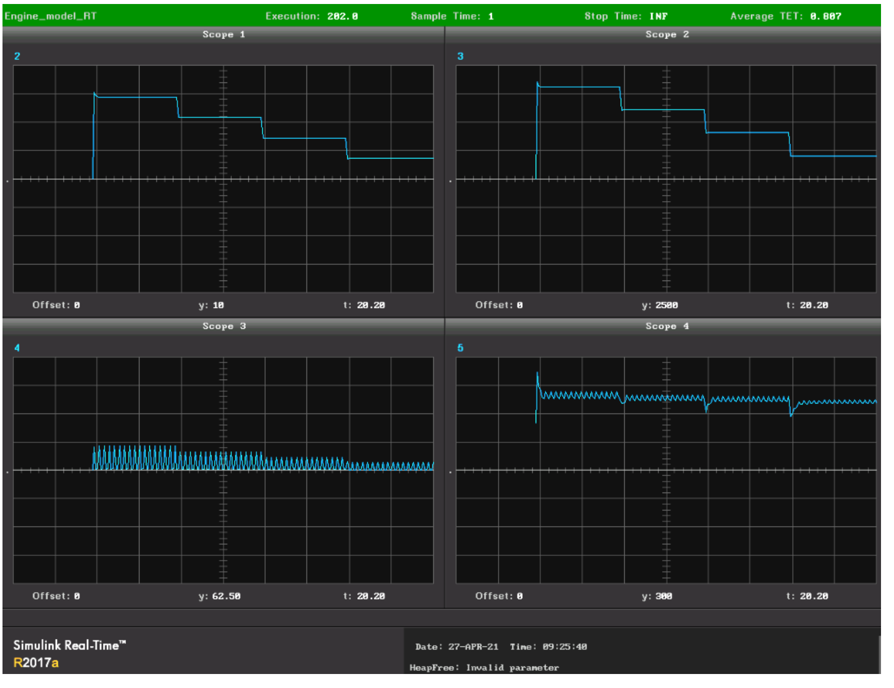

Figure 6. Engine model run on the target PC in Simulink Real-Time. Scope 1 is BMEP (bar), scope 2 is brake torque (Nm), scope 3 is cylinder pressure (bar) and scope 4 is exhaust temperature before turbine (K).

The whole combined model was not real-time simulation capable on the target PC. The target PC was however an old PC with lower computational power than the Speedgoat. Therefore, next step is to investigate how to get the combined real-time application running on the real Speedgoat Performance Real-Time Target Machine.

It was concluded that more computational power is needed in order to be able to use a smaller sample time for the engine model and to run the whole combined model as a real-time application.

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