Simulation using Controller in Loop in Off Highway Programs

Tribeni Deka [a] , Sneha Patil[b] , Tejas Kinjawadekar[c] , Yusuf Poonawala[d] , Pranita Adsul[e] , Sohan Agashe[f] Vritika Gupta[g] , Vivek Tiwari[h] , Gagandeep Theti[i]

Cummins Technologies India Pvt Ltd., India, 411038

Abstract: Traditionally, companies manufacturing large, complex systems have relied on hardware testing to develop and validate their products – this has been the case for engine and powertrain manufacturers as well. Real world engine testing is necessary but requires lot of resources (test facilities, prototypes, etc.) and time for performing iterations. There are also constraints on what combinations of noise factors and operating conditions can be tested.

With developments in physics and data-driven models and computing power, virtualization or model-based-design has progressed significantly in Cummins. By coupling detailed engine and aftertreatment system models with controls (closed-loop simulation setup), we can analyse how the system will behave in real world – and this virtual test environment is very useful in product development. This presentation gives an overview of development, validation of such a simulation setup and examples of its uses on BSIV and BSV Off-highway products, in performing diagnostics robustness for different engine ratings, software transparency, fuel economy studies and other use-cases.

Keywords: Virtualization, Model-based-design, Controller in Loop Simulation

Introduction

The testing and development complex real-time embedded systems in today's time is done by Hardware in loop simulation. HIL simulation helps in testing by adding plant models to the test platform. Including a mathematical model of the plant's dynamic systems in testing and development allows for a more realistic simulation, addressing complexities and refining the control system's performance with greater accuracy. These mathematical representations are referred to as the "plant simulation" and interacts with the embedded systems. This presentation gives an overview of development, validation of such a simulation setup and examples of its uses on BSIV and BSV Off-highway products, in performing diagnostics robustness for different engine ratings, software transparency, fuel economy studies and other use-cases.

Hardware-in-the-loop (HIL) simulation is the process of testing various functionality features both in open loop and closed loop environment.

HIL Bench is a Hardware-In-The-Loop (HIL) Simulator designed to test controls and diagnostic software in both open and closed-closed loop modes.

The closed loop model is generally an integrated model comprising of Engine plant models, Sensor and Actuator models and a real hardware ECM.

This HIL model has been able to perform fuel economy studies, steady state tests, transient cycle tests (NRTC, Customer/Application Duty cycles) etc. successfully.

The paper is organized as follows. In the first section the application of HIL method to perform various use-cases is explained. Next, the benefits of the proposed solution are discussed and finally concluding the paper with the future work. Figure 1 is the overview diagram of Hardware in Loop & Figure 2 is the physical HIL setup.

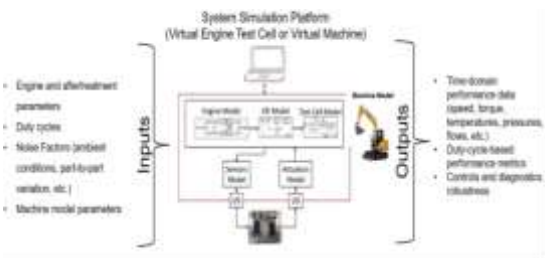

Figure 1 : Hardware in loop set up

Figure 2 : Physical Hardware in loop set up

Application of HIL method

1. Validation of duty cycle with test cell data

The prime use-case was to validate the accuracy of HIL model for the off-highway program of BSIV Engine.

The model has been able to predict the accuracy with NRSME value of 5% when compared with that of test cell data. Transient cycle (NRTC) was run on the bench with initialization set same as that in test cell. The calibration was used as in test cell for validation. Setup was able to predict both engine and aftertreatment performances very well. Figure 3 shows the comparison plot of test data vs simulated data.

2. Software Transparency

Secondly, the most important and commonly used case was software transparency.

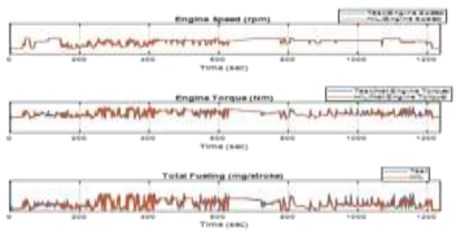

Figure 3 : NRTC validation plot

Before the release of new calibration, HIL model provided the platform to perform this test including all the different types of transient cycles. The model predicted the accuracy so well that it helped to reduce a lot of testing iterations and process improvement for calibration release. Figure 4 shows plot of RMC

(Ramp Modal Cycle) cycle and figure 5 shows NRMS Error table. Tests passed the primary criteria used in test cell i.e., NRMSE value for all performance signals <2%.

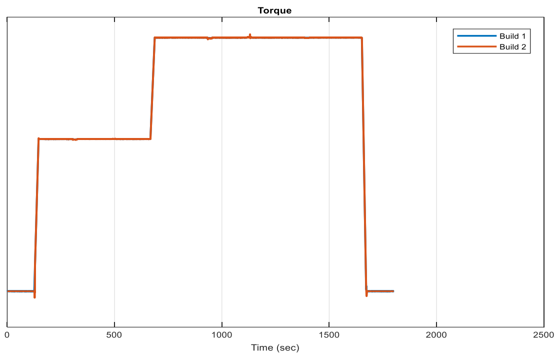

Figure 4 : plot of Ramp Modal Cycle

	NRMSE	STATUS
engine_speed_error_nrms	0.1899	Pass
engine_torque_error_nrms	0.5171	Pass
Total_fueling_error_nrms	0.5080	Pass
COP_error_nrms	0.9549	Pass
Charge Pressure	0.4817	Pass
Exhaust_Manifold_error_nrms	1.0772	Pass
Exhaust_Manifold_temp_error_nrms	0.3406	Pass
ETV_Out_Temperature_error_nrms	0.7929	Pass
DOC_Inlet_Temperature_error_rms	0.1690	Pass
DOC_Outlet_Temperature_error_rms	0.0711	Pass
SCR_out_Temperature_error_nrms	0.0771	Pass
COT_error_nrms	0.3060	Pass
CAC_outlet_temperature_error_nrms	0.1419	Pass
Coolant_error_nrms	3.4751	Partially p...

Figure 5 : NRMS Error table

Conclusion

Relying only on hardware testing whether in test cells or in field can be very time consuming and expensive. System simulations, including the hardware-in-loop setups described here, help to assess real-world scenarios in a controlled, virtual environment.

- The HIL work on CEV BS4 and BS5 programs has helped in calibration development and robustness and optimizing testing efforts.
- There is now broader confidence on these simulation setups within the organization.
- Currently, Simulation Based Product Development (SBPD) is a key initiative in Cummins.
- It focuses on thoughtfully integrating simulation with complementary testing to deliver products and solutions that are right the first time and robust for all our customers' uses.

The benefits of this controller in loop simulation include:

- ❑ Successfully integrated fast running model like GT and AVL boost with HIL setup and provided real time results.
- ❑ With simulation approach, today for off highway programs BSIV and BSV engines, decision making became simpler.
- ❑ Time consumption and cost overall reduced.
- ❑ It delivers quality results with higher safety and provide alternate solution for all kind of performance testing.