# HIL testing of Micro-Hybrid Controller on midsized dSpace Simulator

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## ABSTRACT

In this paper Model Based Testing of micro-hybrid controller has been explained using dSpace midsized simulation bench. Functional tests and diagnosis of Stop Start controller have been performed on dSpace based HiL setup. Physical Stop Start controller has been interfaced with the plant model, which had been built for real time simulation on dSpace mid size simulator and experiments has been created using dSpace Control desk to perform the tests. Several critical tests, which were difficult to perform in real vehicle, could be performed under the safe environment of lab within the desired level of accuracy. Stop-Start functionalities in different Indian drive cycles have also been compared using HiL setup. HiL testing has not only reduced the overall testing time significantly but it is also highly repetitive in nature.

## INTRODUCTION

With the increasing price of gasoline and emission regulations becoming stricter, HEV/EV vehicles are taking the center stage slowly but steadily in the automotive domain. Throughout the globe almost all OEMs have already adopted or in the process to adopt the HEV technology in their product line. As in xEV vehicle there is an Electrical propulsion system present either in place of ICE system or in sync with it, its controls has become more complex. Not only the complex propulsion system but also the high voltage system has put the whole system on the radar of safety and regulations. Apart from the new hardware, there are several added features available in such vehicle like Stop-Start, regeneration etc has made the validation of system more time consuming and cumbersome.

As the number and functionalities of the controllers have increased significantly, conventional testing methods are becoming obsolete and are being replaced by Model based approach by engineers. Depending on the stage in the development V-cycle, MiL/SiL/HiL etc approach is being used for the controller testing and validation.

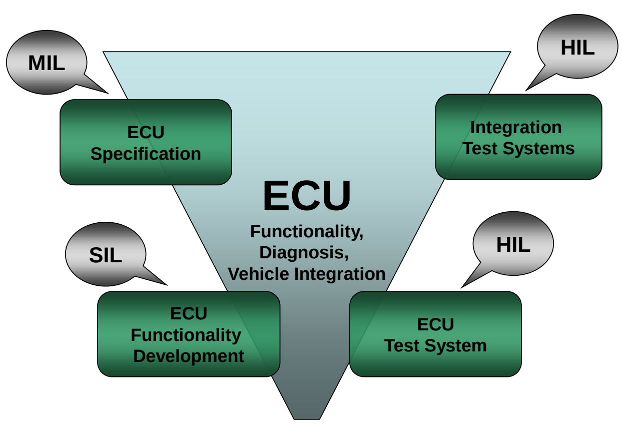


**Figure 1: Control Development V-Cycle**

HiL validation is used, when the actual prototype of controllers is available. In one such activity at MSIL, HiL approach has been adopted for the validation of micro-hybrid controller in a closed loop real time environment. The setup used for the activity was based on dSPACE tools set. Using the setup most of the functionality check and diagnosis had been performed under the lab environment.

## MICRO HYBRID ELETRICAL VEHICLE ARCHITECTURE

Hybrid Electrical Vehicle is being classified based on several criteria, like architectures, electrifications, power split etc. Based on architecture HEVs are classified as Series Hybrid, Parallel Hybrid and Powersplit hybrid. Depending on the level of electrification of the system HEVs are termed as micro-hybrid, mild-hybrid, full-hybrid and plug-in-hybrid. Similarly it has been classified as input split, output split and compound split. All these configurations have their own benefits and limitations.

In the micro-hybrid configuration referred in this paper, micro-hybrid controller takes care of the Start-Stop functionality of the vehicle whenever vehicle is idling under specific conditions. Stop-Start Controller works closely with the engine, body and chassis controls to make the decisions of engine stop and engine start. DC-DC converter supports accessories such as audio unit to remain powered during engine stop/start.

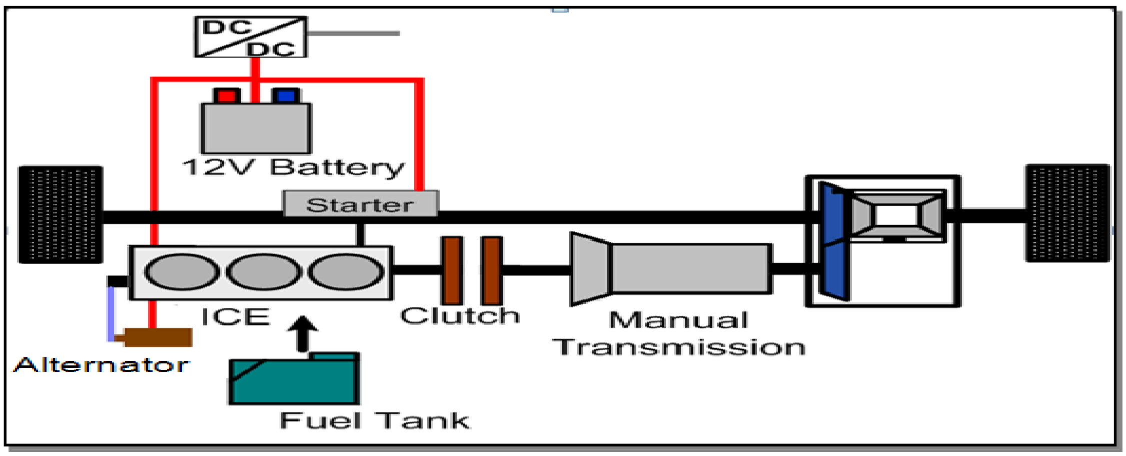


**Figure 2: Micro-Hybrid Vehicle Architecture**

## MODEL BASED DESIGN OF MICRO HYBRID VEHICLE

PLANT MODEL DEVELOPMENT - As per the first step, closed loop plant model of the vehicle has been prepared which has interfaced with the Stop Start controller. The Plant model is the behavioral definition of the vehicle system built on the Mathworks tool base. The fidelity and details of the model is directly governed by the requirement of the test to be conducted in the lab. The model is in executable form which can run simulation with high accuracy with given inputs. Model is developed in a way to support discrete, fixed time step solver, run in real time and also suitable for both MiL and HiL validation. Considering the ease of maintenance, model developed for MiL has been reused for the HiL process as well with minimum required change. Having the same model for MiL and HiL also provide avenues to reuse MiL test vectors derived from control requirements. All functional test cases thus do not require tests to be reinvented for HiL. This process reduces man-hours and thus reduces overall cost of the product.

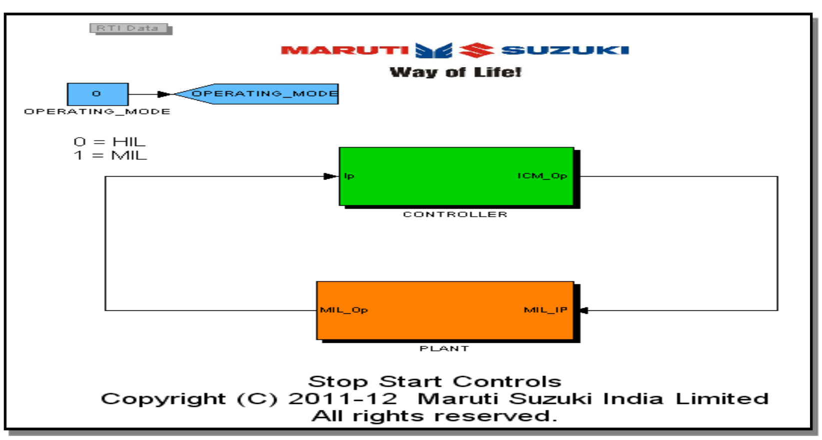


**Figure 3: Model Based Design of Micro-Hybrid Vehicle**

MODEL VALIDATION - Standalone testing has been conducted for different subsystems during development process by giving manual inputs. Before putting the integrated plant model on the HiL bench simulator, the plant model had been validated with the vehicle data. The model has been simulated for the full MIDC drive cycle and the result had been compared with the real field data. Through figure 5, it can be inferred that simulated drive cycle matches with the field test data with a good level of accuracy.

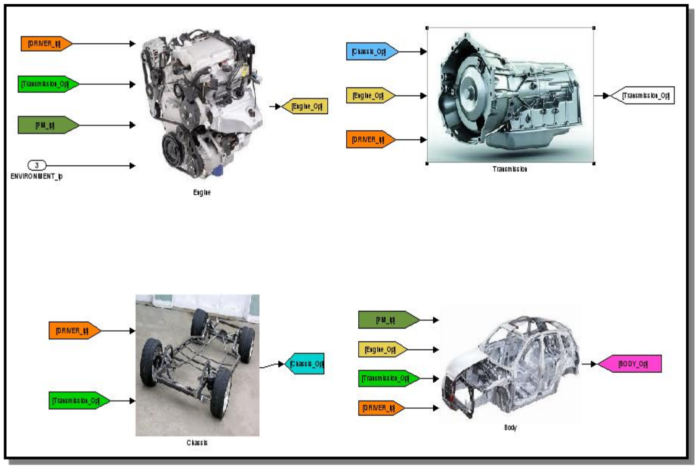

**Figure 4: Micro-Hybrid Vehicle Plant Model**

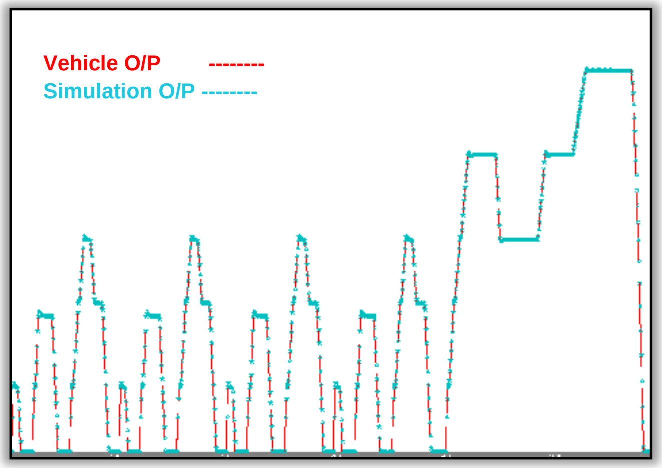


**Figure 5: Vehicle Plant Model Validation**

## HARDWARE IN LOOP SYSTEM SETUP

HiL setup is used for the functional validation of the controllers in real-time. Depending on the configuration it can have the single controller in loop (component test) as well as all controllers in loop system (full vehicle simulation). In this case, a single controller (stop start) is in loop with the simulator.

In real life, it is very difficult to set a state of charge/health in the battery like scenario. Real time simulation of battery model using DS1006 made several tests possible. Moreover, repeatability of such a test in the field is not guaranteed. HIL makes it possible to have functional test results pass on repeatable basis. The major challenge to perform HiL test is to build a real time capable simulation model which should be accurate and fast enough to run in real time. HiL bench consists of processor boards, I/O boards, signal & load conditioning, fault insertion cards and power supply.

Here the HiL setup is prepared for the stop start controller function validation.

HiL INTERFACE - The model has been prepared for the HiL application by creating HiL interface into the model. Using dSpace RTI blockset, which is part of dSpace toolchain, all signals including digital, analog, PWM, CAN had been configured in the plant model. All CAN signals has been mapped and configured for the board DS2211. After building the model for real time system description file has been generated along with several other files.

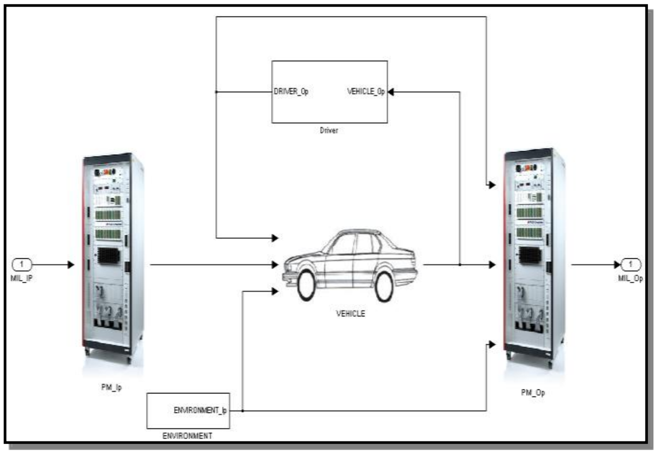

**Figure 6: Vehicle Plant model and HiL interface**

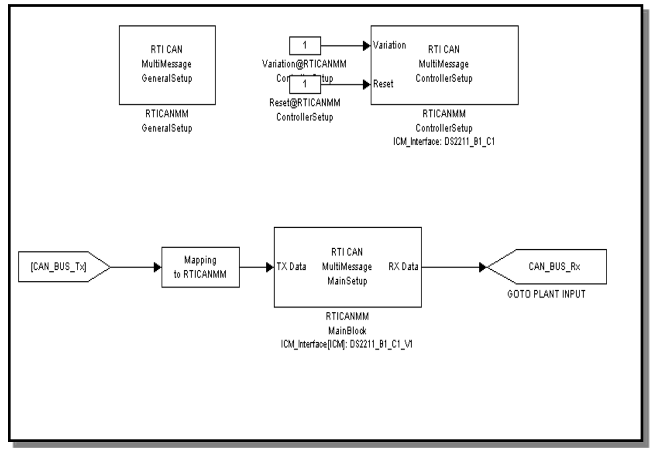

**Figure 7: CAN multi-message setup**

SIMULATOR SETUP - dSpace mid-Size simulator provides an excellent platform to test the controller functionality and integration tests. It is very well suited for the real load connection, electric failure simulation and signal conditioning. The real time built simulation model is loaded on the simulator and it runs on the hardware processor. Using I/O boards, dSpace simulator generate as well as measures the input/output signals for the controller. At MSIL, DS1006 processor board based mid-sized dSpace simulator has been used for the HiL setup of Stop Start controller, which has DS2211 HIL I/O- board connected to the controller.

Stop-Start controller has been connected with the HiL simulator through a breakout box as shown in figure 8.

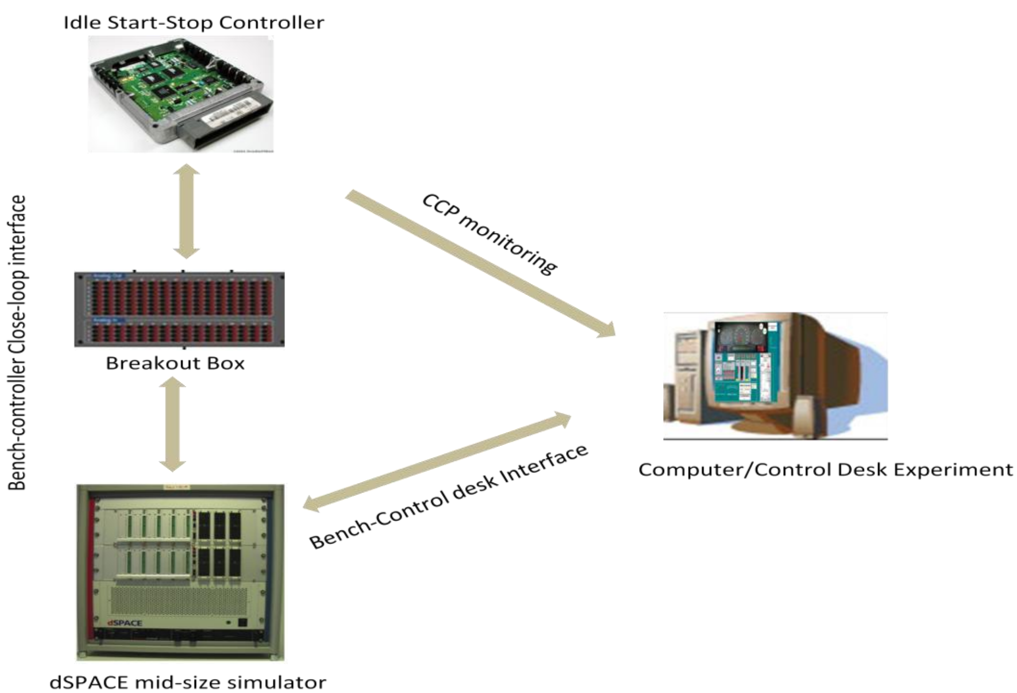


**Figure 8: Stop-Start HiL setup**

CONTROL DESK EXPERIMENT - Control desk experiment has been created on dSpace ControlDesk next generation, keeping in mind the functionality check of the stop start controller. Using the system description file generated at the time of build process of the plant model for the real time, variables had been mapped with the instrument panel of the control desk.

For the simplification of the experiment, the layout of the experiment has been created in layers. Front layer represents the instrument panel of the vehicle, where scope variables had been mapped for the reference purpose. Plant model output and input signals like, engine speed, vehicle speed, accelerator/brake/clutch pedal position etc has been created mapped on the front layer. Also different mode to run the plant model, like manual mode, speed control mode, drive cycle run mode could be selected front this layer. MIL lamp, buzzer, Auto stop LED lamps had been created and configured with the respected variables for HiL testing.

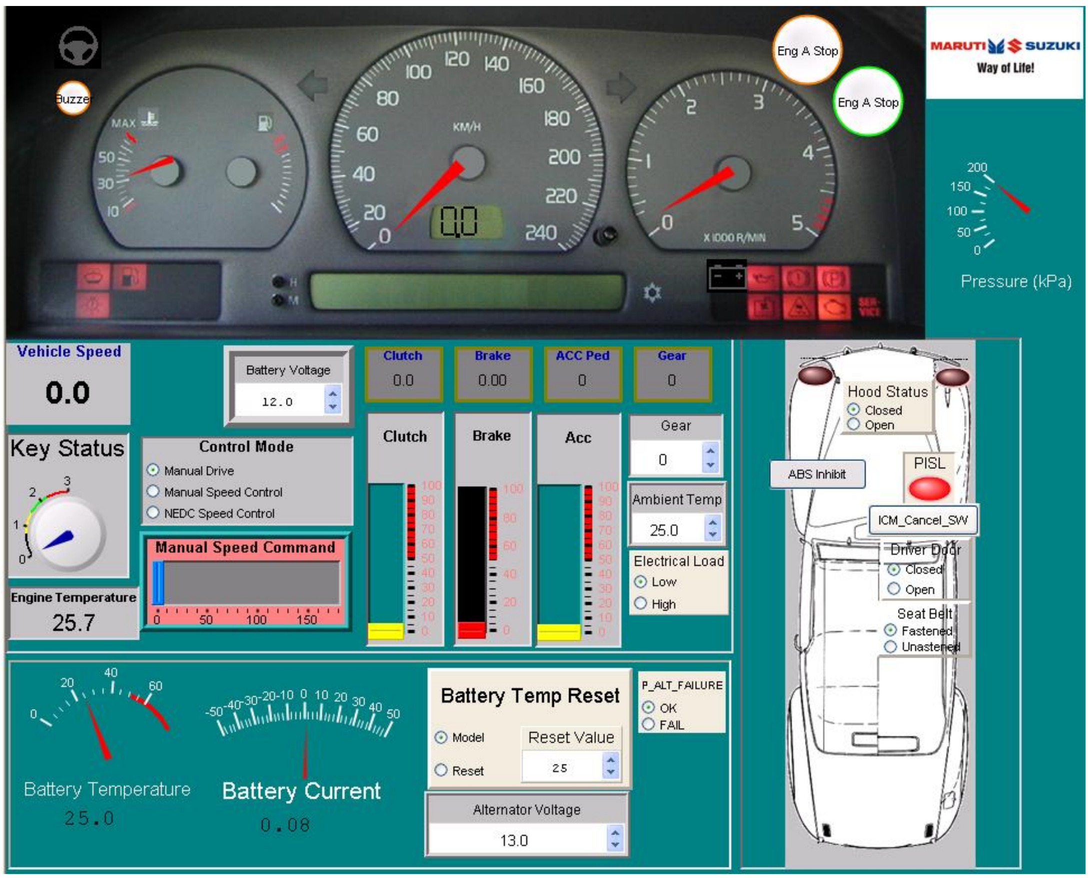


**Figure 9: ControlDesk Experiment front layer**

To provide manual override for certain variables while performing manual tests, second layer has been created. Signals value can be taken either from the closed loop plant model or can be provided manually from this layer. While running certain test case manual values are decided based on test cases scenarios.

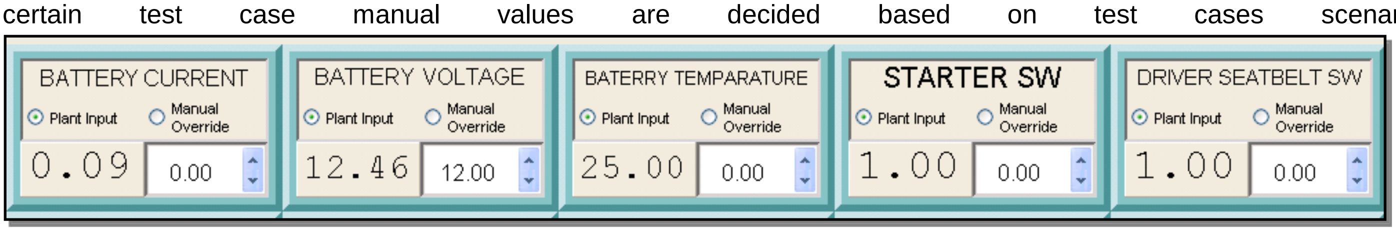


**Figure 10: ControlDesk Experiment Manual override layer**

For failure simulation purpose, third layer had been created, from where user can change the validity of specific signals. User can toggle between valid and invalid signal to the model to diagnose the controller logic. Controller decides whether to honor the signal or not, based on the validity flag attached with the signals.

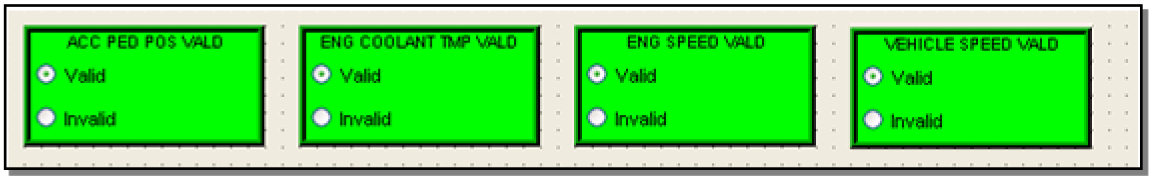


**Figure 11: ControlDesk Experiment Validity layer**

## STOP START CONTROLLER VALIDATION USING HILS SETUP

Hil testing has been performed for different test cases under different driving conditions. Developed experiment can run in three driving conditions, i.e. manual mode. Speed control and drive cycle. In manual drive mode, test engineer has to operate the model while giving input through the accelerator, brake, clutch and gear position.

In speed control mode, test engineer selects the speed at which he wants to run the vehicle and using this as reference plant model decides the accelerator, brake, clutch and gear lever position.

Similar to speed control mode, drive cycle mode runs the complete model for the whole drive cycle. In this mode test engineer provide the vehicle speed profile for the complete drive cycle.

STOP START ANALYSIS FOR MIDC- To visualize the Start-Stop frequency in the MIDC cycle, experiment has been conducted while running the setup under drive cycle mode. The model has been provided the MIDC velocity profile and run for the whole 1180sec cycle. The HiL setup had provided the clear picture of Start-Stop frequency for the whole cycle. It could be very well tested under the given specific conditions like coolant temperature, frequency of the Start-Stop. Similarly the Start-Stop frequency could be compared for different drive cycles. Also, the effectiveness of the system in urban drive cycle and highway cycle could easily be compared.

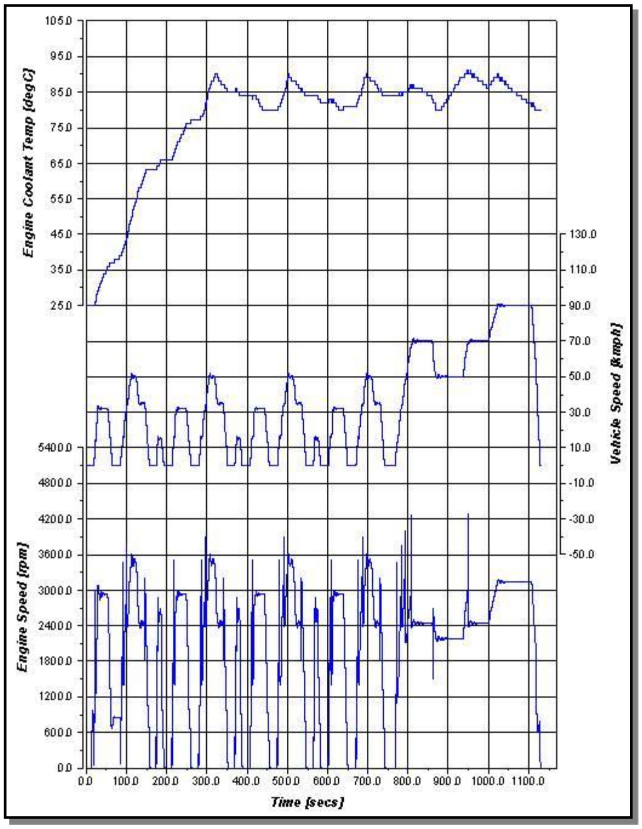


**Figure 12: MIDC Cold Test on HiL**

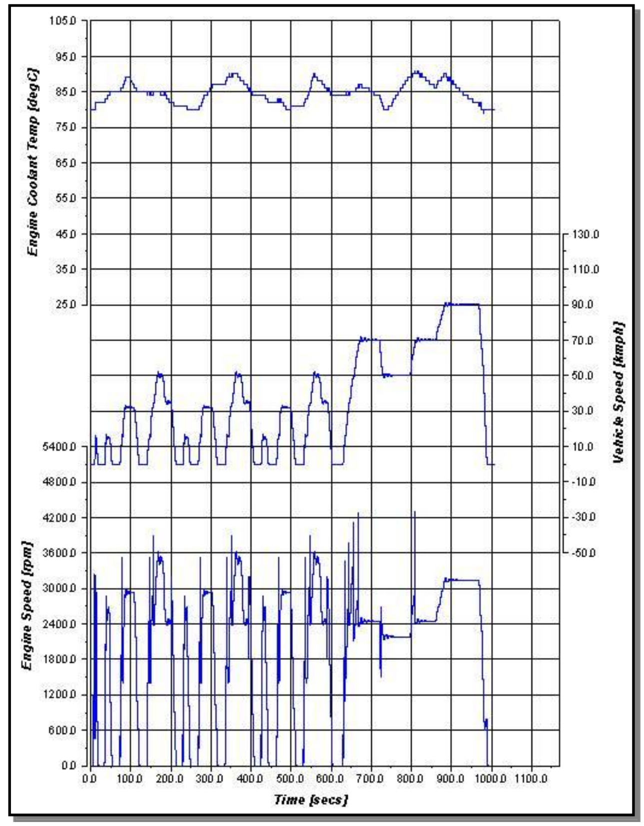


**Figure 13: MIDC Hot test on HiL**

From the test results in the Figure12 and 13 we can compare the Stop-Start frequency of the vehicle for both engine cold and hot conditions. We can see from the cold test data that while coolant temperature is below threshold, Auto-Stop conditions is inhibited, while in hot engine condition Auto-Stop-Start is happening from the very beginning of the drive cycle giving better utilization of the Stop-Start functionality. Results also presents a clear picture of the Stop-Start frequencies for urban and highway drive conditions, where we can see the system becomes more effective with the increase in traffic conditions. Similar tests can be run and analyzed for different drive conditions using the same lab setup.

SAMPLE TEST CASE EXECUTED ON HILS - HiL Setup has provided an excellent real time platform to validate the whole check list for the controller. The complete check list could be verified on the bench with a high level of accuracy. The test run data is being captured using INCA for the analysis purpose. Using the test plan for different tests, signal values have been provided using manual override. All possible scenarios like auto stop, auto start, engine stall and forced start is simulated on the bench.

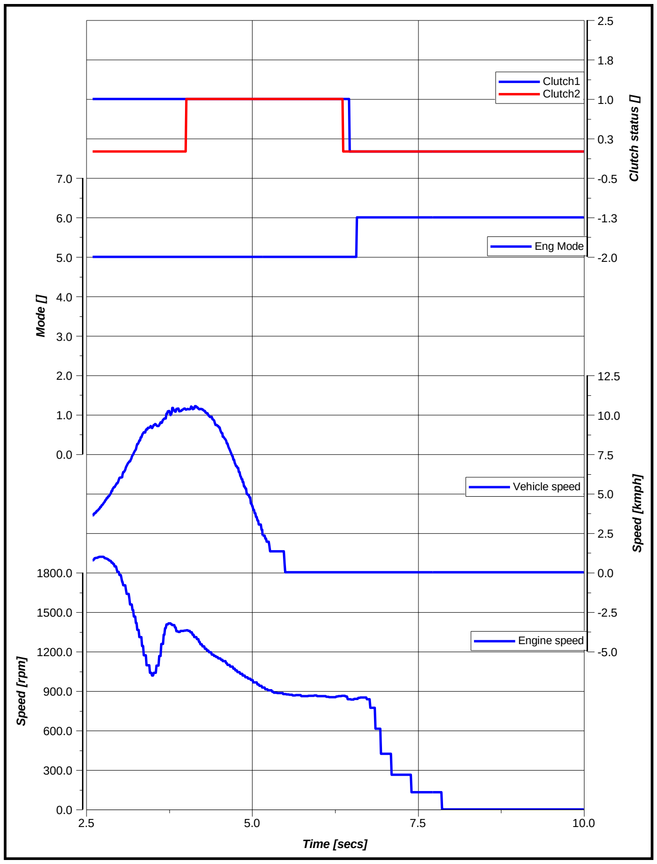


**Figure 14: HiL Test for Auto-Stop**

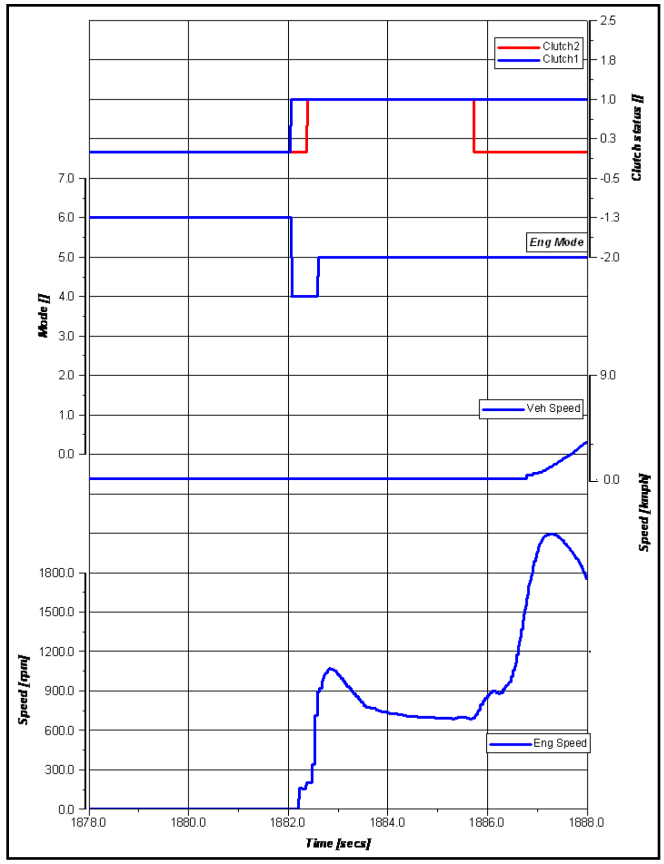


**Figure 15: HiL Test for Auto-Start**

TEST FOR AUTO-STOP - While the vehicle meets specific conditions for the Auto-Stop and no inhibit condition is present, vehicle will run in to Auto-Stop mode. One of the test cases is presented in Figure14 where it is shown that when vehicle speed reaches below a specified threshold, vehicle goes in the Auto-stop mode and engine speed reaches zero. Detail analysis is done with system parameters such as battery during autostop mode.

TEST FOR AUTO-START - HiL test has been conducted for the vehicle Auto start scenario. After the first Auto-Stop of the vehicle, controller checks for specific conditions to put the vehicle in Auto-Start mode. Figure15 shows that after the Auto Stop conditions are met, vehicle has been put in auto stop mode and when clutch pedal is pressed, controller commands engine to crank for auto start.

Apart from Auto Stop-Start conditions, several other tests had been performed to validate the functional behavior of the controller on desired maneuver. Also, controller diagnostics has been performed by changing the signal validity status manually.

## CONCLUSION

Model based approach has been adopted to validate and test the micro hybrid controller for its functionality. The plant model for MiL and HiL is same thus creating a possibility to use the unit test vectors during integration test at HiLs. HiLs in general helped to perform the tests under the safe lab environment. Some of the diagnostic checks were performed on HiLs which would have otherwise been very difficult to perform on vehicle safely. dSPACE HiLs provide a platform to evaluate system performance of Stop start system by running various city drive cycles in simulated environment. This reduced overall cost of development and project time.

## FUTURE WORK

Manual HiL testing has been performed to validate the functionalities and diagnosis of Stop Start micro-hybrid. Going forward all tests can be automated using AutomationDesk. Further, the plant model may be enhanced to improve the dynamics associated with the model and improve the fidelity, mainly in the transient state.

## ACKNOWLEDGMENTS

The authors of this paper would like to thank the whole HEV team at MSIL for their support and guidance throughout the project.

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## DEFINITIONS, ACRONYMS, ABBREVIATIONS

**MBD** – Model Based Design

**MIL** – Model in Loop

**HIL** – Hardware in Loop

**SIL** – Software in Loop

**ECU** – Electronic Control Unit

**HEV** – Hybrid Electric Vehicle

**MIDC** – Modified Indian Drive Cycle

**PWM** – Pulse Width Modulation

**CAN** – Controller Area Network

**MSIL** – Maruti Suzuki India Ltd