HARDWARE IN LOOP TESTING FOR AFTERTREATMENT SOLUTIONS

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Abstract

The Hardware in loop (HIL) testing is a simulation technique that is used in the development and testing of Engine control module (ECM) as the real time embedded control system. The ECM control module, which controls all electrical subsystems related to an automotive. It controls two subsystems namely Regeneration System (CRS) and Selective Catalytic Reduction (SCR). Manual testing and automatic testing methods are incorporated using various testing tools and test result monitoring software. Testing also includes GUI based script development for conventional and frequent test methods using python scripting in the back end.

Keywords— Hardware in Loop testing, After treatment Process, dSPACE, Data logging, Emission control

1. Introduction

An engine is considered to be the heart of a vehicle. Engines are machines designed to convert any form of input energy into energy that can be used for mechanical motion. Generally heat engines are world wide to convert fuel by burning them to create heat, which in turn creates a mechanical rotation. As technology improved, electronics started control of every operation of the engine and its associated modules.

A model presents the philosophy behind the design of test cases and the tools developed to evaluate the control law and air data system modules on the Iron Bird platform, and the procedure to clear the test results. [1]. Hardware In the Loop modeling and simulation for Diesel after treatment controls system development is discussed. Lean NOx Trap (LNT) based after treatment system is an efficient way to reduce NOx emission from diesel engines [2].

An ECU test process example in which an advanced driver assistance function is tested on a hardware in the loop (HIL) test system. The necessary process steps and interdependencies to ISO 26262 are identified. The paper also explains how to simulate an ideal test process under consideration of the version and variant flows, and how to use different validation systems to perform different validation steps throughout the development process[3]. The HIL system uses NI TESTSTAND and NI LabVIEW to automate the conventional FMET process. The system is implemented on engine emulator called Load-box User Interface System (LUIS Bench) and FMET box. The developed Hardware – in – loop system is more accurate and reduces the testing time significantly[4].

The characteristics of automotive model-based development processes, the consequences for test development and the need to reconsider testing procedures in practice is discussed. Furthermore, we introduce the test tool "TPT" which masters the complexity of model-based testing in theautomotive domain[5].A hardware-in-the-loop facility aimed at real-time testing of architectures and algorithms of multisensor sense and avoid Systems is discussed[6]. The hardware – in – loop (HIL) testing can be used for great range of systems from simple embedded systems such as room temperature controllers to sophisticated embedded systems like the dosing system consisting of large number of sensors and actuators [7].

In this paper, ICE of type diesel engine is considered. The Diesel engine, also known as compression ignition engine uses the heat of compression to initiate the ignition to burn the fuel, which is injected into the combustion chamber. As Diesel engines are more advantageous than petrol engines in case of they burn less fuel than petrol and generates very less waste heat in cooling and exhaust and also diesel engine have better torque characteristics compared to petrol engines.

2. Methodology

Electronic Control Module (ECM) or Electronic Control Unit (ECU) is an embedded system that controls one or more of the electrical systems or the automotive subsystems in the vehicle. The ECM uses microprocessor which can process the inputs from the engine sensors in real time. Thus the ECM processor or controller gets information from numerous sensors and process the voltage or current value to drive actuator valve, lamps or relays electronically for mechanical modules. The block diagram of the ECM is shown in Fig.1.

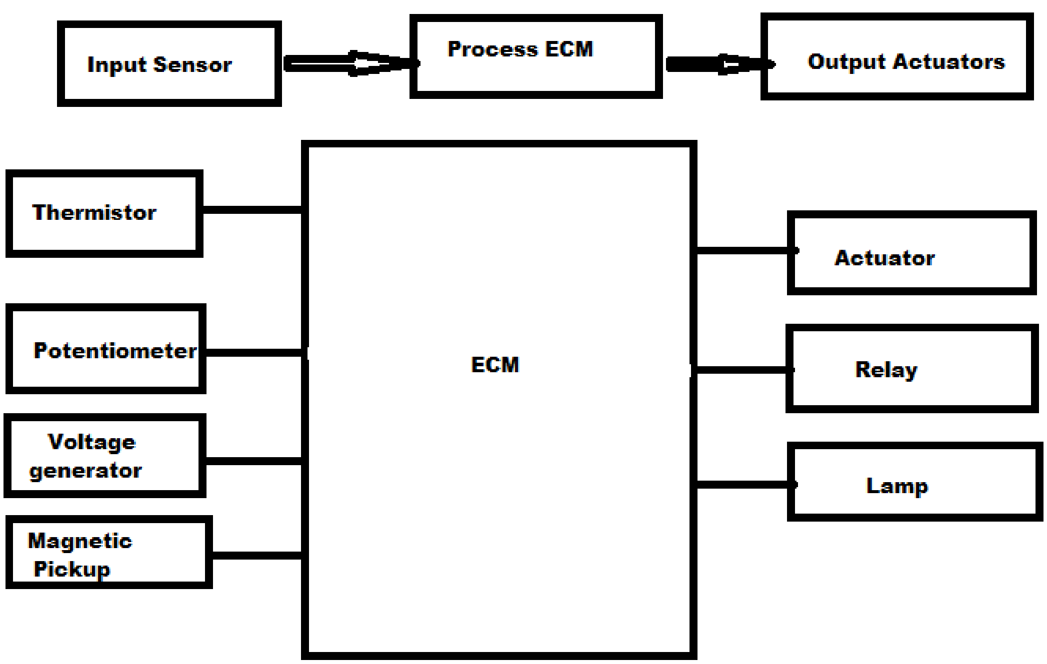

Fig 1: Block diagram for ECM

All such ECM related controls are implemented in vehicles primarily to reduce cost and ensure safety to the passengers and drivers.

2.1 Engine subsystems

The diesel engine is not a single module but a combination of many subsystems. These subsystems work together, communicate with each other with a help of a protocol and make sure every part of the vehicle is running within limits and ensure safety to the people. The ECM monitors all the required values from subsystems and sends it to other subsystem, which is in need of those values. Hence all subsystems are inter related for the efficient functioning of the engine.

2.2 Emissions

Based on the increasing demands for low pollutant combustion systems, the exploration of more homogenized diesel combustion systems identifies another central task for diesel combustion system research. One approach to realize such advanced combustion systems is the investigation new calibration strategies for a multiple injection event, such as pilot, split and multi-event injection, especially in conjunction with modern, highly flexible and capable injection systems. Hence the need for advanced aftertreatment exhaust systems are essential to meet the stringent emission norms in decreasing the emissions from automobile and maintaining a pollution free surrounding.

2.2.1 Source of Harmful Emissions

Exhaust gas or flue gas is emitted as a result of the combustion of fuel such as natural gas, gasoline/petrol, diesel, fuel oil or coal. According to the type of engine, it is discharged into atmosphere through an exhaust pipe, flue gas stack or propelling nozzle.

Internal combustion engines such as reciprocating internal combustion engines produce air pollution emulsions, due to incomplete combustion of carbonaceous fuel. The main derivatives of the process are carbon dioxide (CO_2), water and some soot, also called Particular Matter (PM). There are, however, some additional products of the combustion process that include nitrogen oxides, sulphur oxides, and some uncombusted hydrocarbons, depending on the operating conditions and fuel-air ratio.

Not all the fuel will be completely consumed by the combustion process; a small amount of fuel will be present after combustion, some of which can react to form oxygenates, such as formaldehyde or acetaldehyde, or hydrocarbons not initially present in the fuel mixture. The primary causes of this is the need to operate near the stoichiometric ratio for gasoline engines in order to achieve combustion and the resulting "quench" of the flame by the relatively cool cylinder walls, otherwise the fuel would burn more completely in excess air. When running at lower speeds, quenching is commonly observed in diesel engines that run on natural gas. It reduces the efficiency and increases knocking, sometimes causing the engine to stall. Increasing the amount of air in the engine reduces the amount of the first two pollutants, but tends to encourage the oxygen and nitrogen in the air to combine to produce Nitrogen Oxides (NO_x) that has been demonstrated to be hazardous to both plant and animal health. Further chemicals released are benzene and 1, 3-butadiene that are also particularly harmful; and not all of the fuel burns up completely, so Carbon Monoxide (CO) is also produced.

Carbon fuels contain sulphur and impurities that eventually lead to producing Sulphur Monoxides (SO) and Sulphur Dioxide (SO_2) in the exhaust which promotes acid rain. One final element in exhaust pollution is Ozone (O_3). This is not emitted directly but made in the air by the action of sunlight on other pollutants to form "ground level ozone".

A relatively small part of combustion gas is undesirable noxious or toxic substances, such as Carbon Monoxide (CO) from incomplete combustion, hydrocarbons (C_xH_x) on emissions-test slips, from unburn fuel, nitrogen oxides (NO_x) from excessive combustion temperatures, Ozone (O_3) and particular matter (mostly soot).

2.2.2 Effects of Emissions

1. CO_2 from the exhaust causes "Green House Effect".
2. CO (Carbon monoxide) concentration over 0.1% is lethal for human and reduces the ability of blood to absorb oxygen.
3. HC_s (Hydro carbons) are carcinogenic; more or less poisonous.
4. NO_x (Oxides of Nitrogen) are Main reason for smog; irritation to respiratory system.
5. SO_2 (Sulphur dioxide) are Main reason for "Acid rain" and deforestation.

2.3 Functions of After treatment System

Functions of aftertreatment include transfers Exhaust Gas to CEM, transfers charge air to Combustion Air Valve, transfers coolant to CRS Head, transfers fuel to CRS Head, transfers oil to Combustion Air Valve, Filters intake air to Engine, transfers return coolant to Engine, transfers return oil to Engine, creates backpressure on engine, removes Particulars, HC, CO from Exhaust (Emission compliance), regenerates DPF, silence Engine Exhaust Airborne Noise, minimization of Generated Shell Noise (DPF, Muffler, SCR) , maintain 250 C Skin Temperature / Underhood Temperature Required

2.3.1 Regeneration System

The Diesel Particular Filter (DPF) is one advanced technology option for manufactures to consider in reducing Particular Matter (PM) emissions from diesel engines. DPFs are the most effective control technology for reducing particulate emissions with efficiency 90% and show mechanical and thermal stability suitable for diesel engine applications.

The Diesel Particulate Filter shown below assumes a honey comb patter, made primarily of a ceramic material. These filters have alternate plugged channels to allow entrance of "dirty" exhaust and exit of "clean" exhaust is then filtered through porous, ceramic wall in the filter, cleaning the particulates from the exhaust.

The walls of the filter are lined with catalyst (DOC), usually platinum, palladium, or any other base metal oxide. This catalyst reduces the amount of hydrocarbons and carbon monoxide through simple oxidation. These wall-flow filters have an allocation of very fine pores in the walls, which must be carefully controlled during the manufacturing process. The total material porosity of this typically between 45-50%nor higher, as the medium pore sizes generally range from 10-20μm. The filtration mechanism for wall-flow filters is a combination of surface depth filtration. For a clean filter, depth filtration is the dominant mechanism as the particulate matter is deposited in the pores inside the wall material. As the soot builds up inside the walls, surface filtration becomes the predominant method.

2.4 Software validation and Testing

2.4.1The V-Model

The V-Model gives equal weight to coding and testing in software development process. "V-Model" maps the types of test to each stage of development.

The idea of the V-Model is to have an implementation plan for the software testing at each level namely component, interface, system, acceptance, and release of the software project. The reason for V is, most of the phases on the left have a corresponding phase of activity on the right. Figure shown in fig.2 is the V-Model in software development and testing.

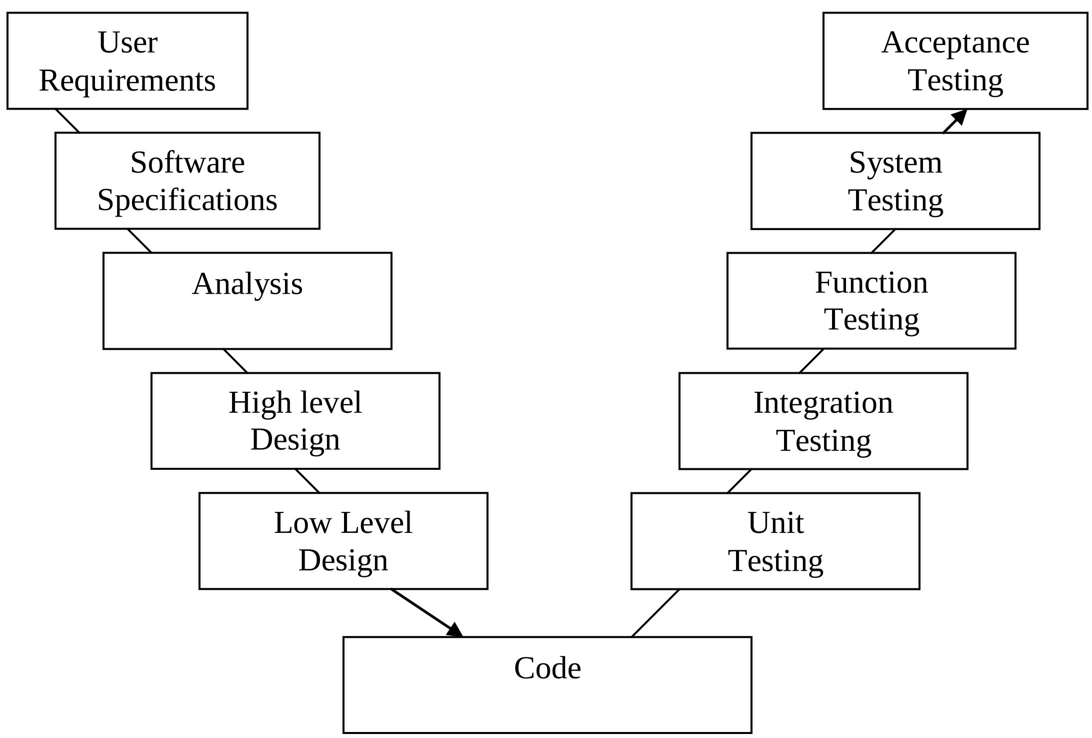

Fig 2: V-Model SDC

First step in the development is a “Business Case”, it outlines a new system, or change to an existing system, which will deliver business benefits, and outlines the costs expected when developing and running the system. Next step is defining a set of “User Requirements”, which is a statement by the customer of what the system shall achieve in order to meet the need. This involves both functional and non-functional requirements. “Requirements” are then passed to developers, who produce a “System Specification”. This takes features required, maps them to various components and defines the relationship between these components. Each component then has a “Component Design”, which describes in detail exactly how it will perform its piece of processing.

The first level in testing is “Component Test”, it involves checking whether each feature specified in the “Component Design” has implemented in the component. As the component are constructed they are linked together to check if they work each other. The “System Design” defines the relationship between the component, what a component can expect from another component in terms of services, how these services will be asked for, how they will be given, how to handle non-standard conditions and errors. Testing of integrated modules to verify combined functionality after integration. System testers are employed to check the system as a whole. Finally “Acceptance Testing” checks if the requested system has delivered the User Requirements fluffily.

2.4.2 Aftertreatment Software Testing and tools

2.4.2.1 dSPACE simulator

The dSPACE system provides solutions for automotive, aerospace and other real time embedded systems. Hardware-in- the-loop (HIL) simulation is the method used to test the functions, system integration, and communication of electronic control modules (ECMs). ECMs are indispensable for vehicle, airplanes and robots. The technical environment of the ECMs and interconnected system parts are simulated in HIL simulation. The HIL tests are very systematic and also completely safe, even when critical thresholds are exceeded. The main goal is to detect errors in ECMs. Once detected, the situation produces the error can be reproduced whenever and however required.

dSPACE simulator is a Hardware in loop simulator for testing the software (ECM). The simulation model runs on a processor board, DS1006. It generates and measures I/O signals via the DS2211 HIL I/O board.

2.4.2.2 Role of dSPACE in V-Model

dSPACE plays an important role in the software development cycle. Figure shown below describes the role of dSPACE in the V-Model.

ECM Testing on HIL simulator (a virtual vehicle) has the following advantages,

- Automated testing and reports
- Reproducibility and time reduction for test execution
- Integration of dynamic modules

- Measurement of all electrical lines including the bus signals line CAN
- Stepwise system tests
- Fast switching between variants.

2.4.2.3 dSPACE Tools

1. **Control Desk**

Control Desk application will provide the environment (GUI), which is intended to coordinate simultaneous access to the dSPACE processor boards by several host applications. It is also used for instrumentation, parameterization, measurement and experiment control. Control Desk also serves as a basis for test automation via Automation Desk, it provides various instruments to access, debugging, capturing and automating the test sequences, diagnostic tests with failure insertion.

2. **Automation Desk**

Automation Desk is a software tool for creating and managing any kind of automation task. This creates graphical automation blocks with the sequence builder. Each Automation Block are provided by the Automation desk library in a graphical representation of an encapsulation Python class.

Python Scripting

Python is a remarkably powerful dynamic programming language that is used in a wide variety of application domains. It has very clear, readable syntax, strong introspection capabilities, intuitive object orientation, Natural expression of procedural code.

Python Scripting in Automation Desk

AD uses python as the back end platform for scripting. It has an excellence support for developing and debugging automation scripts to carry out conventional test. It supports all tools related to the HIL testing implemented for ECM testing. AD uses Python for the following advantages,

- Synchronous execution of test scripts and simulation model
- Concurrent execution of several independent test scripts
- Python interpreter integrated into application via Real-Time Workshop build option
- Real-Time-Capable Python interpreter for the DS1005 PPC Board and DS1006 Processor Board
- Dynamic test loading during model and test execution

2.4.3 Regeneration Types and DPF Warning Lamp

Regeneration System is a subsystem, which deals with the exhaust gas soot treatment. It comes under the Configuration, Integration, validation and testing team. Fig. 3 shows the testing subsystems of the CIV&T team. It is the process of cleaning the DPF when required. A timely regen is mandatory so that it is assured that the exhaust pipes are not chocked. If the exhaust is chocked, it leads to disaster of the engine. Hence there are many regen types based on few parameters, which ensure that the DPF filter is kept clean.The regen occurrence mainly depends on the amount of soot deposited.

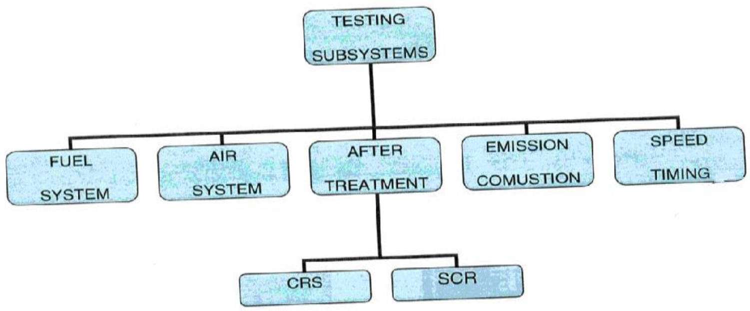

Fig 3 : Testing Subsystems

There are also many other factors from which a regen can occur based on the proprietary software design.In spite of the all automatic regens occurrence there is a manual regen or forced regen that a driver can actually initiate based on soot deposits. Fig.4 shows the DPF regen switch in the dashboard of a heavy-duty truck.

Fig 4 : Forced regen Switch in Dashboard

A warning lamp indicator is also present in the dashboard, which goes ON during high soot levels and for other regen desired factors.

3.Test Bench Setup

The dSPACE test bench is to be set up for the regen to run. The following are the pre requisites for the test bench before commencing the test.

- The MATLAB model built and loaded in the dSPACE processors with help of control desk
- Appropriate software release file flashed in the ECM with the help of service tool

- The after treatment ECM should be connected to real time CRS sensors and actuators to simulate real time diagnostics and events
- Few sensors related to CRS are Soot sensors, Auxiliary Regeneration Device (ARD) air valve, Actuator relays
- CANape loaded with the database of the signals, sensors, maps and parameters to be monitored

3.1 Regen Monitoring

Tests are performed in the flashed software for its quality assurance. Hence test cases must cover all possible scenarios, which can happen during the real time run of an engine. Hence the test engineer will override parameters that are required to meet a certain test case. These parameters reflects a change in the ECM memory, which in turn brings about changes in the outputs of other parameters as desired. For a regen to run, there are many parameters that are to be overridden to meet the initial conditions of a regen to run.

3.2 DPF Warning Lamp

The DPF warning lamp as mentioned earlier is a lamp in the dashboard of the heavy-duty vehicle . This lamp, if ON, indicates that a regen is highly desired and indicates the driver to switch on the Manual regen button in the dash board. The lamp as such has a number of conditions for itself to turn ON and turn OFF.

Fig 5 : DPF Warning Lamp

Fig.5 shows the DPF warning lamp in the dashboard. Lamp strategy testing involves overriding all the initial conditions required for the lamp to get ON. There are many test cases for the lamp to switch on and off based on the value of soot deposited and also the other type of DPF accumulates.

4. Regeneration analysis and Results

4.1 Model loaded in dSPACE Processor

The model has to be initially loaded into the dSPACE simulator with the help of Control desk. Once the model is loaded into the processor , the simulator will be ready to generate the required signals to the corresponding address in the ECM through a properly designed harness

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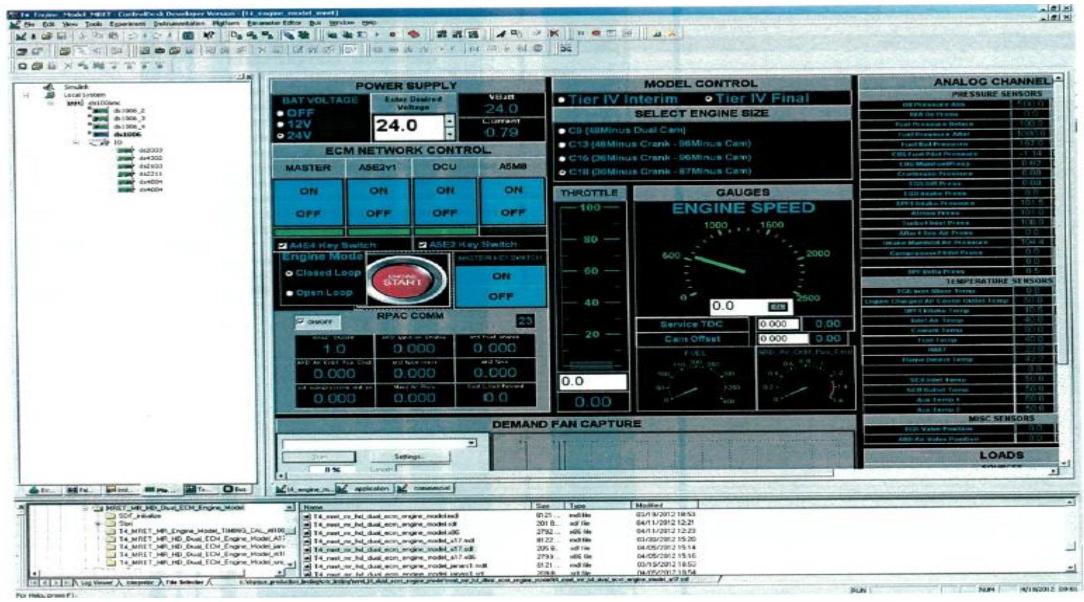

Fig 6: Control Desk Window

Fig.6 shows the Control desk window, which shows parameters, related to CRS inputs and outputs. Required overrides can be done through the same application or the CANape. Once the model gets loaded in the processor, Control desk has the virtual key switch simulation button, which actually turns on the battery set of the vehicle.

4.2 Service tool

The service tool helps in flashing the software flash files in to ECM. Once flashed the tool displays the proprietary release versions of the software.Fig.7 shows the events showed in flash file.

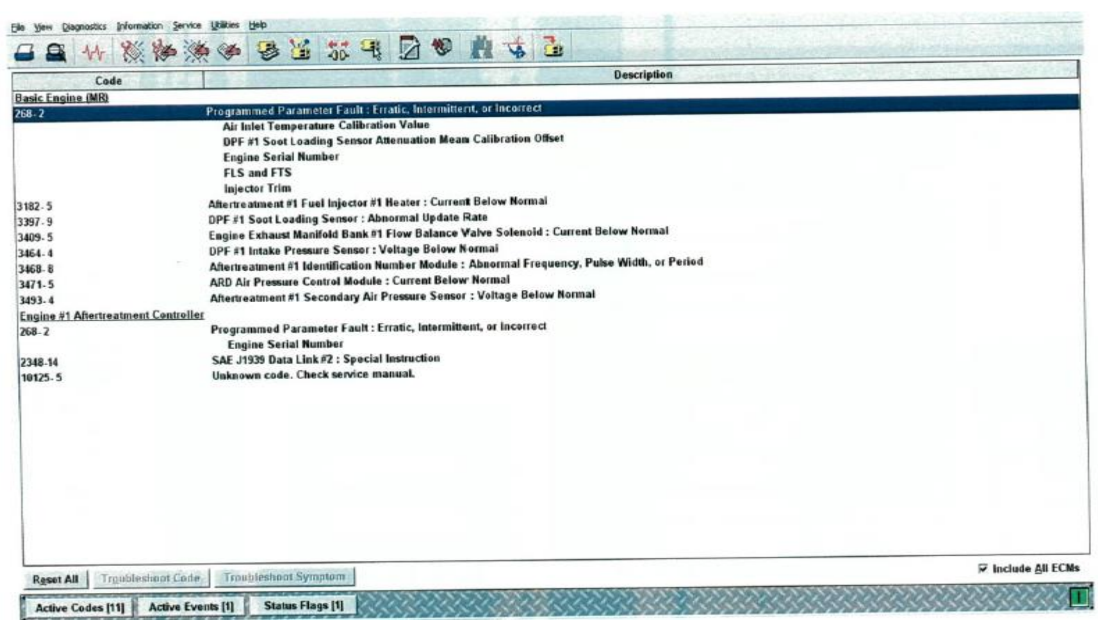

Fig.7 shows the diagnostics and events that are present in the current flash file.

4.3 Automation Desk Window

The automation desk window, shown in Fig. 6.3, has sequences that can use in- built libraries accessed through Python. These libraries are useful to communicate with the service tool, CANape and Control desk.

The regen types are generic for all software releases and hence automation project for such a testing can save a lot of time instead of manual operations. Automationdesk project involves python coding for communicating with Control desk to load the model, communicating with service tool for flashing the ECM and communicating withCANape for all necessary conditions and the measurement calibrations

4.4 CANape Window

The CANape is a calibration and measurement tool. It involves pulling all related variables and overrides required for the particular testing. This tool can communicate with many ECMs in the network simultaneously and can give the change in measurement details for every 30ms. Fig.8 shows the parameters for the regen types while doing a manual test.

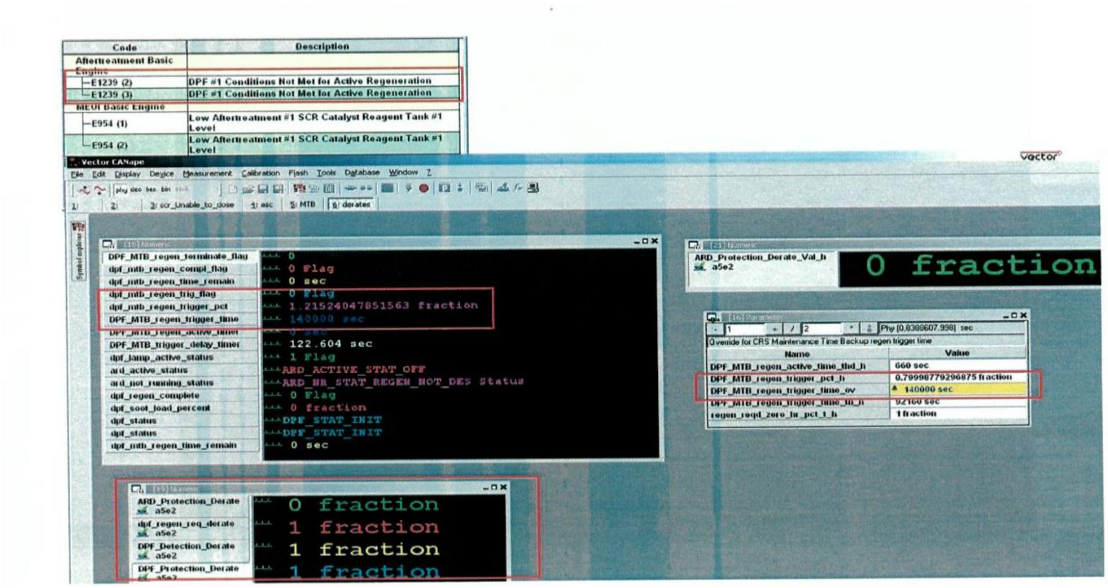

Fig 8 : Manual Testing in CANape

4.5 Measurement Capture

CANape captures all variables data and stores as a measurement data file (.mdf). This mdf files can be used to determine flaws in the software while testing. The file is generated in the form of a graph, with all captured signals in the same window. This highly helps in checking the transitions of multiple signals during an instant. Regen types have various test cases which involve multiple signal shifts. Fig.9 shows the result of a completed regen.

Fig 9: CANape generated Measurement Data File

4.6 AD report

Automation Desk has the feature of report generation in a readable form so that any mistake in the software can be recorded in the desired form. AD reports have table formats, graphs and other text options to effectively generate a report based on a test sequence. Any user who does not know the tools of testing can easily view the report and understand the test results.Fig10 shows the AD report.

CRS_Regen_Types (Sequence)			
Start time:	2012/02/28 08-35-18	Stop time:	2012/02/28 08-45-44
Execution duration:	625.899 sec.	Name:	CRS_Regen_Types
Library link:		Creation date:	2008/11/6, 15-55-22
Modification date:	2012/2/28, 8-45-44	Author:	OldAdmin
Hierarchy:	CRS_Regen_Types_CE _T4F_DUAL_kicha. CRS_Regen_Types		
Description:			
Result state:	Executed		

DPF WARNING LAMP ACTIVATION - TIER 4F

DPF LAMP TURN ON CONDITIONS

DPF_Lamp_On_Regen_Reqd_Perc 0.899993896484

DPF_Lamp_Switch_Off_pct 0.880004882813

Soot Percentage	Expected DPF Lamp Status	Actual DPF Lamp Status	Result
0.1	0	0.0	PASS
0.400024414063	0	0.0	PASS
0.89501953125	0	0.0	PASS
0.904968261719	1	1.0	PASS
0.89501953125	1	1.0	PASS
0.869995117188	0	0.0	PASS

Desulf trigger	Auto regens disabled	Expected DPF Lamp status	Actual DPF Lamp status	Result
0.0	0.0	0	0.0	PASS
0.0	1.0	0	0.0	PASS
1.0	0.0	0	1.0	FAIL
1.0	1.0	1	1.0	PASS

DPF WARNING LAMP OFF CONDITIONS

Fig 10: AD generated Report for DPF lamp Test Cases

5. Results and conclusion

Thus the given three regen types were tested, both manually and with automation tools. The testing tools were utilized for the same purpose and the calibration, monitoring and the result window screen shots have been produced. The reports and the measurement data for the tested automation package were generated and the reports were as expected.

6. References

1. Ambalal V. Patel,Vijay V. Patel,Girish Deodhare(2014),Clearance of Flight Control System Software with Hardware in Loop Test Platform, Journal of Aircraft,51(3),pp.748-760.
2. Yang, H., Tsourapas, V., K, P., Yuan, Q et al (2009),Hardware In the Loop(HIL)Modeling and Simulation for Diesel After treatment Controls Development, SAE Technical Paper 2009012928, doi:10.4271/2009012928
3. Tino Schulze, JannEve Stavesand(2016,May,12-13), Hardware in the Loop Test Process for Modern E/E Systems, Springer International Publishing, 7th Conference, Berlin,pp343-360.
4. Renuka M. Kulkarni, Rohita. P. Patil, Chidambar Rao Bhukya(2016), Hardware–In–Loop Test Bench Based Failure Mode Effects Test Automation, International Journal of Innovative Research in Electrical, Electronics, Instrumentation and Control Engineering ,4(6),pp.217-220
5. Eckard Bringmann, Andreas Krämer(2008,April 9-11), Model-based Testing of Automotive Systems, International Conference on Software Testing, Verification, and Validation, DOI 10.1109/ICST.2008.45,pp.485-493
6. Giancarmine Fasano, Domenico Accardo, Lidia Forlenza, Alfredo Renga, Giancarlo Runo, Urbano Tancredi, and Antonio Moccia(2013),Real-Time Hardware-in-the-Loop Laboratory Testing for Multisensor Sense and Avoid Systems, International Journal of Aerospace Engineering, Article ID 748751.
7. Mr. Abhijeet Taksale, Mr. Vishwas Vaidya, Mrs. Priti Shahane, Mr. Goutham Dronamraju, Mr. Vivek Deulkar(2015,May, 28),Low cost Hardware-in-Loop for Automotive Application, IEEE International Conference on Industrial Instrumentation and Control (ICIC), pp 1109-1114.