Automation Testing and Validation of Electric Vehicles: A Review

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Abstract – *Electric vehicle usage is rapidly growing in the automotive domain. Electric vehicle comprises a number of Electronic Control Units (ECU). Open-loop or Closed-loop testing of each ECU is done in order to validate its functionalities. To deliver high performance and safe electric vehicles, its proper testing and validation is crucial before its use in the market. A lot of research is carried out in this regard. With the advances in the automotive industry, Automation testing methods are extensively progressing. This paper reviews some of the work carried out related to the approaches followed for electric vehicle testing like Model-in-loop (MiL), Software-in-loop (SiL), Hardware-in-loop (HiL) simulation technique, etc.*

Key Words: **Electric vehicle, Electronic Control Unit (ECU), Model-in-loop (MiL), Software-in-loop (SiL), Hardware-in-loop (HiL).**

1. INTRODUCTION

The utilization of electronic frameworks in automotive industry is ceaselessly growing, even at quicker pace. In contrast to the conventional vehicles, new models of hybrid and electric vehicles have more functionalities, intended to enhance the availability, security, drivability and comfort.

More vehicle functionalities implies increased number of electronic control units with additional complex programming. Because of the unpredictability and size of the control programming, it is necessary to utilize an advanced development procedure which will improve the general quality of the product, increment development effectiveness and dispense programming bugs.

V- Cycle is one of the conventional software development process utilized in the automotive domain [1]. The V model parts the software development process into a few stages that incorporates prerequisite definitions, programming configuration, plant model design, testing and validation processes. This can be seen in Figure 1.

Some of the testing methods include testing of model in Matlab/Simulink (Model-in-Loop), Modules testing using Software/Coding (Software-in-Loop), Testing for integrated ECUs (Hardware-in-Loop), etc.

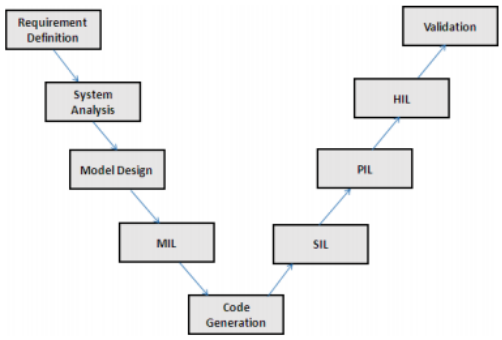

Figure 1: V-cycle process for automotive testing and validation

With the aid of these advanced testing and validation methodologies, it is feasible to test electric vehicles in hazardous circumstances / failure modes, where real traffic testing is difficult; and it is also viable to test certain real world safety test cases within an indoor environment mimicking real vehicle behavior.

This paper reviews some of the methods of autonomous vehicle testing and validation that ensures high performance, safety and reliability of electric vehicles.

2. LITERATURE REVIEW

The work proposed by Ili, Velibor, Srđan Popi, and Milan Kovači. [2] depicts methods for secure and automated data flow of ECUs testing procedure. In the explained testing method, it is prescribed to utilize the computerized testing conditions that creates definite reports about each fragment of tested ECU. The automation testing process decreases human errors done while manual testing. The automation testing is done with the help of programming languages. The test results are obtained in automatically generated Test reports in html, txt formats.

Ramaswamy, Deepa, et al. [3] utilized two sorts of simulation model designs to test ECU. The principal kind is known as Open-Loop Test Platform (OLTP) models that mimics just the low level input-output functionalities in the framework. The simulation of the physical plant is excluded from the OLTP. The subsequent kind, called Closed-Loop Test Platform (CLTP) models all the physical I/O functionalities along with plant I/O processing. Both testing designs discovered broad use in the controller improvement process.

Bringmann, Eckard, et al. [4] proposed TPT test approach for Model-based Testing of Automotive Systems. Model-based improvement caused an extreme change in automotive framework advancement. The need to test sooner, to test on different incorporation levels, under real-time requirements, with practical multifaceted nature, give interdisciplinary exchangeability, encourage consistent sign taking care of and numerous other aspects set elevated standards for testing systems, procedures, strategies and instruments. TPT is one test approach that encourages the plan, execution, evaluation, and report generation of experiments for automotive model-based frameworks. TPT experiments are compact, for example reusable on various test stages, for example, MiL, SiL, or HiL. TPT reinforces responsive tests and can be executed progressively.

Huang, WuLing, et al. [5] have described various approaches for autonomous vehicle testing such as Software Testing, Simulation Testing, X-in-the-loop Simulation Testing, Driving Test in Real Traffic, Autonomous Vehicle System Architecture, Autonomous Vehicle Functional Testing, Autonomous Vehicle System Validation Approach, Autonomous Vehicle Evolutionary Design and Test Flow, and Evolutionary Autonomous vehicle system testing methods.

Kocić, Jelena, and Harald Axmann [6] proposed a configurable and comprehensive simulation method for ECU testing. In this method CAN and K-Line physical protocols are utilized and this method is seen to be beneficial due to the flexibility of code used. Thus, the proposed ECU simulator method can be used to test all protocols present in the automotive diagnostic device. Hence rigorous testing can be carried out in order to verify the designs of vehicle for all the protocols.

Shruthi T. S. and KH Naz Mufeeda [7] presented the use of CANoe tool for testing of communication between Brake ECU and Electronic Stability Program. Manual testing of various ECUs in a vehicle becomes a tedious job; hence Vector CANoe tool is used for automated testing of ECU communication. Since this testing is done prior to the component production, rate of failure and manufacturing cost is narrowed. By using Vector CANoe setup, ECUs can be tested effortlessly and productively. CANoe tool gives precise estimation and test outcomes.

Tamás, György, et al [8] proposed a trial study for a virtual reality simulation for testing the behavior of automotive propulsion systems. Vehicle model is designed and linked to propulsion model in Simulink; Virtual Reality Environment (VRE) gives inputs to the model. The outcomes of this simulation show good feasibility of MiL testing in the beginning phases of development process. The setup consists of a Simulink model for automotive propulsion system, a Unity3D practical environment and TCP/IP protocol connection. These demonstrations show that utilizing MiL in vehicle development can reduce time consumption and cost in prototyping stage. Further HiL process is carried out in which controller, sensors, battery and other necessary components are tested. The outcomes of HiL testing are used to upgrade MiL testing.

To resolve the manual testing errors in automotive domain Jeong, Sooyong, and Woo Jin Lee [9] proposed SiL (Software-in-loop) simulation that is an automated software testing method for AUTOSAR software components. The integration of automated testing equipment to the SiL simulator is proposed, that automatically generates SiL simulation results. Test case conversion methods are utilized for automation. A case study is carried out using automation testing for auto-braking software of the vehicle and its outcomes shows proficiency of the proposed automation testing method.

The work proposed by Ahamed , Fasil, et al. [10] centers around the Software-in-loop (SIL) simulation and validation which was created in Gazebo utilizing Robotic Operating System (ROS). The objective is to fill in as a stage to make numerous vehicle models and help clients to approve and look at the various algorithms for several models. This work also demonstrates in detail the technique to make a vehicle model and a custom condition to show the proficiency of the proposed system. The outcomes of the experiments show the effective usage of the system in a custom domain.

Hansen, Norman, et al. [11] presented a tool called Arttest that tests the functioning of block diagrams created in Matlab/Simulink. Using closed-loop testing concepts, signal specification language/scripts, test implementation is created and further along with Simulink blocks model-in-loop and software-in –loop tests are carried out with Arttest.

Stahl, Konrad, et al. [12] presents hardware in the loop (HIL) testing approach for research in dynamic vehicle security frameworks. The framework comprises of a PC simulation of the vehicle and the vehicle environmental factors. A steering system with a real time ECU and sensor equipment is hardwired in the close control loop. Steer controlling by both driver and actuator is taken into the simulation environment and then the stability, performance and safety of vehicle is tested and validated.

Taksale, Abhijeet, et al. [13] proposed a novel minimal effort approach in HiL testing dedicated to an on-street electronic speed limiter of a business vehicle. This approach incorporates a vehicle model simulation to validate control logic of ESL framework and testing of ESL framework with an actuator based electronic throttle control as device under test. The created HiL articulates an actual emulator that mimics as per inputs and give results similar to that of a real vehicle plant. The test outcomes help in investigating execution of actuator utilizing different driving cycles. HiL tests are carried out in a reproducible, controllable and effective approach to recreate a real time conditions similar to outside test situations.

Hongyu, Wang, et al. [14] proposes an electric vehicle control approach based on HiL simulation technique that is tested on Wei Chai Motor's SUV model called ENRANGER G3. A HIL setup is developed with precise mathematical models, unique HIL control boards in which the plant models run and real ECUs for controlling devices. This setup enables the controlling devices to reflect realistic behaviour in order to test and validate the target ECUs. The outcomes show that the HIL setup decreases development time and exertion by enhancing the standard of controlling methodologies.

Haupt, Hagen, et al. [15] proposed "Hardware-in-the-Loop Test of Battery Management Systems". Testing with HIL test systems has become a standard methodology in ECU advancement. Creating HIL test systems for battery management frameworks caused new difficulties for HIL gadgets and real time models. dSPACE has built up a battery cell voltage imitating board that recreates cell voltages with high accuracy and furthermore has adequate current sink and source ability to permit latent and dynamic cell balancing on the HIL test system. The new multi-cell battery models reproduce the fundamental static and dynamic impacts of the cells and are real-time proficient.

Bagalini, E. and M. Violante [16] proposed a simulation framework for HIL and fault injection methods for approval of control procedures in injection control ECUs. When applied to a genuine use case, the proposed framework lessened testing exertion up to 90% when compared with manual tests. The framework consolidates off-the-shelf equipments with specially crafted motor models that combine minimal effort, precision and computational productivity. In such a way, safety prerequisites can be fulfilled in a brief timeframe decreasing time to market by utilizing a programmed approach that is feasible small land-medium enterprises (SMEs).

Vo-Duy, Thanh, et al. [17] proposed a signal hardware-in-the-loop model of electric vehicles that incorporates driving framework and vehicle model running continuously in dSPACE-DS1103 control card. All the necessary conditions of the electric vehicle are observed in Matlab/Simulink platform. The model is tested and approved by running necessary test cases.

In the proposed work by Ma, Jiaqi, et al. [18] a hardware-in-the-loop (HIL) testing framework for Connected and Automated vehicle (CAV) applications is proposed. This study develops a HIL proof-of-concept testing prototype for CAV applications in a vehicle-to-vehicle (V2V) environment. The outcomes of this study include building up a HIL testing design for V2V-based CAV applications, implementation of the proposed HIL architecture, building up a model and testing Cooperative adaptive cruise control (CACC) as the chosen use case to observe the HIL framework execution.. This work contributes to a better understanding of CACC string performance.

Li, Bo, et al. [19] assembled a test stage dependent on LabVIEW to test Vehicle Control Unit (VCU) and Battery Management System (BMS) and the control methodologies of the fabricated test stage are tested by various experiments. Utilizing equipment items, information obtaining, CAN communication, fault injection and signal modelling, the HiL setup is established. In this framework, real time vehicle model and the battery model are created by Simulink, and with Load simulation units, a vehicle simulation condition is built up. It is demonstrated that VCU and BMS run well on the HIL test stage, meet their test prerequisites and the combined diagnosing capability towards VCU and BMS is confirmed.

Nibert, Jonathan, et al. [20] presented multi-stage model development approach for vehicle testing. In this approach, a model is passed through the diverse advancement phases of MIL, SIL, and HIL without keeping up various variants of the full model. Rather, just lightweight variants containing only the interface layers should be separated. Hence, keeping up variants is made simpler since just a little subsection of the model has to be changed between variants. Also, it guarantees probity of the control logic since the practical layer can be decoupled from the interface layer and hence it is equivalent in all variations of the model, regardless of the equipment conditions identified with interfacing.

Nalic, Demin, et al. [21] presents a methodology and execution of a virtual structure for testing and approval of Automated Driving (AD) systems. The created structure comprises of an extensive traffic flow model which is adjusted with real traffic estimations. This guarantees a realistic traffic condition where any AD framework can be tried with a high number of extensive traffic situations utilizing a Matlab GUI along with the simulation among CarMaker and VISSIM. In view of these real traffic situations a number of real traffic situations can be created and utilized for testing AD vehicles. This methodology is exhibited for a Highway Chauffeur work and permits future systematic testing.

Ciceo, Sebastian, et al. [22] proposed model-based structure and testing technique concentrating on the electric vehicle driveability perspective. The procedure is classified in 2 steps. First step is the MiL co-simulation along with electric drive which is modeled in MATLAB/Simulink. Second step is HiL simulation in which physical and plant model electric drive are integrated in real time. The co-simulation approach is favored because of the upsides of joining control designing given by MATLAB/Simulink and framework building given by LMS Imagine Lab Amesim in development stage, and the simplicity of coordinating both the control and framework model in the HiL testbench for verification reason.

3. CONCLUSION

This paper highlights the significance of testing, verification and validation of electric vehicle to deliver its high performance and safety and describes various works carried out in this regard. After a comprehensive review, it is seen that Open-Loop Test Platform mimics just the low level input-output functionalities in the framework excluding the simulation of the physical plant; whereas Closed-Loop Test Platform models all the physical plant behaviour in addition to the I/O processing, hence Hardware-in-Loop concept is preferred as it allows the tests of controllers creating a real vehicle behavior within an indoor environment. Hardware-in-Loop simulation allows to check how controller responds in real time.

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