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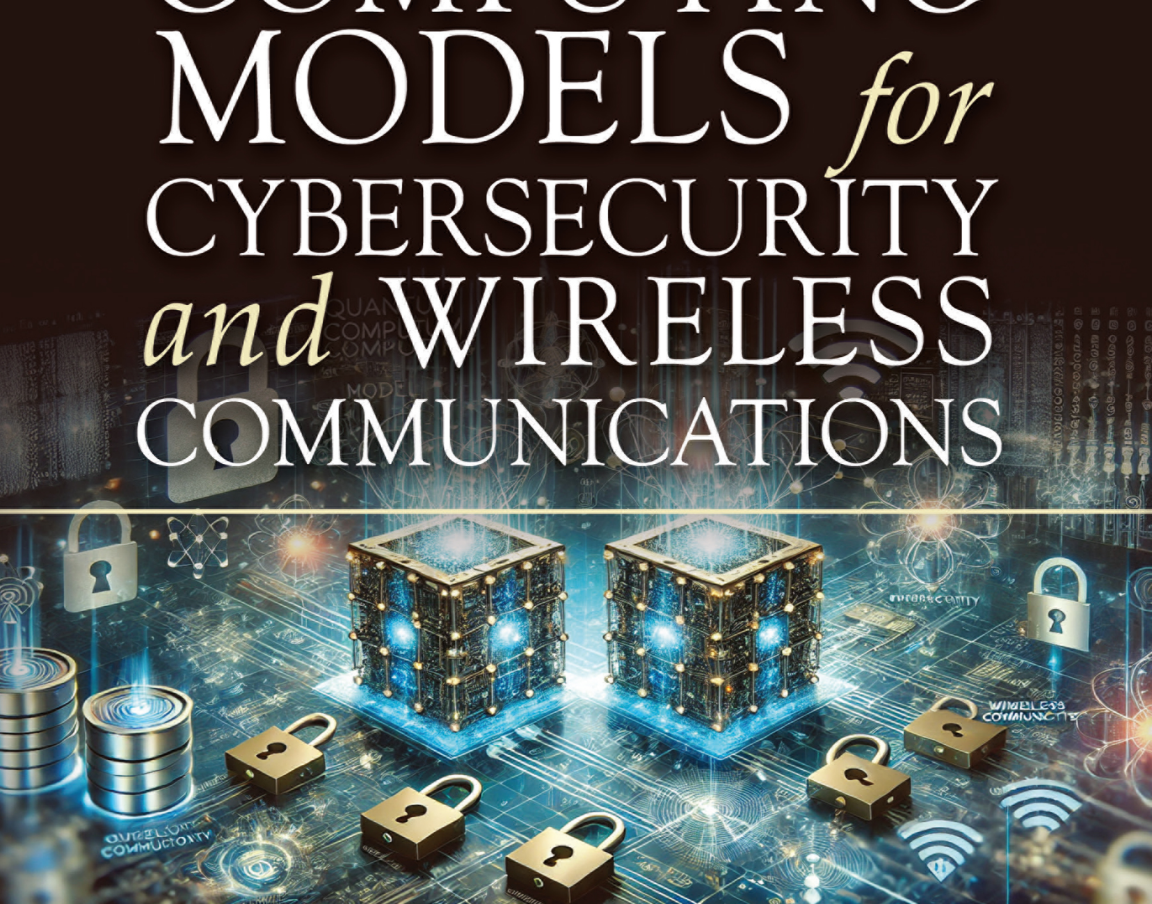

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Quantum Computing Models for Cybersecurity and Wireless Communications

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Contents

Preface

Artificial intelligence, cybersecurity, and practical cryptography are just a few of the areas where quantum machine learning has the most potential. Advanced data encryption techniques are urgently needed as our growing reliance on the internet exposes us to threats brought on by cyber-attacks. Although many current encryption standards may not be breakable by current quantum-based machines, it is vital to keep ahead of the impending threats and prepare for sophisticated cyberattacks using quantum-proof solutions. The difficult issues that classical computers are unable to address, such as the techniques employed in data encryption, can be solved by quantum computers. Modern encryption techniques are based on mathematical formulas that would be impractically difficult for traditional computers to decrypt. Working tirelessly to create quantum-secure encryption techniques is the research goal. One possible method is for securely transferring a quantum key between two endpoints that makes use of the quantum physics qualities known as quantum key distribution (QKD). Before recent developments, this technique could only be used with fiber optic connections, but now quantum key transfer is also possible over the Internet. Although there are still many unsolved problems concerning quantum computing, it is evident that present methods of cybersecurity and encryption are at risk. We need to adapt the way we safeguard our data and take a defense-intensive strategy characterized by many layers of quantum-secure security to lessen the threat. To protect themselves from potential quantum threats, security-conscious organizations are actively looking for quantum-ready encryption solutions, including those provided by Quantum Exchange.

Future quantum machines will exponentially boost computing power, creating new opportunities for improving cybersecurity. Both classical and quantum-based cyberattacks can be proactively identified and stopped by quantum-based cybersecurity before they harm. Complex math-based problems that support several encryption standards could be quickly solved using quantum machine learning. The traditional cryptography standards on classical computers, which rely on difficult mathematical calculations like prime factorization, would take millennia or more. However, these issues might be resolved by quantum machines in a manageable amount of time. Despite the lack of widespread commercial quantum devices, it is wise to plan for quantum-based cybersecurity difficulties and deal with present restrictions. The security and privacy of commercial organizations will greatly increase as a result of this preparation. For instance, today's adversaries could penetrate private networks. When large-scale quantum machines are made commercially available in the future, this enormous computational capacity could be used to undermine networks and infrastructures by decrypting critical data. Quantum machine learning-based cybersecurity, especially in the context of quantum computing and quantum chaotic characteristics, presents stronger and more exciting chances for protecting important and sensitive information by outpacing these possible attacks. Through book chapters, academics, researchers, and scientists have contributed their ideas, concepts, and use cases on cutting-edge technologies like blockchain, quantum machine learning, cybersecurity, IoT, and SDN. The main purpose of this book is to publish the latest research papers focusing on problems and challenges in the areas of data transmission technology, computer algorithms, artificial intelligence (AI) based devices, computer technology, and their solutions to motivate researchers.

This book serves as a ready reference for researchers and professionals working in the area of quantum computing models in communications, machine learning techniques, the healthcare industry, and IoT-enabled technologies.

Acknowledgment

We, the editors of the *Quantum Computing Models for Cybersecurity & Wireless Communications,* wish to acknowledge the hard work, commitment and dedication of the authors who have contributed their wonderful chapters to our edited volume in the stipulated time.

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We wish to bestow our best regards to all referees for providing productive comments to the authors to improve their chapters to meet the required standard. A successful book publication is the integrated result of everyone's contribution and not just those named as editors or authors.

Finally, the editors acknowledge everyone who helped us directly and indirectly.

Budati Anil Kumar
Singamaneni Kranthi Kumar
Li Xingwang

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Performance Evaluation of Avionics System Under Hardware-In-Loop Simulation Framework with Implementation of an AS9100 Quality Management System

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Abstract
Performance evaluation of avionics subsystem is mandatory before the deployment of the system. In the aerospace and defense industry it is critical to validate the embedded system software along with the flight subsystem in real time before real launch. The launch of the flight vehicle is single shot operation and involves so many factors. To avoid the catastrophic failures due to errors in algorithms, subsystems integrated working under real time, it is essential and mandatory to validate the software using Hardware-In-Loop Simulation (HILS) platform. This is unique platform that evaluate the performance of mission software i.e. control and guidance software using different criteria and conditions. This is cost effective tool to evaluate the performance for the expensive flight trial and using its rapid prototyping technique designer can validate their software in early stage of development. Development of AS9100 Quality Management System (QMS) in the HILS process is essential and inevitable part of avionics design to improve the process. This paper focus on the embedded system testing, validation, and certification area. The HILS test-bed designed as part of performance evaluation, different configuration of the HILS for centralized and distributed architecture, test plan for all software test cases with different perturbation cases. The lifecycle of the HILS process is explained in details with respect to AS9100 QMS requirements and implementation. Development of HILS test-bed for centralized and distributed

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architecture configuration is explained in details. The results are discussed and the conclusion and suggestions for future improvement are discussed in last section.

***Keywords*:** 6Dof plant model, hardware-in-loop simulation, inertial navigation system, on board computer, OBC-in-loop, quality management system

1.1 Introduction

Performance Evaluation of avionics system specially used in aerospace vehicle is essential and critical task that ensure the success rate of developmental flight trial. The evaluation of the On-Board Computer (OBC) mission software along with the integrated flight hardware is carried out using the unique Hardware In Loop Simulation Test-bed [1, 2]. There are number of steps involved in testing phase of HILS. Design of the test-bed, development of the simulation software, testing of the OBC software. All the errors or deficiency related with mission software has been validated in HILS with number of test cases. Unit level testing carried out by the developer is not sufficient to test system completely. This unit testing only verifies the system independently working as per design. The integrated level testing and user acceptance testing is performed at HILS as shown in Figure 1.1. This testing highlights the design issues like lags, communication delay, bandwidth etc. for the individual system when it is integrated with other sub-systems.

In the total product life cycle of software development HILS is important phase for the validation and testing of avionics system is shown in Figure 1.1. HILS consists of both Hardware and Software parts: Simulation computer based on the configuration of the avionics system that is helpful to select the I/O cards of the system like MIL-STD 1553 cards, ADC cards, DAC cards and RS-422 cards [7]. The second part is the 6Dof software development part based on the Real Time Operating Systems. The problem is that the HILS process has many branches and there is no process control. It has been experienced the delay and ineffectiveness in the early stages of the HILS. It was highly essential to establish a stepwise process with the effectiveness

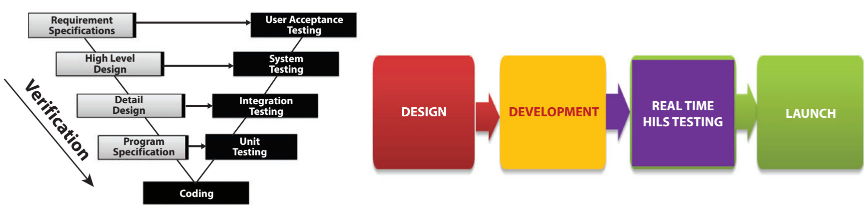


Figure 1.1 Testing phases of software and the avionics product lifecycle.

and timely delivery of the product from HILS. So more focus and effort has been given to develop unified HILS process that will be stepwise process with the effectiveness of the Quality Management System for ensuring the timely completion of the process. The process of HILS is covered under the Aerospace Standard AS9100. The problem is to develop the methodology that defines the scope of the HILS process that is critical part of the project cycle to evaluate the performance of the software and flight hardware in integrated mode. This paper has given the detail explanation about the development of HILS process and the development of AS9100 QMS standard that is adopted for this process that has been bonded together first time to achieve the quality objective for the HILS as well as at the laboratory level to be recognized as global level. First the concept of the performance evaluation is explained with HILS Configuration, then the development of control i.e. Test plan, Test cases, Test results followed by induction of AS9100 quality absorption to HILS activities. The Key Performance Indicator (KPI) that shows the effectiveness of the concept of development of QMS at process level and the performance of the HILS according to that is discussed at the end with conclusion and suggestion at the end.

There are White Box Testing and Black Box Testing. White Box testing only verify the algorithm by visual inspection or flow chats. Performance evaluation is also called as the Black Box testing methodology that execute the algorithm and evaluate that the development is meeting the goals of design. This uses the input design specifications and parameters and measure output generated after execution of the software in real time. Hardware-In-Loop Simulation Framework is unique setup that is used for the performance evaluation of the Avionics system for both centralized architecture as well as distributed architecture.

Centralized Architecture

In this scheme all the algorithms are built using single processor with On Board Computer is shown in Figure 1.2. All the required interfaces are controlled by the processor. The sub systems are mainly electro mechanical that do not have any processing or computing unit inside the subsystem.

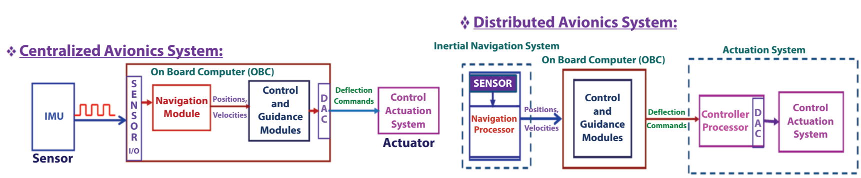


Figure 1.2 Centralized and distributed architecture of the avionics system.

Distributed Architecture

There is processor available in each subsystem and the data processed inside the subsystem itself is shown in Figure 1.2, e.g. in the case of Inertial Navigation System, the raw data gyros and accelerometers samples are processed inside the INS unit and the processed data i.e. positions, velocities, rates, accelerations, quaternions are posted to the OBC at regular interval. Similarly actuator setup has their own processor to process the deflection commands and send back the feedback information about the actuator at regular interval.

The challenge is to establish testing methodology for both architecture and the develop the uniform methodology in this area. The recent research paper has been studied for the development of the process effectiveness. Paper title "Development of Hardware-In-Loop Simulation Test-bed for testing of Navigation System-INS" by Rajesh K & B Ramesh Kumar explain the testing methodology for INS. It is limited for INS system only. Another paper titled "On joint hardware-in-the-loop simulation of aircraft control system and propulsion system" by Yao Zhao explains about the HILS system of the aircraft system. The development of the process for timely completion of the HILS activities and control for the effectiveness monitoring of the process paper is essential to help the researcher and engineers to have a layout of methodology for future experiments in this area.

1.2 HILS Process and Quality Management System

There are many AS9100 is Quality Management system for Aviation, Space and Defence industry released by International Aerospace Quality Group (IAQG). AS9100 Quality Management System goes hand to hand with each process of the Aerospace Research and Development Laboratory. After the Design and Development phase is finalized then the simulation and testing of the subsystem in integrated mode has been initiated. HILS process is the part of testing of the product and covered under QMS. Four Major processes has been defined and covered under QMS.

- HILS Planning and Configuration Management.
- Development of the HILS Setup
- OBC Software Validation
- Hardware In Loop Simulation.

A. HILS Planning and Configuration Management

Planning is crucial as all the schedule of the further testing and real launch depends on the HILS planning as shown in Figure 1.3. In parallel with the

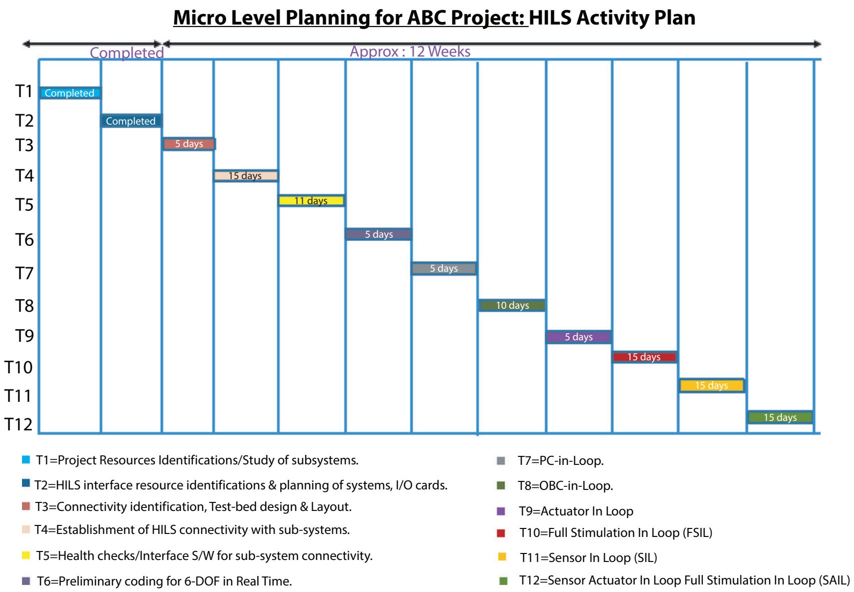


Figure 1.3 Planning of HILS activities of the project.

development cycle, development of HILS testbed, planning of test cases and HILS testing is established. Test-bed development focuses on the configuration, Timeline required and the HILS test cases for the mission software validation. Development of HILS testbed and development of simulation software mainly depend on the avionics configuration, Interface Control Document (ICD) of each sub-system and interface communication protocol of different sub-systems. This all together is covered under the HILS configuration and planning.

B. Development of HILS Test-Bed

Generally, the design and configuration of the HILS Setup is based on the avionics system used for the aerospace vehicle. The process block diagram is shown in Figure 1.4. The data acquisition system based on popular communication protocols, MIL-STD 1553, RS-422, ADC, DAC, and Digital Input/Output. These all the I/O systems are integrated with the HILS System for the configuration of Simulation System. Application layer of the simulation computer is plant model algorithms. Two different configurations have been designed and developed for Centralized architecture of avionics system and distributed architecture of the avionics system. The 6Dof equation that is part of simulation system is developed using the mathematical model [4] and under the real time operating system [7].

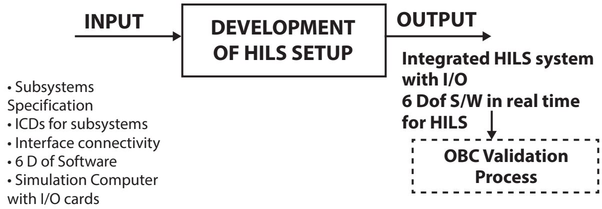


Figure 1.4 Development of HILS setup" HILS QMS process.

The other supporting modules like thrust, aero, interpolation computational algorithm has been developed using real time operating system and high-level software language. This integrated plant software is tested using the input data provided by the designer. The output data that is generated after execution of the HILS run that is controlled process. Mainly the 6Dof parameters i.e. three rates and accelerations are compared with the designer data. Here, the process coverage focuses on the coding standard, white box testing as a part of algorithm verification and the output parameters.

C. OBC Software Validation

The Second process is the OBC software validation. The Control and Guidance (C&G) algorithm are developed with On-Board Computer [8]. The execution time, lags, transportation delay issues get addressed in HILS by execution of OBC software [5]. The water fall methodology as per the software engineering is followed for the testing of the OBC software is shown in Figure 1.5. The iterative software is tested and the observation has been given to the developer to improve the code. This in the iterative

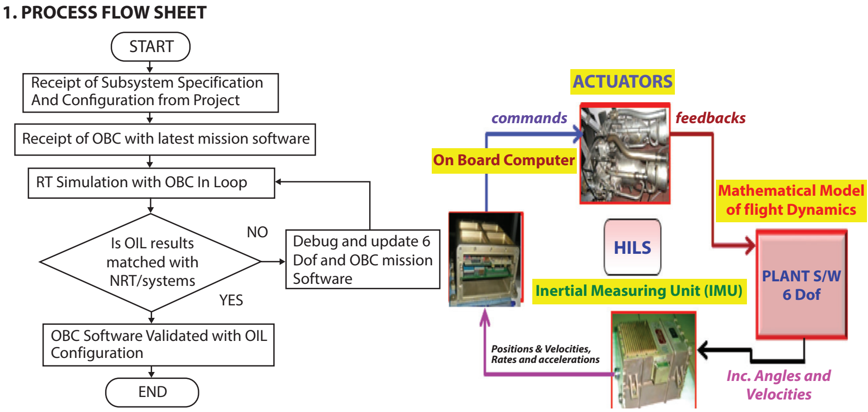


Figure 1.5 "OBC software validation" process flow.

process this testing has been carried out. Only OBC software and hardware is validated in OBC-In-Loop in initial phase of HILS process. Other flight subsystems i.e. INS and actuators are simulated in plat model. Plant model execute the INC and Actuator simulator based on mathematical model of the sensor and the actuator model. The HILS simulation is developed under Real Time Linux operating system [14].

1.3 HILS Testing Phase

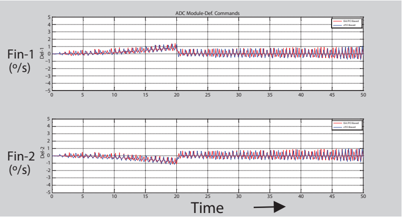
Final phase of HILS testing is carried out in step-wise manner. After the validation of OBC-In-Loop, in stepwise manner flight hardware is introduced in HILS for their hardware and software validation [11].

- *Actuator-In-Loop (AIL)*: In the case real actuators are integrated and the performance of the actuator dynamics is validated [3]. The parameters like lags, bandwidth and the dead zone related with Actuator is validated and rectified in AIL [9, 10].
- *Full-Stimulation-In-Loop (FSIL)*: INS consists of two parts: sensors and Navigation algorithm. In FSIL only navigation algorithm of INS is validated. This is type of static test with bypassing the real sensor and only stimulated data is sent to INS to validate the navigation algorithm [6].
- *Sensor-In-Loop (SIL)*: INS sensor performance is validated. The INS/IMU experience three directional rotation by the HILS Flight Motion Simulator (FMS). According to the trajectory dynamics, rotations by 6Dof plant model has been sent to FMS with the three directions simultaneously. This Gyros rotate and send the information to OBC for the validation of C&G algorithm [6].
- *Sensor-Actuator-In-Loop (SAIL)*: This is the final stage of the HILS validation process. Flight hardware Actuators as well as INS are integrated in HILS as per the communication interfaces. Both subsystems are executing their algorithm simultaneously. The integrated performance in real time is validated [10].

Number of test cases has been generated to test the robustness of the software as well as system is tabulated as per Table 1.1. These test cases has been performed in different conditions and in different configurations.

Table 1.1 Test cases of HILS for OBC software.

	Non Real Time Runs (NRT)	OBC In Loop (OIL)	Full Stimulation In Loop (FSIL)	Sensor In Loop (SIL)	Sensor Actuator in Loop (SAIL)
Case-1	OK	OK	OK	OK	OK
Case-2	OK	OK	OK	OK	OK
Case-3	OK	OK	OK	OK	OK
Case-4	OK	OK	OK	OK	OK
Case-5	OK	OK	OK	OK	OK



Input data like Thrust profile, stability related parameters changed to see the impact on the simulation. These cases are tabulated in Table 1.1. These perturbation cases are defined as Case-2 to Case-5 with variation in input conditions. Nominal case is as per design and called Case-1.

Embedded system testing has been performed under HILS platform to test the hardware and software. After the extensive testing the flight subsystem and final software integrated with the aerospace vehicle. Simulation runs generates the output data and that has to be validated with the designer parameters/results. This is required to confirm the proper execution and software of the control and guidance algorithm. The standard deviation from the design results should not be more than the tolerance limit with all the factors like delays, bandwidth, and bias taken into account

After the results found to be satisfactory, the software is integrated with flight vehicle and proceeded for the real test.

1.4 AS9100 QMS Integrated with HILS Process

HILS testing is final clearance after the software development phase. This is iterative process that means the software errors or improvements has been modified and in the next release version software treated as final one. For every software version, all the test cases are performed in HILS and the data is captured for the analysis.

During the total span of HILS testing, if there is no controlled procedure or layout with plan and configuration then there is huge impact on the further schedule. Hence development of stepwise HILS methodology with the development of AS9100 QMS procedures cover all the aspect of the HILS process. This enables the on time delivery of the tested mission software for deployment that is real launch for user acceptance.

At the AS9100 certified Research and Development Laboratory level, Apex manual is the reference for the QMS standard. At every process level, Function Manual is the main reference document that explains all the aspect of process. All the process, responsibilities for the process, input required for the process/activity, output of the process, KPI of every activity is covered in the systematic form in function manual. The calibration of the equipment used for measurement is required and done at regular interval. The major critical machinery and equipment installed in HILS have to be maintained with all the records and logbooks [12]. QMS with HILS process integrated with each step/activity in such a way that the effect of the implementation of QMS only resulted in better and timely output. Different records are maintained for the functionality and traceability of HILS process.

Version Control and change control Management: Software version control is mandatory. Software undergoes many changes based on the requirement of the configuration. Many times, software change has also been done due to HILS observations. The software version with checksum and release date is maintained in HILS along with the change note. In the case of distributed architecture, version control is maintained for each and every subsystem and the HILS runs are carried out with final software version.

Configuration Management: Different configuration is used for HILS like OIL, AIL, FSIL, SIL, and SAIL etc. All the details are controlled under configuration Management [7, 6].

HILS planning, Reports, and Logbook: HILS planning document is available at the initial level of the project to brief about the configuration, planning, and test cases.

Key Performance Indicator and customer Feedback: KPI is defined milestone of each HILS process achieved during the total cycle of HILS testing of the project. The KPI in the below graph showing the data analysis

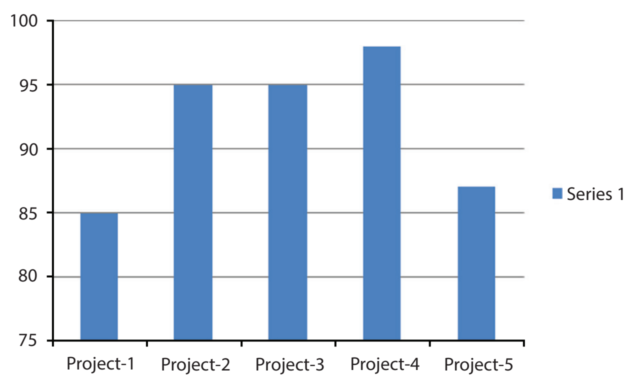


Figure 1.6 KPI and Customer satisfaction index for different projects.

of projects running in HILS based on the customer i.e. project and the KPI achieved during the process. It is shown in the Figure 1.6 that for every project almost HILS process performance is more than 85 % that shows the QMS importance and implementation level.

1.5 Conclusion and Suggestions

Embedded System testing, validation, and certification process has been carried out systematically in HILS and explained in detail in this paper. Performance evaluation in the real time is carried out using HILS in real time that is unique facility for aerospace applications. It is cost effective and rapid prototype test setup that is used to address any design issues before real launch and improve success rate of real launch. The significance of this paper is to explain about the Embedded system's testing, validation and QMS process developed during HILS as scope of the HILS is more border with software and hardware are involved in HILS process. The systematic approach after QMS has improved HILS process significantly and the HILS runs are done in short span of project time cycle. AS 9100 QMS development and implementation for aerospace industry goes hand to hand during project cycle for effective completion of the project. This paper focused on HILS process and the development and implementation of the AS9100 QMS for HILS. The paper covered all the HILS processes, development of HILS Test-bed to validation and testing of mission software and implementation of QMS to each of these sub process. The adoption of QMS in the HILS process improved the performance of the HILS process in recent years and the data shown in this paper shows that the objective of HILS process has been met by development of AS9100. In future the QMS standard specifically developed for HILS will be developed specifically focus on HILS for the significant improvement and global recognition of HILS Laboratory.

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