Implementation of Test Automation for Data Center Automation System

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BACHELOR'S THESIS

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Abstract

This Bachelor's thesis was commissioned by ABB Oy Distribution Solution unit. The Data Center Automation System is an automation system that controls a switchgear automatically. The system is designed according to the IEC 61850 standard in terms of architecture and communication. This thesis is focused on the Test automation which is the application that is used for automated testing of the system.

The purpose of this thesis is to study and implement a Test Automation for Data Center Automation system. The Test Automation is based on ABB's PLC AC500 and the ABB Zenon software, which is used for automated testing.

The thesis covers various aspects of the Test Automation, such as Test automation levels, test case management, test case documentation and reporting, and maintainability. This thesis also partly covers implementation of the Test automation (reporting) in a customer project.

As a result of this thesis, various levels of Test Automation were defined. Further, a report was designed, configured and implemented using report viewer functionality in the ABB Zenon software, from which the reports can be exported into PDF and Excel files. Finally, a break-even analysis was carried out, in which manual testing was compared against several use-cases of automated testing.

Language: English
Key words: Test automation, automated testing, levels of automation, SCADA

EXAMENSARBETE

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Inriktning: Automationsteknik
Handledare: Roger Mäntylä, Mikael Snickars, Mika Rajaniemi

Titel: Implementering av automatiserat testsystem för Data Center Automation System

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Datum 19.4.2021 Sidantal 20

Abstrakt

Detta examensarbetet har beställts av ABB Oy Distribution Solution. Data Center Automation System är ett system som styr ställverk automatiskt. Systemet är utformat enligt IEC 61850-standarden beträffande arkitektur och kommunikation. Detta examensarbete fokuserar på det automatiska testsystemet, som är applikationen som används för automatiserad utprovning av Data Center Automation System.

Syftet med examensarbetet var att studera och implementera ett automatiskt testsystem för Data Center Automation System. Det automatiska testsystemet baseras på ABB:s PLC AC500 och ABB Zenon-programvaran, som används för automatiserad testning.

Examensarbetet täcker olika aspekter av det automatiska testsystemet, såsom olika grader av automatisering, testfallshantering, testfallsdokumentation och rapportering, samt underhåll. Denna avhandling täcker också delvis implementering av det automatiska testsystemet (rapportering) i ett kundprojekt.

Som ett resultat av detta examensarbete definierades olika grader av automatisering. Vidare designades, konfigurerades och implementerades en rapport med hjälp av rapportfunktionaliteten i ABB Zenon-programvaran, från vilken rapporterna kan exporteras till PDF- och Excel-filer. Slutligen genomfördes en break-even analys där manuell testning jämfördes mot flera fall av automatiserad testning.

Språk: engelska
Nyckelord: testautomation, automatiserad testning, nivåer av automatisering, SCADA

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Tiivistelmä

Tämän opinnäytetyön toimeksiantaja on ABB Oy Distribution Solution -yksikkö. Datakeskuksen automaatiojärjestelmä on automaatiojärjestelmä, joka ohjaa kojeistoja automaattisesti. Järjestelmä on suunniteltu IEC 61850 -standardin mukaisesti arkkitehtuurin ja kommunikaation suhteen. Tämä opinnäytetyö on keskittynyt testausautomaatioon, joka on sovellus, jota käytetään datakeskuksen automaatiojärjestelmän automaattiseen testaukseen.

Opinnäytetyön tarkoituksena oli tutkia ja toteuttaa testausautomaatiota datakeskuksen automaatiojärjestelmälle. Testiautomaatio perustuu ABB:n PLC AC500:een ja ABB Zenon -ohjelmistoon, jota käytetään automaattiseen testaukseen.

Opinnäytetyö kattaa testiautomaation eri näkökohdat, kuten testiautomaatiotasot, testitapausten hallinnan, testitapausten dokumentoinnin ja raportoinnin sekä ylläpidettävyyden. Tämä opinnäytetyö kattaa myös osittain (raportointi) testiautomaation toteuttamisen asiakasprojektissa.

Tämän tutkielman tuloksena määriteltiin testiautomaation eri tasot. Lisäksi raportti suunniteltiin, konfiguroitiin ja toteutettiin käyttämällä raporttien katseluohjelman toimintoja ABB Zenon -ohjelmistossa, josta raportit voidaan viedä PDF- ja Excel-tiedostoiksi. Lopuksi tehtiin kannattavuusanalyysi, jossa manuaalista testausta verrattiin useisiin automaattisen testauksen tapauksiin.

Kieli: englanti
Avainsanat: testiautomaatio, automaattinen testaus, automaation tasot, SCADA

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1 Introduction

This bachelor's thesis was written for the Data Center Solution in Distribution Solution department at ABB Oy. The task was to study and analyze automated testing of Data Center Automation system. The thesis includes a theory part and an implementation part which mostly consists of configuring the ABB Zenon project.

1.1 Purpose

The purpose of this thesis is to study and investigate different means to standardize and enhance the development model considering testing and test automation of Data Centre Automation system. The following aspects have been considered during the study:

- Test Automation levels,
- Test case management,
- Test case documentation and reporting,
- Maintainability

The focus of this thesis is to study how it would be possible to apply different levels of Test Automation to the automation system. The study will investigate the possible benefits by introducing different levels of Test Automation system. This thesis also partly covers the implementation of the Test Automation (reporting) in a customer project.

1.2 ABB oy

ABB is a leading global technology company and one of the world's largest engineering and networking companies. ABB is a result of a merger between Allmänna Svenska Elektriska Aktiebolaget (ASEA) and Brown, Boveri & Cie (BBC) in 1988.
ABB focuses on four business areas: electrification, process automation, motion, robotics, and discrete automation. Electrification area provides lots of products for example distribution automation digital solutions and data center solutions. Process automation provides the solutions for process and hybrid industries for example control technologies and marine and turbocharging. Motion area provides drives, motors and generators and mechanical power transmission. Lastly, robotics and discrete automation provides different solutions for robotics, machine, and factory automation.

1.3 Data Center Solution

Data Center solutions offers intelligent solutions for the data center electrical distribution system for example, intelligent grid connection, data center power distribution, data center power protection, data center smart automation and data center cooling system.

2 Theory

This chapter will explain the theory information which is related to this thesis. This includes an explanation of a switch gear control system, SCADA (Supervisory Control and Data Acquisition) system, automated testing, regression testing, test level, levels of automation and test case specification and test logs according to IEEE standard 829.

2.1 Switchgear control system

The switchgear consists of switches, circuit breakers, relays etc. that can be closed or opened in both normal and abnormal conditions. The functions of the switchgear are to monitor and measure the power system, to switch the power system on, to switch off the power and to isolate the false section from the rest of the network (Singh, 2009).

According to the IEC 61850 standard, all manufacturers can be adapted to the ethernet technology for substation automation communication which includes the related data modelling of protection and control functions (Starck;Wimer;& Majer, 2013).

Substation Automation is an automatic control system that enables the remote control of a substation. A SCADA system is used for controlling the commands from remote users to control devices in the systems. The Substation automation system has three levels which are station level, bay level and process level (V;L;& R, 2016).

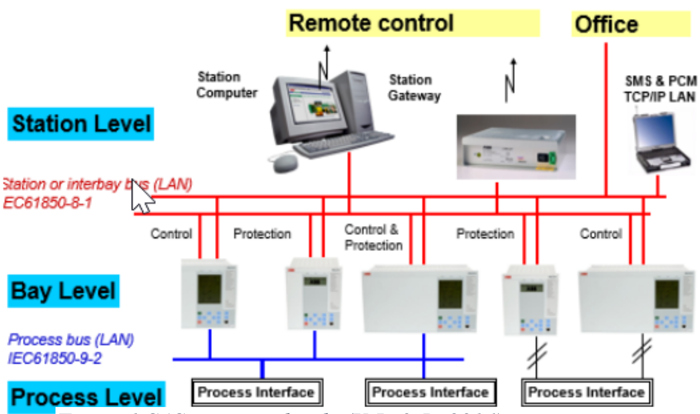

Figure 1 SAS structure levels (V;L;& R, 2016)

The process level in Figure 1 consists of all the power-system devices which are connected to the IEDs (Intelligent Electronic Devices) in bay level for controlling and protection. In the bay level, the IED's functions are to control, monitor and protect. The highest level according to (Substation Automation System, 2016) is the station level. This level enables local or remote station control through the SCADA system.

2.1.1 PLC

Programmable Logic Control (PLC) is a microprocessor-based controller which used in a wide variety of automation systems and processes. The main components in PLCs are input- and output-modules and the CPU (Central processing unit), which is executing the application software. The function of PLCs is to monitor the input's status, execute the programs as instruction and then carry out commands via the output modules. PLCs and computers are typically similar to each other except PLCs are developed for controlling the tasks but computers are developed for calculating and displaying the tasks (Bolton, 2015). Figure 2 shows an example of PLCs.

Figure 2 Examples of PLCs (ABB, 2021)

2.1.2 Soft PLC

Soft PLC or Software PLC uses a PC (Personal Computer) as a platform to control the system as a traditional PLC. Soft PLC can be used for two purposes; software development and actual execution of software. There are three kinds of implementation versions of the Soft PLC controlling the system which are traditional PLC, control scheme based on embedded controller and control scheme based on industrial computer.

The traditional PLC is a hardware platform that customizes PLC to run the system. The embedded controller scheme is a software platform with embedded operating system, which can be applied as a small real-time controller. Lastly, the industrial computer scheme is a combination of software and hardware platform that makes it easy to build bus control systems and network control systems. Soft PLC running the system, administrate the whole system, exchange data, and clarify the program (Liang & Li, 2011).

2.1.3 IEC 61850 Communication

IEC 61850 is an international standard that defines communication protocol for substation automation systems or between different intelligent electronic devices (IEDs). IEC 61850 also guides design, development, construction, and maintenance for the substation automation system (Yuan & Yang, 2019). IEC 61850 contains several parts that define different aspects of the substation communication network (Mackiewicz, 2006), such as:

- IEC-61850-6: Configuration description language for communication in electrical substations related to intelligent electronic devices (IEDs)
- IEC-61850-7-2: Basic information and communication structure – ACSI
- IEC-61850-8-1: Specific communication service mapping (SCSM) – Mapping to MMS (ISO 9506-1 and ISO 9506-2)
- IEC-TR-61850-90-1: Use of IEC 61850 for the communication between substations
- IEC-TR-61850-90-2: Using IEC 61850 for communication between substations and control centers
- IEC-TR-61850-90-3: Using IEC 61850 for condition monitoring diagnosis and analysis.

IEC 61850 defines to two different protocols; MMS (Manufacturing Message Specification) and GOOSE (Generic Object-Oriented Substation Events). MMS is *"an application layer protocol which specifies services for exchange of real-time data and supervisory control information between networked devices and/or computer application"* (Sorensen & Jaatun, 2007). MMS specifies the communication between client and server. MMS is used for communication between the IEDs and the control units.
GOOSE is defined by IEC-61850-7-2. GOOSE exchanges data and events between devices in a substation or a switchgear by means of a local Ethernet network such as indication and alarms, which is used by IEDs when communicating directly to each other.

2.1.4 Intelligent Electronic Devices (IEDs)

IEDs or Intelligent Electronic Devices are devices which receive and send data to other devices. There are two common types which are used in substations; functional relays, and integrated digital units (Padilla, 2015). Functional relays (digital relays) read inputs, then process the inputs using logical algorithms to establish outputs for example, trip or alarms. Integrated digital units (multifunctional relays) are normally used in medium voltage substations to improve the functionality of the substation by reducing the cost because they have several functions in one component (Padilla, 2015).

Figure 3 Example for IEDs devices (ABB, 2021)

2.2 SCADA

Supervisory Control and Data Acquisition (SCADA) is used to control and monitor a system with a combination of hardware, software and procedures (Endi;Elhalwagy;& Hashad, 2010). According to Endi et al (2010), SCADA system architecture has three layers; field instrumentation control, process control and supervisory control.

The field instrument control layer consists of sensors, which perform measurement (supervision and data acquisition) and actuators, which perform the control. This layer is the lowest layer of the SCADA architecture. The process control layer (Remote Terminal Units (RTUs)) consists of more devices for example, Programmable Logic Control (PLC), analog input and output modules and digital input and output modules. The supervisory control layer is the highest layer which has two main functions; periodically achieve the data from previously layer and control through the operator station.

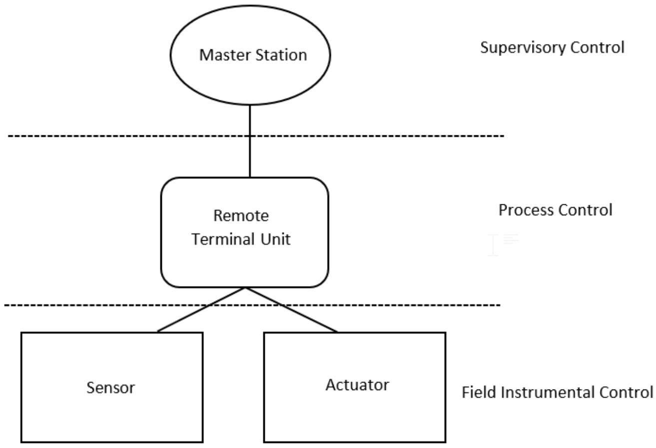

Figure 4 SCADA system architecture adapted from (Endi, Elhalwagy, & Hashad, 2010)

2.3 Automated Testing

Automated testing defined by Dustin et al. is *"The management and performance of test activities, to include the development and execution of test scripts so as to verify test requirements, using an automated test tool* (Dustin;Rashka;& Paul, 1999).

A testing framework includes four components which are:

- ***Test suites*** are the test cases or sequences which defined based on customer requirements. The test suites can be minimized, selected, and prioritized for regression testing which will be described in the next sub-title.
- ***The test runner*** is a software or testing method which operates test cases or sequences execution and reporting.
- ***Software under test*** is a software which will be tested for example, a software that created by requirements of customers. This also performs diagnosis and analysis systems behaviour.

- ***Test reports*** is a document made by the test runner which reports test scenarios and results for example passed and failed test cases (Winkler, Hametner, Östreicher, & Biffl, 2010).

Figure 5 shows an example of how all four components in a framework connected.

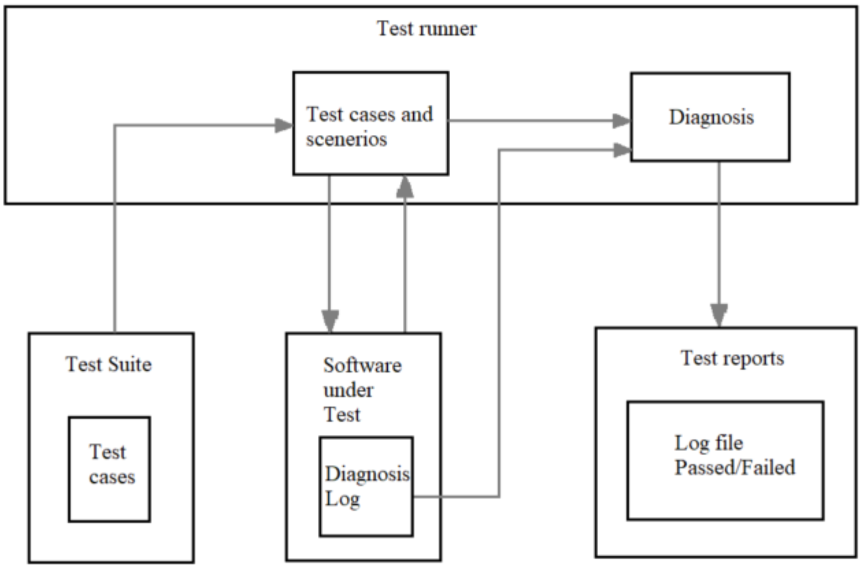

Figure 5 Framework components for automated testing in automation systems development, Adapted from (Winkler;Hametner;Östreicher;& Biffl, 2010)

2.4 Regression Testing

Regression testing is an iterative testing process based on retesting parts of a software that have been modified and have not provided new errors (Duggal & Suri, 2008). There are many approaches for regression testing such as retest all, regression test selection, test case prioritization and hybrid approach. Retest all method is expensive compared to another due to the time consumed. Regression Test Selection (RTS) is performed instead of rerunning all test suites. The test suites can be divided into reusable test case, retestable test cases, and obsolete test cases. Test case prioritization is to *"prioritize the test cases so as to increase a test suite's rate of fault detection that is how quickly a test suite detects faults in the modified program to increase reliability"* (Duggal & Suri, 2008).

2.5 Test levels

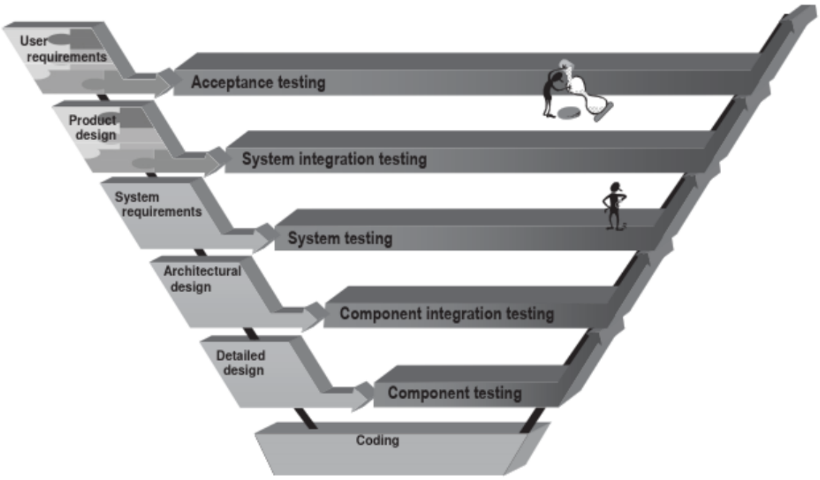

Figure 6 The V model of Dynamic test levels (Hass, 2008)

Hass (2008) describes the V-model of dynamic test levels, see Figure 6. The levels include acceptance testing, system testing, component integration testing, and component testing. Test levels are different according to terms of target and scope of the system. Each organization make their own test strategies to the levels which are compatible with the project types.

Component testing can be found at the bottom level because it is the stage that will be the first to start. In this level, bugs or mistakes will be found. A summary report should be created because this is helpful in the next testing stage. Next level is integration testing. This performed to integrate the components which are defined. System testing is to find bugs in the system compared with the requirements. Lastly, acceptance testing is performed together with customers or end users. In this level, the software is expected to be working as required (Hass, 2008).

2.6 Levels of Automation

Nowadays, most of the operations performed by humans are replaced by machines because it can reduce the time, increase quantity, and improve quality. The role of the operator has also changed from manual to supervisory through fully automated activities. The interaction of the human and the systems is demonstrated and specified from the automation involvement to the different taxonomies or Levels of Automation (LoA) as in Figure 7 (Gutierrez;Ponce;Balderas;Khakifirooz;& Molina, 2020).

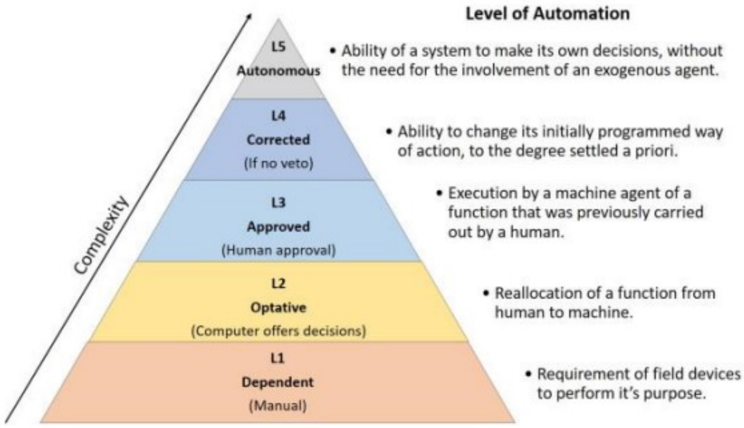

Figure 7 LoA taxomomy (Gutierrez;Ponce;Balderas;Khakifirooz;& Molina, 2020)

2.7 Test case specification and test logs

According to the standard IEEE 829, which covers Software Test Documentation, test deliverables include documentation of test case specifications and test logs.

Test case specification is the document that define test cases. The document shall have the structure as:

- Test case specification identifier,
- Test items,
- Input specification,
- Output specification
- Environmental needs,
- Special procedural requirement,
- Inter-case dependencies.

A record of details about the execution of a test is called Test log. A test log includes test log identifier, description and activity and event entries.

The Test log identifier should identify and specify information to make the test log unique. The Description is used to describe the test case in detail, for example, version or revision of the test log and identification of the testing environment that is used for the test.
Activity and event entries are the record of events, dates, and times for the testing (IEEE Standard for Software Test Documentation, 1998).

3 Data Center Automation System (confidential)

3.1 System Architecture

3.2 Tools for Test Automation

3.2.1 ABB Zenon

3.2.2 ABB Automation Builder

3.3 Network and communication

4 Test environment and process aspects (Confidential)

4.1 Test Automation application

4.2 Test Automation levels

4.2.1 Comparison between fully automated (level 5) testing and manual testing (level 2)

4.2.2 Advantages and disadvantages

4.3 Test case management

4.4 Test case documentation

4.5 Maintainability

5 Implementation of the Test Automation in small scale

The goal of the practical part of this project is to implement the Test Automation in a small scale. I decided to configure the ABB Zenon application which is the platform that is used to test the system to generate test reports. The advantage of this is to make it easier to monitor the test results and status for the regression testing. The tester can easily see from the results which test have failed and which test have passed by monitoring the screen or reading from exported log files. The report viewer screen is configured using the Report Definition Language (RDL) in ABB Zenon runtime.

5.1 Configuration of report viewer

The configuration begins with opening a backup file from earlier project in ABB Zenon. After the configuration has been restored, a project manager window will appear (see Figure 8). The project manager window contains important components which are used to configure the project for example variables, screens and files.

To configure the report viewer, a *report definition file* is created, see Figure 8. Microsoft Report Builder is used for that purpose.

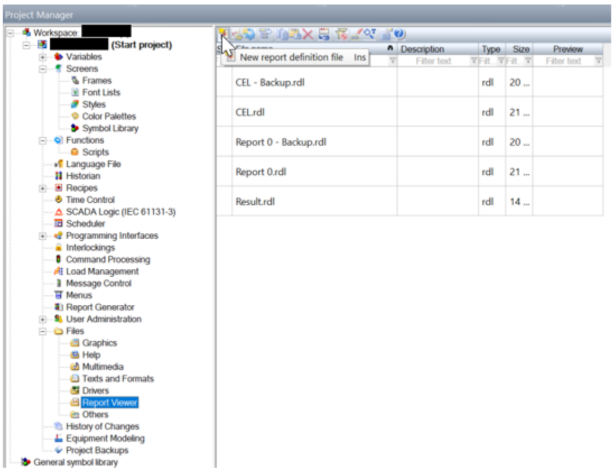

Figure 8 - Create new report definition file

Before starting to configure the RDL file, a report viewer screen is created by configuring the screen type of report viewer and selecting a template for the Runtime, see Figure 9.

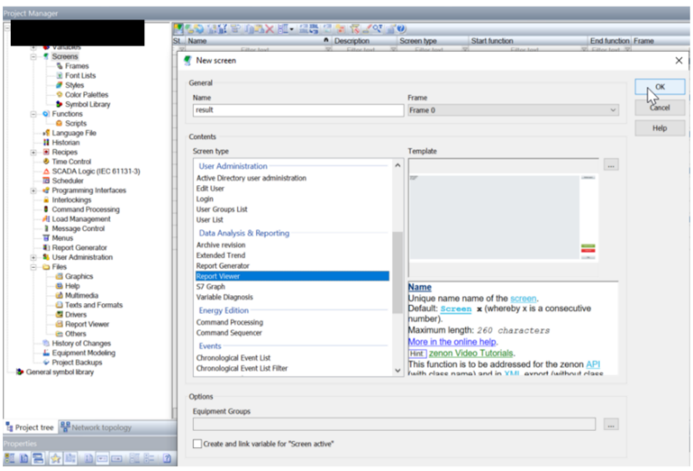

Figure 9 Creating report viewer screen

The next step is to create a *screen switch function* and *report exporting functions* to the screen. The switch function is connected to the report viewer screen and the report definition file which is created earlier according to parameters (Figure 10).

Figure 10 - Screen switch properties.

The filter in the parameters is configured according to Figure 11. The *Time filter* has a relative time period, according to which selected variable values are constantly updated. Data sets are created to be able to add variables and archive values. The desired variables are *status of the test cases*, *test case description* and *failure modes*.

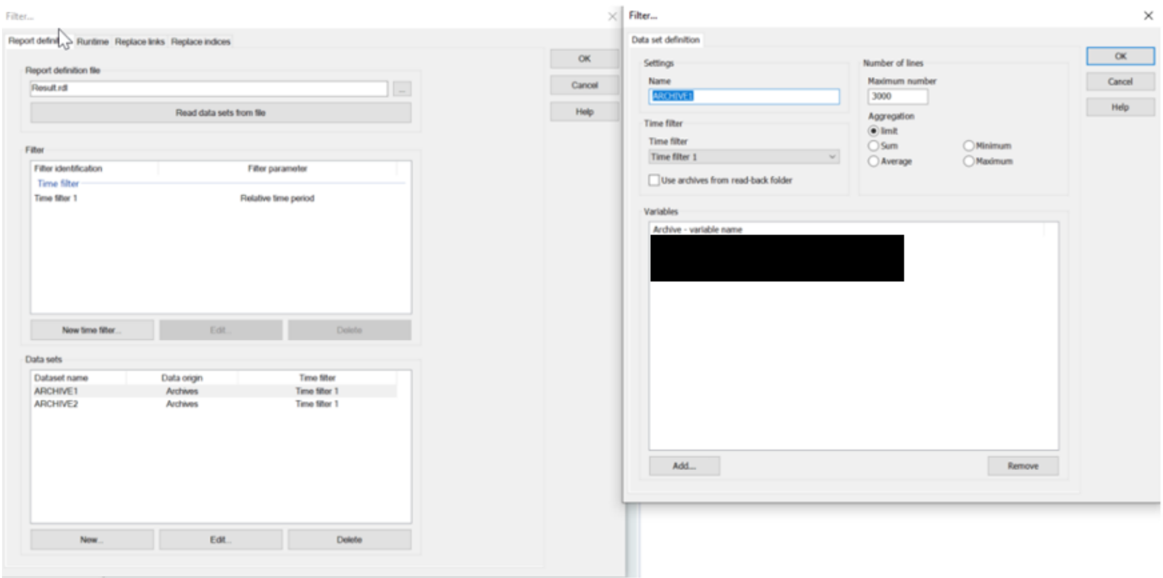

Figure 11 - Filter configuration

Two export functions are created for exporting the report in PDF and Excel file. The export functions are created by adding new functions and by selecting report viewer: export/print, after which, the report viewer settings window will appear (Figure 12). The report output is selected as PDF or Excel and the file name is defined.

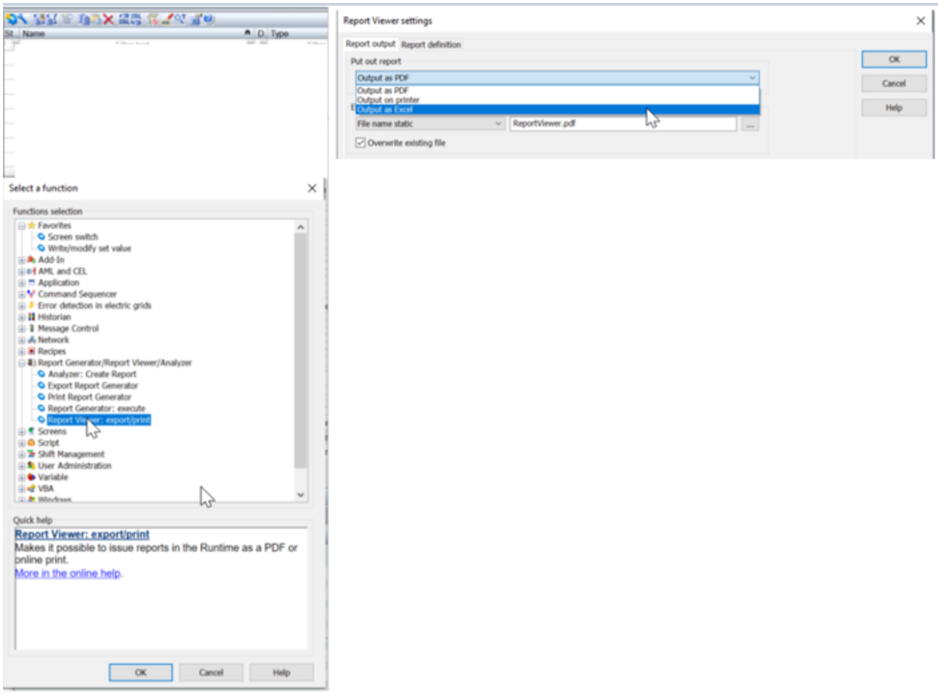

Figure 12 - Report Viewer setting window

The project has a footer, which for example includes buttons for auto test, manual test and event list page. A button is added and named RESULT, see Figure 13. This button starts a script to execute the report viewer page and set a page number.

Figure 13 - A picture of the footer for the project

After the screen and functions have been created, configuring and designing of the report definition file in Microsoft Report Viewer is done. Lastly, the report definition file is saved, the result of the configuration in Microsoft Report Builder is shown in Figure 14.

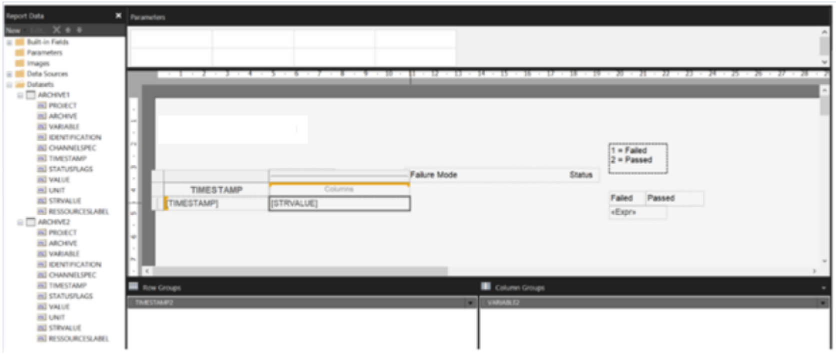

Figure 14 - Microsoft Report Builder design.

6 Testing

The testing was done in a small scale by running automated testing in some sequences with a switchgear test rack. The Test Automation was connected to the test rack according to **Error! Reference source not found.** and **Error! Reference source not found.**. The report vi ewer will show the values include timestamp, test description, failure modes, status and total failed and passed values. By clicking on Create Excel File and Create PDF, both files will be exported to the user's computer.

The results of the testing are shown in Figure 15, in which test description and failure mode as defined by the customer specification requirements can be seen. The status of the results (1 = Failed and 2 = Passed, as defined in the PLC AC500 program) can also be seen.

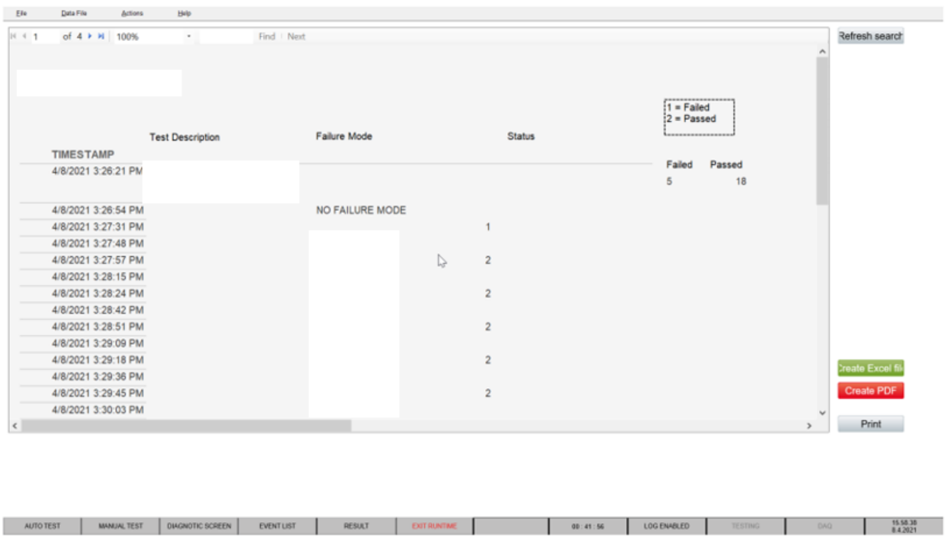

Figure 15 - Results in ABB Zenon Runtime.

Lastly, both PDF and Excel files are exported correctly and stored in the computer, see Figure 16.

Figure 16 - PDF and Excel file exported to the computer.

7 Results

The results of this thesis include the levels of automation that have been defined in the Test Automation. Further, advantages and disadvantages of Test Automation were analyzed, and a small scaled implementation for report viewer in ABB Zenon. The implementation was done by configuring an HMI page that shows the report of the test cases when testing automatically. The configuration was created by using ABB Zenon Editor along with the Microsoft Report builder to create a report viewer page. The results of the test cases can be reported in a form of PDF and Excel files.

To analyze the (potential) time saved when performing automated tests versus manual test, a break-even analysis was carried out, in which manual testing was compared against several use-cases of automated testing. The time usage for one test case is presented in Table 1.

Table 1 Time usage per one test case of automatic and manual testing.

Time usage per one test case	
Automatic	
Execute test:	26,7 s
Manual	
Check initial condition:	40,0 s
Execute test:	60,0 s
Verify final condition:	40,0 s
Document test:	60,0 s
Sum [s]:	200,0 s
Sum [min]:	3,3 min

Table 1 shows the time usage for both automatic (see **Error! Reference source not found.**) and manual (approximated) testing per one test case. The analysis further takes into consideration time usage needed to modify the test system to accommodate various sizes and complexities of the tested system (data center automation system). In order to calculate the break-even point (in terms of number of test cases) a calculation sheet was developed, with which the various cases were compared. Table 2 shows the results in time saved (or time exceeding) for the various cases. In Table 2, the (estimated) time usage needed to modify and execute the test depending on the system size and architecture complexity is also shown. The system size is defined into three levels; *Small*, *Medium* and *Large*. The architecture complexity is also defined into three levels; *Low*, *Medium* and *High*. The Data Center Automation system for an ongoing project is used as a reference. The reference system has medium size and medium architecture complexity.

Table 2 Test Automation break-even simulation.

System size (default = Medium): Architecture complexity (default = Medium)	**Small**	**Medium**	**Large**
Low			
modifications to complexity:	37,5 h	37,5 h	37,5 h
modifications to number of components:	37,5 h	0,0 h	112,5 h
System setup:	2,0 h	2,0 h	2,0 h
Execute test:	11,1 h	11,1 h	11,1 h
Sum:	**88,1 h**	**50,6 h**	**163,1 h**
Saving / exceeding:	**-4,8 h**	**32,7 h**	**-79,8 h**
Medium			
modifications to complexity:	0,0 h	0,0 h	0,0 h
modifications to number of components:	37,5 h	0,0 h	112,5 h
System setup:	2,0 h	2,0 h	2,0 h
Execute test:	11,1 h	11,1 h	11,1 h
Sum:	**50,6 h**	**13,1 h**	**125,6 h**
Saving / exceeding:	**32,7 h**	**70,2 h**	**-42,3 h**
High			
modifications to complexity:	75,0 h	75,0 h	75,0 h
modifications to number of components:	37,5 h	0,0 h	112,5 h
System setup:	2,0 h	2,0 h	2,0 h
Execute test:	11,1 h	11,1 h	11,1 h
Sum:	**125,6 h**	**88,1 h**	**200,6 h**
Saving / exceeding:	**-42,3 h**	**-4,8 h**	**-117,3 h**

The break-even points for three cases (Low complexity / Small size, Medium complexity / Medium size and High complexity / Large size) as compared to manual testing is presented in Figure 17.

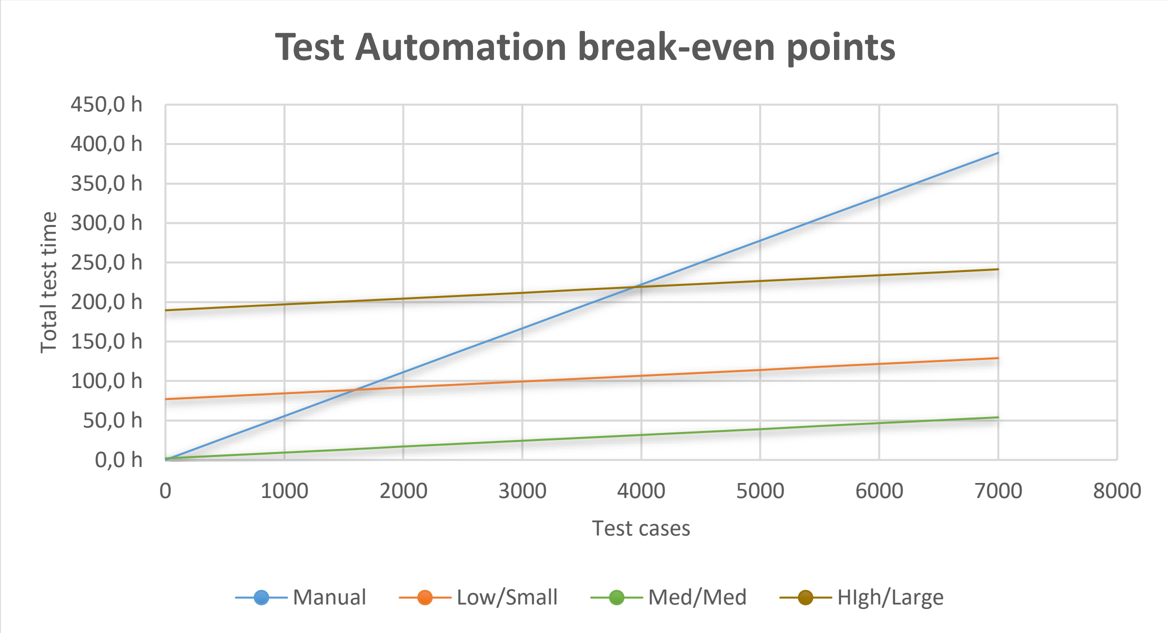

Figure 17 Test Automation break-even points.

8 Discussion and conclusion

The purpose of this thesis was to study and investigate different means to standardize and enhance the development model considering testing and test automation of Data Centre Automation System.

This thesis also studies the advantages and disadvantages of the Test Automation. Implementation of the test automation provides the ability to monitor the result of test cases when running the test automatically.

Easy access to important information concerning test cases, e.g., verification of failed test cases for regression testing and total amount of passed and failed cases, is one of the advantageous outcomes of this thesis.

The relatively large scale and complexity of the systems (Test Automation system and Data center automation system) represented a significant challenge to this study. In order to address that challenge, the scope of the thesis was scaled down to suitable level, in terms of both the study part and the implementation part.

While the results from the break-even analysis, as presented in Figure 17, contain some assumptions, it could possibly be used as a guideline for future projects, when determining whether to use manual or automated testing. Further, there are also other factors that impact the decision of using the Test automation, for example the experience level of the tester, which may have a significant impact on the time usage in manual testing.

Recommendations for future research could be a study / further optimization of the Test Automation system application in order to facilitate scaling of the Test Automation system in terms of system complexity and size in the most efficient way, in order to further shift the break-even points towards favoring automated testing over manual testing for an increased number of cases.

Another (more limited) recommendation for future development, would be to develop a tool for analysis of the test log files in a more efficient way (for systems with a high number of test cases, manual analysis of test log files can be time consuming).

I am overall happy with the results and the tasks were very interesting to study and work on. I have earned a lot of knowledge by reading and implementing on this thesis. The goals of this thesis have, in my opinion, at least partly been accomplished, as levels of automation have been defined to the Test Automation of data center automation system. Further, the break-even analysis has (at least preliminarily) indicated the usefulness of Test automation.

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