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Automatic Test System for Type Tests of the Uninterruptible Power Supply

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Tuotekehityksen oleellinen osa on laitteiden testaaminen. UPS-tuotekehityksessä erilaisia testejä tehdään joka päivä. Testaaminen vaatii monenlaisia mittausvälineitä sekä muita laitteita, kuten laajan kuormajärjestelmän sekä erilaisia testikokoonpanoja. Merkittävä määrä testeistä perustuu UPS:n tyyppitesteihin, jotka ovat määritelty IEC-62040 standardissa.

Testaaminen kuluttaa paljon aikaa ja resursseja. Ongelman ratkaisuksi on tyyppitestien suorittamiseen mietitty automaattista testausjärjestelmää. Tämän diplomityön tavoitteena oli selvittää tarvetta tälle automaattiselle testausjärjestelmälle sekä selvittää vaatimuksia sen toteuttamiseen.

Työssä syvennyttiin tyyppitesteihin ja automaattisen testausjärjestelmän eri osaluokkiin. Näiden lisäksi tehtiin kokeiluja, joiden tuloksena syntyi prototyyppi, jolla voidaan suorittaa automaattisesti suuntaa-antava hyötysuhdetesti UPS:lle. Hyötysuhdetestin lisäksi tutkittiin mahdollisuuksia automatisoida dynaamisen suorituskyvyn testi, joka on tyyppitesteistä vaativin. Tuloksena syntyi testi-prosessin kuvaus sekä LabVIEW-ohjelmia helpottamaan testin suorittamista. Lopulta päädyttiin kuitenkin siihen, ettei testin automatisointi ole järkevää, koska sitä ei toisteta kovinkaan usein ja automatisointi vaatii paljon aikaa.

Tutkimus ja kokeilut osoittivat, että automaattisen testausjärjestelmän toteuttaminen kaikille tyyppitesteille vaatii paljon aikaa ja resursseja. Tästä johtuen automaattinen testausjärjestelmä tyyppitestien suorittamiseen ei ole paras ratkaisu vähentää testaamiseen kuluvaa aikaa ja resursseja.

Avainsanat: Automaattinen testausjärjestelmä, Katkeamaton teholähde, Tuotekehitys, LabVIEW, TestStand, Prototyyppi

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Testing is an essential part of product development. In UPS product development, different tests are made every day. Testing requires large variety of measurement instruments and other equipment such as large load systems and different kind of test configurations. Significant number of performed tests are based on the UPS type tests defined in the IEC-62040 standard.

Testing consumes a lot of time and that way also resources. To solve this problem, an automatic test system for type tests is considered. The aim of this thesis was to clarify the need for the automatic test system, and clarify requirements needed to realize it.

The work was done by reviewing the type tests and different parts of an automatic test system. In addition, an experimentation was made, resulting a prototype. The prototype is able to automatically perform an indicative efficiency test for the UPS. Furthermore, a possibility to automate the most complex type test, a dynamic output performance test, was examined. This examination resulted a description of the test process and LabVIEW programs, supporting the execution of the test. However, the conclusion was that it is not sensible to automate the test, due to the fact that it is not often performed and automating the test requires a lot of time and resources.

The review and the experimentation proved that realization of an automatic test system, able to perform all the type tests, requires large amount of time and resources. Due to this, the automatic test system for type tests is not the best solution to reduce the time and resources consumed by testing.

Keywords: Automatic Test System, Uninterruptible Power Supply, Product Development, LabVIEW, TestStand, Prototype

Preface

This thesis was done between a time line from June 2011 to March 2012 in Eaton Power Quality Oy, New Product Introduction department.

I would like to thank my supervisor professor Seppo J. Ovaska for support and constructive comments and feedback. Thanks for Risto Karola and Otto Asunmaa for the subject of the thesis and giving the time to finish it. Risto Karola was also my instructor and thus I want to thank him also for encouraging comments and constructive feedback.

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I would also like to thank Tuomas Sahramaa for proofreading the thesis. However, if a reader finds mistakes from the text it is not to blame Tuomas but the signer. Thanks also to my wife Sari Nummijoki who helped with structuring the thesis and gave a lot of support during the whole period of making the thesis.

Helsinki, 18.3.2012

Esa J. Nummijoki

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Symbols and abbreviations

Symbols

η Efficiency symbol

Abbreviations

AC	Alternating Current
ATE	Automatic Test Equipment
ATLM	Automated Test Life-Cycle Methodology
ATS	Automatic Test System
CBEMA	Computer & Business Equipment Manufacturer's Association
COTS	Commercial off-the-shelf
CSV	Comma-Separated Values -file format
CT	Current Transformer
DC	Direct Current
DMM	Digital MultiMeter
DOP	Dynamic Output Performance type test
DUT	Device Under Test
DVT	Design Validation Test
ELLI	Electronic Load system in UPS factory of Eaton Power Quality Oy
EMEA	Europe, Middle East and Africa
FAT	Field Acceptance Test
FTP	File Transfer Protocol
GPIOB	General Purpose Instrument Bus
GUI	Graphical User Interface
ID	Interface Device
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
IT	Information Technology
ITI	Information Technology Industry Council formerly known as CBEMA
IV&V	Independent Verification and Validation process
HMI	Human Machine Interface
LabVIEW	Laboratory Virtual Instrumentation Engineering Workbench
LCC	Life Cycle Cost
MS	Microsoft Corporation
NI	National Instruments company
NPI	New Product Introduction department of Eaton Power Quality Oy
OPC	Open Process Control server
PC	Personal Computer
PDF	Portable Document Format
PDU	Power Distribution Unit
PLC	Programmable Logic Controller
SC	Subcommittee of TC of the IEC

RS-232	Recommended Standard 232
TC	Technical Committee of the IEC
TCP/IP	Transmission Control Protocol / Internet Protocol
THD	Total Harmonic Distortion
TPS	Test Program Set
USB	Universal Serial Bus
UPS	Uninterruptible Power Supply (or System)
UUT	Unit Under Test
VI	LabVIEW Virtual Instrument
WLAN	Wireless Local Area Network
XCP	X-format Communication Protocol

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1 Introduction

An Uninterruptible Power Supply (UPS) is a device, whose presence people usually do not notice until something goes wrong. Distribution of the electricity is not trouble-free and often leads to failures when it is disordered. For example, a power failure usually causes unpleasant events, such as data losses and work interruptions. Moreover, in critical applications such as medical devices, a power failure can cause severe problems. During a failure of the electricity distribution, the UPS becomes active. The UPS prevents the most common power failures, including power cut, power surge, frequency variation, power sag, undervoltage, overvoltage, line noise, switching transient and harmonic distortion [1].

Developing a new UPS device is a massive process, although the basic function of the UPS is quite simple. The process may take several years to complete and requires the effort of many workers. Eaton Power Quality Oy is a UPS manufacturer located in Espoo, Finland. The company manufactures UPS systems for non-consumer use and sells them in Europe, the Middle East and the African (EMEA) sales area. The company also has a product development department which cooperates with product development departments in USA and China.

The product development department uses a process management tool called PROlaunch for the new product development process. This tool is based on a stage-gate model which divides the project into five stages [2]:

1. Scoping
2. Build business case
3. Development
4. Testing and validation
5. Launch

Electrical tests are performed throughout the entire life-cycle of the UPS. Actual systematic testing begins at stage four of the product development process. Tests at this stage are divided into two groups: design verification tests followed by design validation tests (DVT) that contain type tests. Design verification tests are mostly complex, which make them difficult to automate. However, type tests are different as these tests follow strict requirements described in the international standard published by the International Electrotechnical Commission (IEC) [3]. The standard contains 35 different electrical tests, which must be performed and documented in order to ensure that the performance of the UPS is at the level specified by the manufacturer.

Finishing all type tests for a new product can require several months. Type tests are also made after the new product is launched in the market, when a component of the product is reworked, or a customer requires additional field acceptance tests (FAT) before the UPS is delivered to the customer. In these cases, not all type tests are performed, only the relevant ones. Performing the test contains many repeatable actions, including measuring electrical quantities, data acquisition, changing the state of the UPS, changing the output load of the UPS, changing the input voltage and its frequency, and reporting any received results. These aforementioned facts

lead to the need of performing the actions automatically, leading to an idea of an automatic test system (ATS) for type tests. An automatic test system for type tests was previously developed in 1997 for Fiskars Power Systems Oy, which was the earlier owner of the UPS factory [4]. However, after being unused for many years the ATS was discontinued in the spring of 2011.

The aim of this thesis is to clarify the current need for the automatic test system, and clarify requirements needed to realize it. This was done by reviewing type tests and different parts of an automatic test system. Two electrical type tests, the efficiency test and the dynamic output performance (DOP) test, were chosen for closer study. The efficiency test was chosen due to the fact that it is the most common type test in the New Product Introduction department in Eaton Power Quality Oy's UPS factory. Whereas the DOP test is the most complex type test, and thus chosen for closer examination. The experimentation was made by developing a prototype able to automatically perform an indicative efficiency test for the UPS.

This thesis is structured as follows: Chapter 2 presents the background of the project consisting of sections introducing an automatic test system based on earlier publications and explaining basic elements of the ATS, and then comparing them to the developed prototype. The next section introduces preliminary requirements for the desired ATS. This is followed by a section discussing different factors concerning the life cycle of an ATS and introducing methods to extend it. After this, a short description of a UPS is presented, followed by a presentation of IEC standards and the efficiency test and the DOP test as described in the standard. A short presentation of the Eaton Corporation is included at the end of the chapter.

Chapter 3 describes the made experimentation. The first section contains a description of the development process of the prototype. This is followed by description of how the efficiency test was automated. The next section contains a description of the developed prototype, consisting of the prototype cart description, load and supply control system description, description of the operator interface, operation description and description of developed LabVIEW virtual instruments (VI). This is followed by a section describing how the automation possibilities of the DOP test are examined. Results of the entire experimentation are discussed at the end of the chapter.

Chapter 4 presents conclusions of the work including a summary, an evaluation of the work and future development of the work.

2 Background

2.1 Automatic Test System

An automatic test system generally means a system which performs any kind of tests such as electrical measurements, mechanical actions or software related tests, automatically for a device under test (DUT). In this chapter, basic elements of the ATS is discussed according to various sources.

Greenspan [5] describes automatic testing by comparing it to manual testing. Every time when a test is made manually, a test technician needs to collect relevant equipment such as measurement devices, power supplies and cables, and make a proper test installation for unit under test. Moreover, usually tests require configurations and connections to be changed multiple times, especially when numerous tests are involved. Normally, a technician uses a manual or test instructions to perform the tests. However, if these instructions are unclear or leave room for interpretation, it will generate uncertainty to the test process. Bakshi [6] adds more drawbacks of the manual testing, such as decreased accuracy due to the operator's skill level. Meaning that slight difference occurs in the results when different persons perform the test. Furthermore, performing all of the actions manually, required by an individual test, is time consuming and thus costly.

These multiple problems in manual testing generated a need to automate the testing process. Greenspan has listed advantages of automatic test system including:

- faster completion of tests;
- less skills required to perform testing;
- test results does not depend operator skills;
- test sequence and measurement tolerance becomes more; consistent increasing confidence in test results.

Greenspan divides automatic test systems to integrated test systems and dedicated test systems. Integrated test systems consists of independent instruments operating together via data bus and controlled using a computer. A dedicated test system is specifically designed for a certain task or series of tasks. In the context of this thesis, the desired ATS falls in the category of integrated test systems. Greenspan presents a block diagram of a typical automatic test system showed in Figure 1. Bakshi [6] describes a typical automatic test system similarly. A typical ATS has following eight elements:

1. Computer controlling the testing process and interpreting and evaluating the test results
2. Stimulus devices to provide inputs required by tests
3. Measurement devices
4. Switching device linking the DUT and appropriate stimulus and measurement devices
5. Man-machine interface devices
6. Repository for test reports and other information

7. Computer program to direct the testing actions
8. Accessories required for specific tests

A control subsystem contains a computer sending instructions to the switching subsystem, and then retrieving data from it. Collected data can include measurement results from measurement subsystem or response data from DUT. The control subsystem also controls a power supply subsystem, which provide power to all other subsystems. The control subsystem receives a test program and user inputs from input devices such as disc drive and keyboard and sends tests result to output devices such as display. A switching subsystem controls the stimulus subsystem according to instruction gave by control subsystem, and retrieves stimulus which is passed to DUT. The switching subsystem also controls the measurement subsystem and passes response of DUT to measurement subsystem. A measurement subsystem sends measurement data to switching subsystem, passing the data to the control subsystem and finally to the user through the output device.

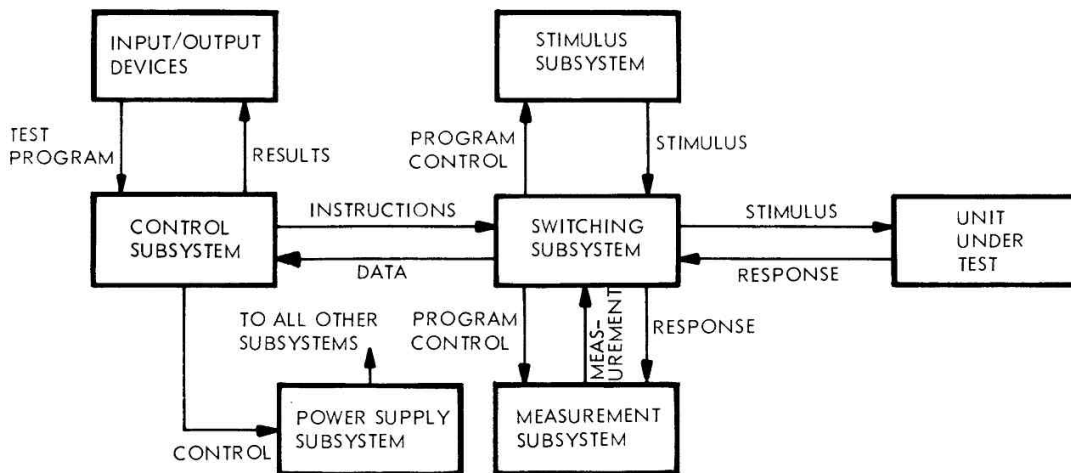


Figure 1: Block diagram of a typical ATS [5].

Although this description of the ATS is from the early days of automation in 1971, it is still valid at the present time. Bakshi's description is quite similar although it has been presented in 2009.

A different approach of describing an automatic test system is presented by Mendes [7]. Mendes describes an ATS from a data flow point of view to help propose a general ATS functional structure. The data flow scheme is showed in Figure 2. In the figure, a top layer of the ATS is a physical system, containing hardware, sensors, transducers and actuators forming a test system interface to DUT. Hardware consists of electrical and mechanical devices supporting execution of the test, such as operation peripherals for sending user commands to test software; visualization peripherals for displaying data; signal conditioning / digitalization for translating signals between the real world signals for test algorithm; and output signals generation for translating test algorithm signals for actuators. The system core is in the software layer containing elements, such as initialization, a test conduction

algorithm, test results data and an user interface control. Initialization contains configuration data for test conduction and user interface control. The test conducting algorithm receives information from sensors and transducers, and commands from user interface control. With this information, the test conduction algorithm performs a certain test sequence, controlling actuators and sending feedback to the user. Finally, it sends the test results to the data block, which is finally shown to the user.

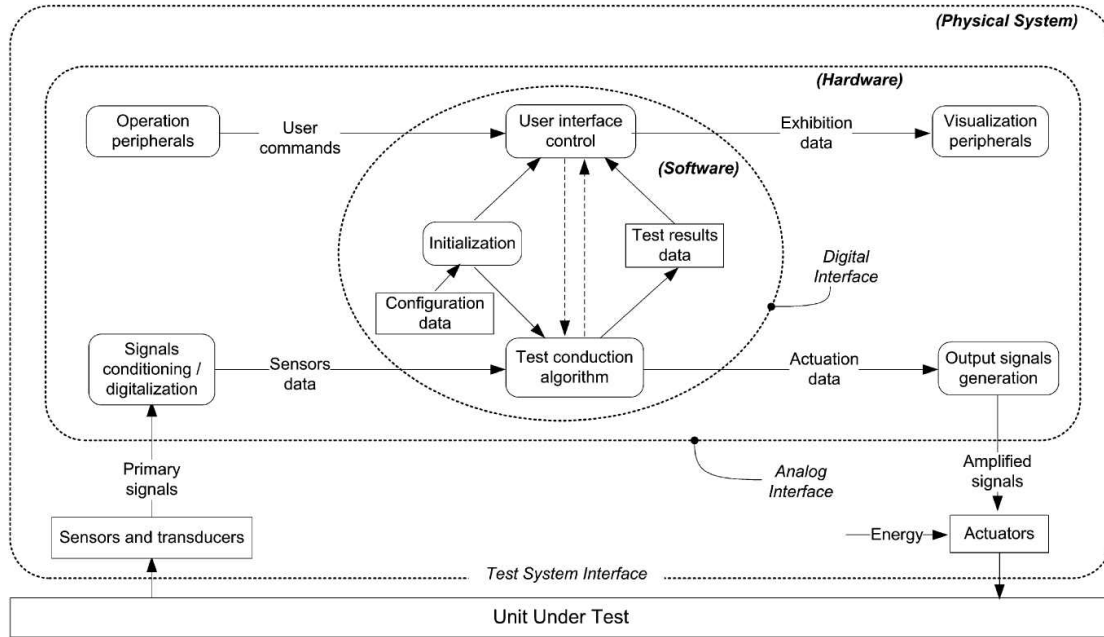


Figure 2: An ATS described in a data flow scheme [7].

Third approach is presented by Flynn [8]. Flynn divides an ATS to three elements including:

1. Automatic test equipment (ATE)
2. Test program set (TPS)
3. Test environment

ATE refers to an independent computer test station containing stimulus, measurement, and switching components under computer control. A TPS is comprised of the ATE interface hardware known as an Interface Device (ID), test program software, documentation, and other assisting equipment connecting the ATE to the DUT. The test environment includes a description of the ATS structure, programming and test specification languages, compiler, development tools, and necessary information about DUT design requirements and test strategy for generation and maintenance of TPS software.

These three different perspectives of ATS proposes that variation of different kinds of automatic test systems is comprehensive, making a concept of an ATS ambiguous. Maybe the most suitable definition of the ATS is used by Greenspan and

thus used as a basis of explaining the ATS in the context of this thesis. However, Greenspan's description does not cover communication interfaces between subsystems. Still, the following sections of this chapter includes a more specific review of the different elements of the typical ATS, presented by Greenspan, and their possible applications when used in the developed prototype.

2.1.1 Control Subsystem

A control subsystem contains a computer and test program software. The software running test sequences is probably the most critical part of the ATS requiring a lot of development. Badly designed software and software development project will lead to increased life cycle costs. Software runs the test sequences and controls every other element of the ATS. National Instruments (NI) offers two widely used tools for making the software for ATS.

Laboratory Virtual Instrumentation Engineering Workbench (LabVIEW) is a graphical control, test and measurement environment development package, developed by NI and launched to the markets in 1986. LabVIEW was made to help automate the world of measurement [9]. LabVIEW programs, also known as virtual instruments, are made using graphical, general-purpose programming language known as G-language [10]. Compared to traditional programming, G-language has advantages, such as the code is easier to decode and support, program creation is simpler, fewer opportunities for human error exist, and problems are easier to locate from the code [11]. In Figure 3, program creation processes are shown with traditional programming language and graphical programming language. As shown in the figure, the traditional programming process contains more steps than the graphical programming process. In the graphical programming process, the source code is not separately compiled and linked like in the traditional programming process. This removes two steps from the process, making the graphical programming more straightforward than the traditional programming. Furthermore, the code is easier to manage due to its graphical interface from where it is possible to see more things with one look, compared to reading through text lines.

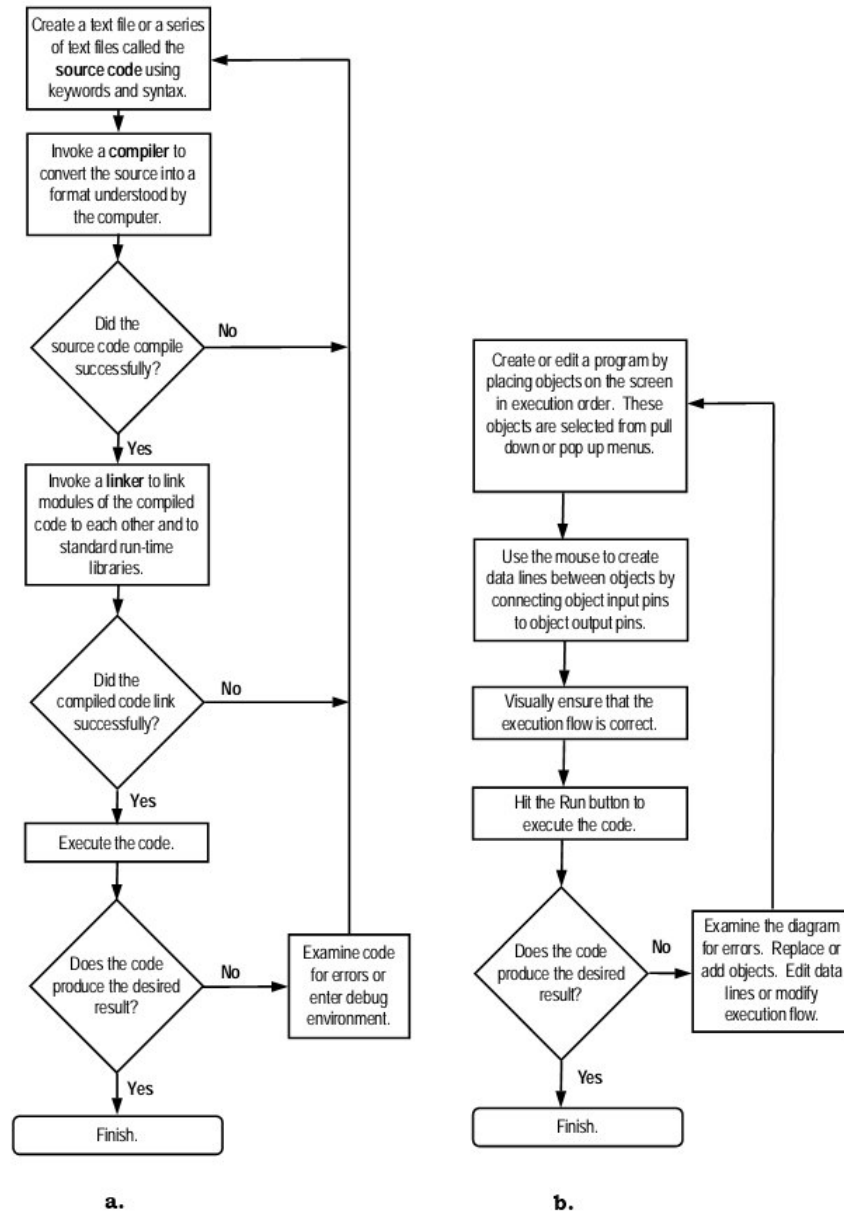


Figure 3: The program creation processes. a. Traditional programming. b. Graphical programming [11] .

LabVIEW was chosen for the software development environment of the prototype mainly because a lot of ready made VIs already exist, due to the use of LabVIEW also in UPS' production test system. Furthermore, LabVIEW is a faster development environment for this purpose than traditional programming language such as the C. Another option for graphical programming would have been the Agilent VEE also known as HP VEE [12], [13].

NI TestStand is a piece of test management software designed for the faster development of automated tests and validation systems. With TestStand's Sequence Editor, it is possible to create test sequences that automate the execution of code

modules. Code modules can be written in various programming languages, such as C/C++ and LabVIEW. Code modules contain functions to perform certain tests or actions. In the test sequence, code modules are invoked using built-in steps which also contain other common testing operations, such as message pop-ups and basic program flow controls. Test sequences also specify reporting, database logging, and connectivity to other enterprise systems. The TestStand also provides example interface and source code for making customized user interfaces.

For successful, fast and low cost development of test systems, modularity and code reuse become crucial features. Building unique test applications from scratch for each new test system is slow and costly. Test management software, such as TestStand, promotes test code modularity and code reuse. Furthermore, TestStand's architecture is reusable, supportable and maintainable with little effort, because of separated software modules controlling the instrumentation and tests [14].

Benefits of the TestStand includes the following features [15]:

- Flexible, open test architecture
- Eliminate programming of common test executive tasks
- Reuse existing test code
- Simplify updates and long-term maintenance
- Accelerate test system development
- High test system performance.

Because of these benefits which enables faster development of the ATS, TestStand was chosen as the test software execution platform for the developed prototype. Moreover, the corporation already had the license for TestStand, thus saving the time and money needed to purchase one. However, one of the drawbacks of LabVIEW and TestStand is a costly license which is also complex to manage. Problems appear especially when trying to change the license to a different person or change the license type from name-based to computer-based. In contrast, C-language or any other traditional programming languages do not necessarily require any license or other costs.

2.1.2 Measurement Subsystem

A measurement subsystem consists of measuring instruments. The minimum requirements for a measurement instrument is to have a communication interface for receiving commands and sending measurement data to a computer. Measurement instruments can be dedicated or commercial off-the-self (COTS) equipments. Dedicated instruments are typically made for a single measurement, and COTS are for multiple measurements. This section introduces COTS instruments used in this thesis project, including the following instruments:

- Yokogawa WT230 digital power meter
- Yokogawa WT1600 digital power meter
- Yokogawa DL750 scopecorder
- Yokogawa DL850 scopecorder

The WT230 digital power meter is capable of measuring three different AC or DC voltages and currents. The measurement of harmonics of the AC voltage, current and active power, and calculation of total harmonic distortion (THD) is also possible [16]. The WT230 suits the prototype well due to its low cost. The meter has a simple 7-segment display which makes manual data acquisition difficult. The meter can be controlled with a computer using a General Purpose Instrument Bus (GPIB) interface, and retrieve measured and computed output, error code output and status byte output from it. In the context of this thesis, the WT230 was selected to measure the DC voltage and current of the UPS' battery.

The WT230 is capable of covering most of the measurements required by type tests, though some tests for example efficiency test requires two WT230 power meters. Due to this, the more sensible way to conduct measurements is to use a power meter that has enough channels to measure all input voltages and output voltages of a three-phase UPS. A capable power meter for this task is the Yokogawa WT1600. The WT1600 can be equipped with six measurement elements, allowing it to measure all input and output voltages and currents of a three-phase UPS. Due to this, the WT1600 can directly calculate efficiency of the UPS. The WT1600 can also measure harmonics of the AC voltage, current or active power, and calculate a THD. To measure both efficiency and harmonics at the same time, two synchronized WT1600 meters are needed [17].

Power meters cannot cover all measurements of the type tests. Some tests require the observation of waveforms with an oscilloscope. A suitable oscilloscope for the type tests is the Yokogawa DL750. The DL750 is a digital oscilloscope, which can acquire 16 signals with a resolution of 12-bits and a sample rate of 10 mega samples per second, plus 16 digital signals with a resolution of 8-bits [18]. This is particularly useful in situations requiring the observation of all input and output voltages and currents of a three-phase UPS. Logic probes, for example, can be used for observing digital gate drive signals of the UPS rectifier. The Yokogawa DL850 is basically similar than the DL750 but it is newer and has more advanced features, such as sample rate of 100 mega samples per second, and larger internal memory.

There are several reasons why these instruments were chosen for the ATS. The first reason was that the company already had these instruments, and this saved time and money from purchasing new instruments. The second and probably most important reason is that many engineers in the company already knew how to use the instruments. Purchasing new instruments would require a lot of time to learn how to use them. The third reason was that all of these instruments can be controlled via GPIB bus and NI provides LabVIEW drivers for each of them. Company also has components that enable GPIB communication, such as GPIB-cables and GPIB-to-USB-adapters. However, a drawback of selecting the WT1600 is that Yokogawa has discontinued production of the WT1600. Due to this, if the WT1600 breaks it must be replaced with the Yokogawa WT1800 power meter.

2.1.3 Communication Interfaces

A lot of different communication protocols exist, which can be used for communication between different subsystems in the ATS. In the context of this thesis, the following communication interfaces were applied:

- GPIB
- Ethernet
- XCP via RS-232

The General Purpose Instrument Bus (GPIB) was the first standard communication protocol between instruments and computers. It was invented by the Hewlett-Packard Corporation in 1974. The bus made interconnection between test instruments and computers simpler. In 1978, the GPIB was adopted as the Institute of Electrical and Electronics Engineers (IEEE) standard 488 (IEEE-STD 488). In 1987, the standard was updated to IEEE-488.2, which is still in use today. The update unified the control of instruments of the hundreds of different manufacturers. The bus is an 8-bit bus with a transfer rate of 1 mega bytes per second (MB/s). It allows 14 instrument connections and allows a maximum cable length of 20 meters [19], [20].

The GPIB is an old communication protocol and faster protocols have been developed, such as VXI which has data transfer rate of 100-MB/s [19]. Despite this, the GPIB was used in this project because the chosen instruments utilized it and the company had a lot of GPIB cables and USB-to-GPIB-converters in storage. Furthermore, the transfer rate of the GPIB is fast enough for use of the prototype. NI provides GPIB drives for each of the instruments. These drives consist of VIs enabling the control of the instruments and the retrieval of measurement data from them with a Personal Computer (PC).

Ethernet means a physical connection to connect two or more devices and to exchange blocks of data. A block of data, also known as a frame, consists of a header, data payload, and an error check. Ethernet systems consist of four elements [21]:

1. The frame
2. The media access control protocol, consisting of a set of rules embedded in each Ethernet interface, allowing multiple computers to access the shared Ethernet channel in the proper way
3. The signal components, consisting of standardized electronic devices, sending and receiving signals via an Ethernet channel
4. The physical medium, consisting of the cables and other hardware, such as Ethernet hubs, used to transfer the digital Ethernet signal between the computers attached to the network.

Besides of these four basic elements, to establish communications between applications running on computers attached to the network, a high-level network protocol is required. In most cases, a Transmission Control Protocol / Internet Protocol

(TCP/IP) suite is used [21]. In the context of this thesis, Ethernet with TCP/IP network protocol is used to receive measurement data from the DL750 and the DL850 oscilloscopes. The oscilloscopes use a File Transfer Protocol (FTP), which is one of the many application layers of TCP/IP.

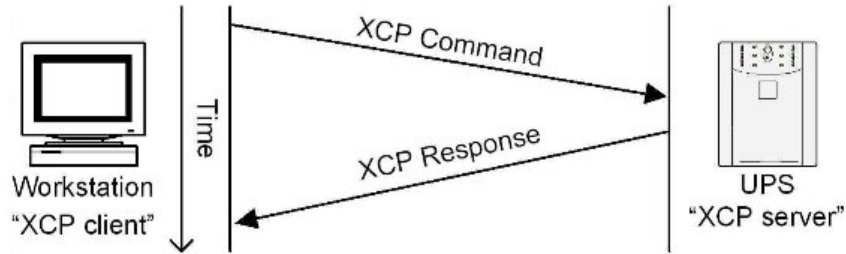
X-format Communication Protocol (XCP) is a standard UPS communication protocol developed by Powerware Corporation which is now owned by Eaton Corporation. In 1997, Powerware had a need to offer UPS, adapter, and software products interoperating properly with each other. At that time, Powerware employed four different protocols, which made interconnections between products difficult. Due to this, XCP was developed [22]. The XCP standard specifies following matters [23]:

- The format of serial and network-based messages to monitor and control UPS devices
- The basic rules for command and response behaviour
- The contents of data for configuration and dynamic readings from the UPS devices
- Meaning of the contents of data
- The control commands for the UPS devices
- The inter-related behaviours of UPS devices as response to the command
- A separate "private" commands for the UPS devices for service and factory use
- Requirements for implementing XCP in the firmware
- Requirements and suggestions for developers of connectivity devices, and monitoring software.

A demonstration of XCP communication is shown in Figure 4. The workstation, usually a PC, works as the XCP client, whereas the UPS works as the XCP server. The XCP software sends a request to the UPS in the form of an XCP command, and receives an XCP Response. Format of the XCP command is shown in the upper table of Figure 4. The header field consists of two bytes Start Frame Delimiter (SFD) and size byte LEN, indicating number of bytes (nnn) in the Data field. The data field consists of a CMD byte which is a control code, telling which command is being requested, and an optional PARAM field, containing additional bytes of information for the command. The checksum field consists of a CSUM byte which is the two's complement checksum of preceding bytes, including SFD, LEN, CMD and PARAM.

The format of the XCP response is shown in the lower table of Figure 4. The header field consists of an SFD, a BLOCK # which is a byte indicating which data block is being sent, an LEN indicating number of bytes (nnn) in the Data field, and SEQ(quence) which is a byte value giving the sequence number of this packet in relation to transmission of the entire response block. These packets are numbered in ascending order with the first being (0x01). If a packet is the last one in a sequence, then the high order bit of this field (0x80) will be set in addition to the final sequence number. The data field consists of DATA bytes and CSUM is the same as in the XCP command [22].

XCP command	Header		Data		Checksum
# Bytes:	1	1	nnn		1
	SFD	LEN	CMD	PARAM	CSUM
example:	0xAB	0x03	0x8A	0x2C 0x01	0x9B



XCP response	Header				Data				Checksum
# Bytes:	1	1	1	1	nnn				1
	SFD	BLOCK	LEN	SEQ	DATA				CSUM
example:	0xAB	0x09	0x04	0x81	0x31	0x8A	0x2C	0x01	0xDF

Figure 4: XCP communication protocol [23].

XCP exploits Recommended Standard 232 (RS-232) to accomplish the interconnection between the computer and UPS. Currently, RS-232 is widely replaced by Universal Serial Bus standard (USB) in PC hardware, and new PCs do not usually have the RS-232 port anymore. However, a USB-to-RS-232 -converter can be used in case the PC does not have an RS-232 port.

2.1.4 Input and Output Devices

Input devices mean human machine interface (HMI) devices such as a keyboard and mouse. These devices are used to give user input to the test software, executing the test sequence. Output devices means devices, such as a printer used to print test reports or display showing the reports, or other feedback from different elements of the ATS. In the context of this thesis, keyboard and mouse are utilized but printer is replaced by a database for storing the test reports. In this case, the database is the company's internal network drive and reports are made with Microsoft (MS) Excel spreadsheet software. The Excel was chosen because LabVIEW provides toolkit for generating Excel sheets and storing data retrieved from the measurement devices. Because LabVIEW was chosen for ATS software development environment, the easiest way to make reports was to use Excel.

Automatic report generation is one of the biggest advantages of the ATS. Compared to manually writing test results and measurements, it is much more faster and more accurate, leaving no room for human error.

2.1.5 Switching Subsystem

A switching subsystem consists of switches controlled by the control subsystem. These switches switch different stimuli to the DUT. In the context of this thesis, switching subsystem switches different supply voltage and output loads into the DUT. Programmable logic controllers (PLC) are used for this task, more specifically the Eaton XC210 modular PLC. These PLCs can be controlled with a PC running Open Process Control (OPC) server, communicating via Ethernet cable using TCP/IP. The PLCs are programmed using CoDeSys PLC programming software.

The switching subsystem can also be used for changing measurement points or measurement devices. For example, in the case that instruments used in efficiency test are not accurate enough to fulfil requirements for measurement uncertainty defined by the IEC-62040-3 standard [3], a power meter measuring input power and a power meter measuring output power must be interchanged, and measurements repeated. In this case, the final value of UPS efficiency is the arithmetic mean of all efficiency measurements.

2.1.6 Stimulus Subsystem

A stimulus subsystem consist of devices providing excitations for the DUT. In the context of this thesis, these excitations are simulated electric grid failures and different load systems. The factory has several test bays containing manually adjustable power supplies, and manually adjustable linear and non-linear loads. Electrical grid failures can be also simulated using a modified Eaton 9395 UPS called MX device, allowing variation of output voltage and its frequency. The MX device is shown in Figure 5. The MX device's output voltage is controlled using a PC running MX GUI -software or Sequencer -software made with LabVIEW [24]. As the Sequencer -software is made with LabVIEW it is possible to implement it as a part of the Test-Stand test sequence without huge effort. Communication between the MX device and a PC is established using the RS-232. As the maximum length of the RS-232 cable is 15 meters, the cable is extended using RS-232-to-Ethernet converters also known as NPorts. With NPorts, Ethernet cables can be used in communication extending the control range.

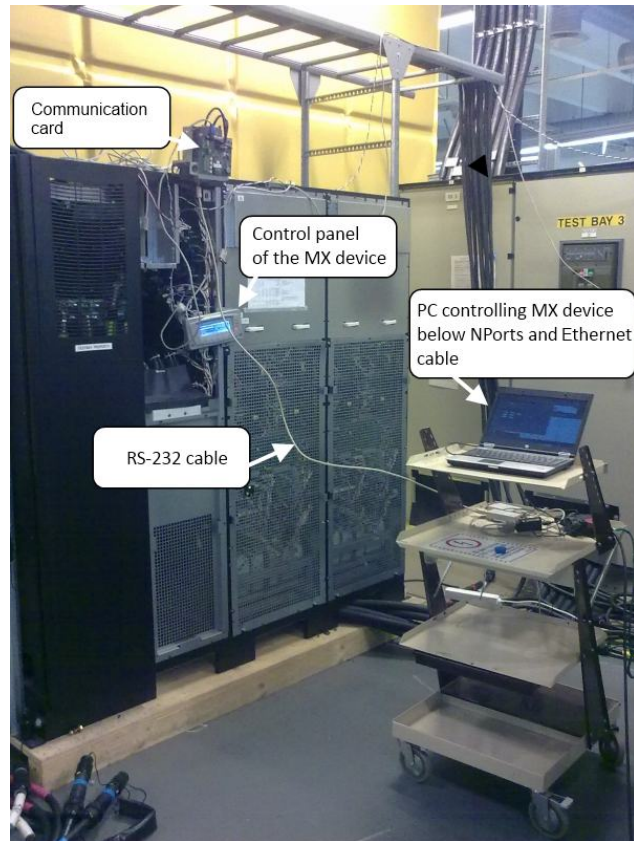


Figure 5: The MX device.

As a load system, the factory has multiple test bays containing resistive loads and non-linear loads (with 0.7 power factor) up to 1 MW. The factory also has an electronic load system (ELLI), consisting of multiple parallel UPS devices with special firmware. This system recycles the load power back to the DUT, enabling higher currents than is possible when drawing straight from the grid. Moreover, recycling the energy is more efficient, consuming about 10% of the energy taken from the grid. This system can provide load from 225 to 4400 kVA [25]. A block diagram of the electronic load system is shown in Figure 6. 10% of the power supplied to the UPS is provided by the grid, and 95% of the power comes from recycled load power when 100% load is connected to the UPS. This means that running the UPS with 100% only 10% of the power, initially taken from the grid, is consumed.

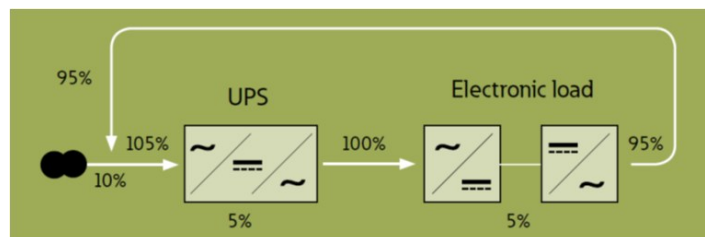


Figure 6: A block diagram of the electronic load system [26].

2.2 Preliminary Requirements

Before starting this thesis project, the preliminary requirements for the ATS were already defined. These requirements are described in the reference [27] and shortly presented in this section. Among the document, more requirements were defined in the beginning meeting of the project.

In Figure 7, a top-level block diagram of the desired ATS is shown. The PC works as a control subsystem and contains a test program. The test program development was suggested to perform using LabVIEW programming language and NI TestStand program. With the UPS acting as a DUT, the PC will give commands to the UPS and receive a response. The response consists of state information, alarm information or data from the UPS' internal measurements. The meters works as a measurement subsystem controlled with the PC, and provides measurement data to the PC. In this context, input/output devices are, the PC display and external network drive that works as a database. The stimulus subsystem contains the MX device, which provides different kinds of input voltage to the DUT, and the ELLI for providing different loads to the DUT.

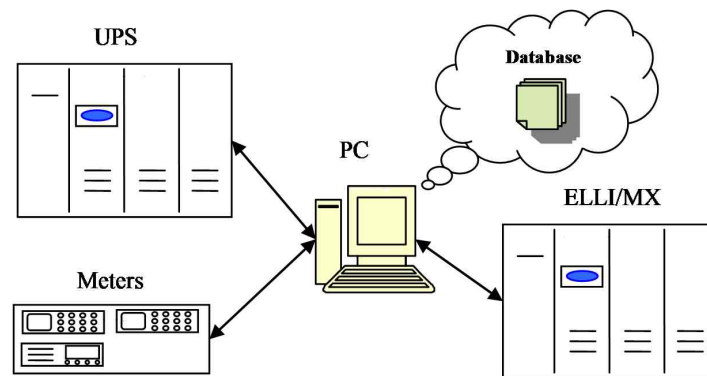


Figure 7: A block diagram of the desired ATS [27].

The equipment shown in Figure 7 are connected to the PC in a number of ways. The meters are connected via a GPIB bus using a GPIB-to-USB adapter. The ELLI and the MX device are connected via an RS-232 interface. Also the UPS is connected via the RS-232. The ELLI can be also connected via Ethernet, which is also used between the PC and the database.

In Figure 8, a circuit diagram of the planned ATS is shown. The test tower consists of a computer and measurement devices. The computer communicates with a load control panel, which adjusts an output load to the DUT. Measurement devices are switched at different test points of the DUT using an I/F board. The computer also controls Known-Good Big Blue (Eaton 9395 UPS) via XCP, providing input voltage to the DUT. The input voltage to the DUT can be chosen straight from the grid or from Known-Good Big Blue using the switch matrix.

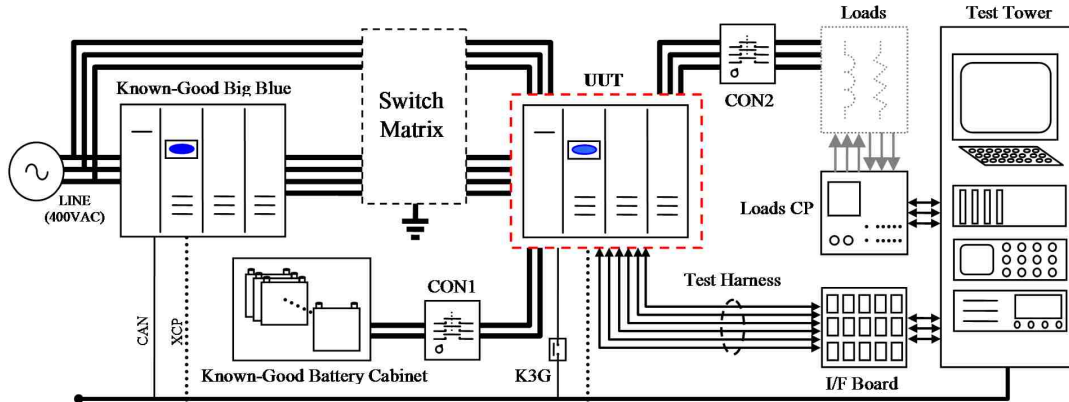


Figure 8: Circuit diagram of the desired ATS [27].

Besides the basic functionality of the ATS, Table 1 lists other relevant requirements for the ATS, according to reference [27]. The requirements presented in this section acted as the foundation on which the prototype was built.

Table 1: Functional requirements.

Requirement	Metric	Rationale
The ATS should be flexible and modular	The ATS could be used in multiple tests and could be extended to cover testing of future UPSs	This extends the life cycle of the ATS and makes it more cost effective
The ATS should store measurement data to local or remote databases	Measurement data from each performed test is stored to the database	The data is used to generate reports and view specific UPS operations afterwards. Furthermore, the stored data is also used as a history of passed tests that could be referenced when similar tests are repeated
The ATS should have a graphical user interface (GUI)	An operator can configure and control tests via GUI	The GUI simplifies the use of the ATS, decreasing requirements for operator's skill level and user instructions

The GUI should display time, date and operator information, DUT information and status, verification testing status and total runtime/run count statistics	Mentioned features are implemented	Displayed information helps performing the test and helps comparing different tests
Meters should be synchronized	Different measurements must be from the same moment in time	This is required by the UPS standard [3]
The test software is in the form of an executable file or the like	The test software can be executed without a development environment	This simplifies installation of the software to multiple test towers
Test software should allow the user to step back and forth inside a step procedure	User must be able to control the flow of the test sequence	Some test steps needs to be repeated
Application architecture shall be implemented in modular base	Different software modules can be modified and every piece of source code can be modified	Makes possible for Eaton engineers to modify existing code or add own code
The whole PC should work as a measurement instrument rather than a normal PC	The PC should be isolated from the corporate network as well as external networks. The only interface to external network should be a connection to the database	Keeping the PC in the corporate network requires constant updating which hinders the test performance
The test software should write a record of each test's steps into the log file	All events shall be written to the log including every test step change and result	This helps comparing different test and evaluating measurement uncertainty
The ATS should allow the diagnosis of each measurement devices	Any user can query all measurement devices	Allows any user to see what configurations are used for certain measurement devices
The ATS should allow self diagnostic	User is allowed to test communication to measurement devices, the database and the DUT, and check operation of relays and contactors	Self diagnostic is for ensuring the right operation of the ATS

2.3 Life Cycle of the ATS

One important aspect of developing an ATS is its life cycle. The former ATS in the New Product Introduction (NPI) department was successfully used for type testing of UPS devices for many years. However, after being unused for several years it was scrapped in the spring 2010. The reason for the ATS being left unused was that the people who designed the system and knew how to use it had left their jobs without leaving enough knowledge about the ATS behind, resulting in no one knowing how to use the ATS. However, the need for a new automatic test system rose again. Due to obsolescence, any components of the earlier ATS could not be exploited in the new ATS prototype. For example, test software was programmed with LabVIEW 5.0 and was not updated for newer versions of the LabVIEW. This led to the problem that these LabVIEW programs could not be opened with LabVIEW 2010. Another example was automatic control of loads, which needed to be reconstructed.

To learn from earlier mistakes, this time the life cycle of the new ATS will be considered in the beginning of the design process. Furthermore, the desired ATS is considered to last multiple UPS development projects and a minimum of 10 years, which increases the importance of life cycle management of the system.

Several methods to manage products life cycle, which can be applied also to the ATS life cycle, are presented shortly in this section. According to various sources, life cycle of the product must be considered thoroughly in the beginning of the design project. In his paper, Liosis [28] presents a method for defining a successful Life Cycle Cost (LCC) roadmap. The roadmap will help design, deliver and sustain a viable product. For an effective LCC system the following areas must be considered [28]:

- Integration of information based systems, such as databases, software tools and documentation
- Well established obsolescence plan and tracking system
- Implemented problem reporting and maintenance data collection systems
- Incorporation of a spares plan and tracking/status system
- Design for expandability

These listed areas of consideration can be integrated into the developed prototype. A network drive works as a database. The database contains test software components and documents such as user manuals, system descriptions, test instructions and test reports. A network drive is a suitable database when the amount of data is small. However, when a database contains large amount of documents, such as test reports, it is more sensible to divide the data into multiple databases. In the case of the developed prototype, the integration of the information based system is considered and there are no visible problems in sight.

Software tools might become obsolete in situations such as installing a new operating system to the computer or a new version of particular software is released. For example, VIs developed with certain versions of LabVIEW must be updated with new versions of LabVIEW to avoid obsolescence.

Documentation is done using MS Excel and Word. The threat in using these software is that Microsoft is constantly changing the document standard, making old Excel and Word files unusable. However, this problem does not appear after few years, though 20-years-old Excel or Word files cannot be opened with the recent versions of Excel or Word. Due to this, it is more sensible to convert Word and Excel files to Portable Document Format (PDF) which is a more durable document standard.

Problem reporting and maintenance data collection can be done, for example, using a proprietary issue tracking software such as Atlassian JIRA. Obsolescence plan and tracking system means that possible threats of certain parts of the prototype becoming obsolete must be identified and a tracking system indicating when certain part needs to be updated or maintained.

Expandability is accomplished in the developed prototype by making it movable. This allows the prototype cart introduced in section 3.3.1 to be mobile within different test bays inside the factory. The load and supply control system introduced in section 3.3.2 can also be integrated into other test bays in the factory.

Independent Verification and Validation (IV&V), represented by Calhoun [29], is a systems engineering process verifying if the ATE meets its specifications, and validates that the ATE performs as customers expect. Part of the IV&V is to organize an independent IV&V organization, employing different methodologies to evaluate the correctness and quality of the ATE product throughout its life cycle. IV&V can be used to reduce costs, duration, and performance risk on the development project of complex ATEs. Furthermore it can be used to manage ATE development risks. IV&V is a guideline to analyse, evaluate, review, inspect, assess, and test ATE hardware and software to meet system requirements. These activities can be done in each phase of the life cycle of the ATE. IV&V makes the ATE development process more transparent. However, IV&V also consumes a lot of resources and time. According to Calhoun, IV&V can offer the following benefits to the development and maintenance of the ATE:

- Identify non-essential requirements
- Identify the lack of critical functional definition required for the execution of the command and control software of the ATE
- Fewer latent defects
- Detect ambiguous or unclear specifications
- Reduce the effort fixing individual faults
- Provide greater reliability of the ATE
- Identify reusable components (requirements document, architecture, code, testing components) that may be used in future developments
- Reduce maintenance costs
- Reduce overall life cycle costs of the ATE

Although the benefits of the IV&V are sensible, it seems to require a lot of resources to implement in the development of the ATS for the NPI. However, IV&V can be exploited for larger automatic test systems such as UPS production's test

system which is developed and maintained by the factory's test engineering department. Furthermore, most of the benefits of the IV&V can be covered by considering the areas listed in the LCC roadmap above.

The third method, called Automated Test Life-Cycle Methodology (ATLM) and represented by Dustin [30], is a structured methodology made suitable for implementation of automated testing of software. As software plays a large role in the ATS, ATLM can also be applied in the context of the desired ATS. An ATLM process consist of the steps shown in Figure 9.

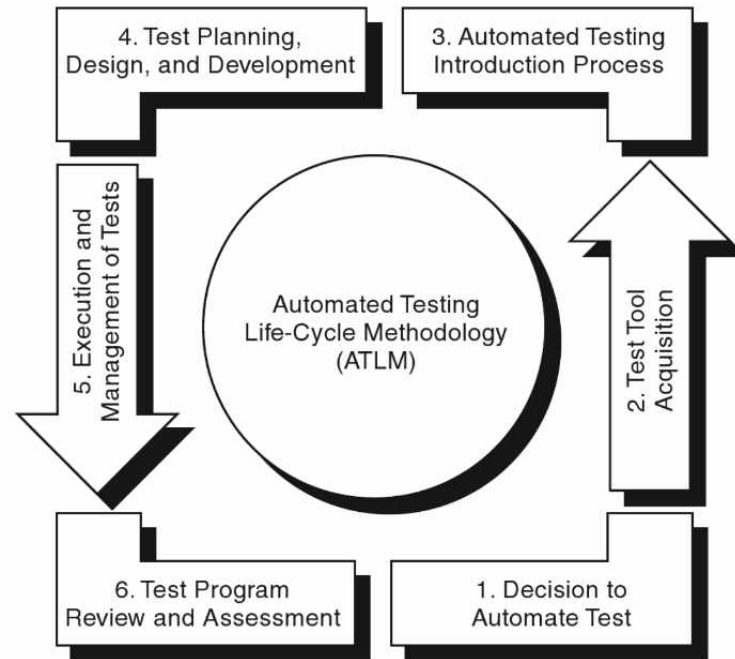


Figure 9: A flow chart of ATLM process [30].

An ATLM process begins by defining expectations for an automated test. Benefits of automating a test should be listed and it is good to acquire management support. In case of the desired ATS for the NPI, management support can be acquired from the factory's test engineering department, for example.

The next step is to acquire test tools required to perform a certain test. The process advises to review the system engineering environment, meaning reviewing the possibility of using tools already available in the factory. Tools available on the markets should be also reviewed. Different tools should be evaluated and finally purchased if necessary. In the context of this thesis, there was no need to purchase any tools. However, the used tools were not perfectly evaluated which means that there is a probability that more suitable tools could have been used. Nevertheless, the review is made as a part of this thesis.

The third step is the introduction process of automated testing consisting of analysis of test process and consideration of test tools. This step suggests that when automating a certain test, a test process should be determined and test tools should be considered according to the determined test process. This means that a

step-wise process description should be made for each test.

The fourth step consists of test plan, design and development. This step suggests that the plan is documented, test requirements are analysed, and that the test is designed and finally developed.

The fifth step consists of the execution and management of the automated test. The automated test should be executed, defects should be tracked, and test metrics should be established.

The final step consists of the evaluation of the process and reflections of improvements. In the context of the thesis project, a thesis document works as this final step of the ATLM process.

The bottom line of these methods is, that in order to extend the life cycle of the ATS, it must be maintained and improved all the time to avoid obsolescence. Moreover, all methods suggest that the life cycle of the ATS must be considered in the beginning of the designing process. The LCC roadmap introduced by Liosis [28] in his paper, suits well for considering factors affecting a length of the ATS life cycle. IV&V was found to be useful but hard to implement due to resource demand. An ATLM would suit well for a guidance for future development of the prototype. Furthermore, the ATS must be fully documented and documents, including system descriptions, user manuals, other instruction documents, must be kept up to date. These documents are useful to operators, developers and maintenance persons of the ATS. The ATLM gives guidance also for this tasks.

2.4 Uninterruptible Power Supply

An UPS is a device which prevents electric power grid failures to damage electronic devices. There are three types of UPS: static, rotary, and hybrid static/rotary. However, only static UPS is presented here. A basic concept of UPS consists of four elements: a rectifier, for converting power from alternating current (AC) to direct current (DC); a battery, providing power to the inverter when supply power is interrupted; an inverter, converting DC power back to AC power to supply electronic device; a by-pass circuit, supplying AC power to the electronic device in case the inverter fails or is overloaded [31].

Basic operation of the UPS depends on the type of the UPS. For example, when it is connected between a wall outlet and a computer, the UPS provides continuous power to the computer, filtering some or all defects which might occur in an electric grid. If supply of the UPS breaks, power is taken from batteries. When the voltage of the batteries is low, UPS commands the computer to shut down. Basic batteries can provide power at about 10-15 minutes but the time can be extended by adding more batteries.

The most commonly used UPS type is the static UPS, which contains three different configurations. An on-line UPS is normally in double conversion mode, meaning that the load, such as a computer, is continuously supplied via rectifier and inverter. In case of malfunctioning or overloading, the UPS has a static switch which bypasses rectifier and inverter, and the load is supplied straight from the wall outlet. A block diagram of the on-line UPS is shown in Figure 10.

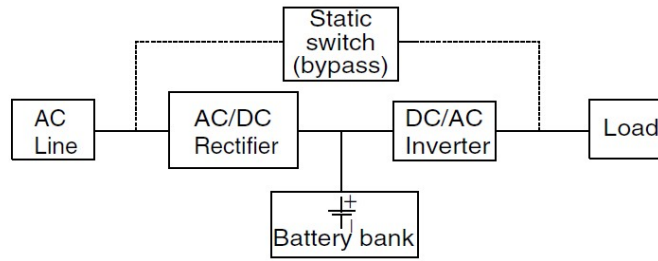


Figure 10: A block diagram of basic on-line UPS [32].

An off-line UPS, also known as the standby UPS or line-preferred UPS, supplies the load via static switch in a normal state. The rectifier is used only for charging batteries. When a wall outlet voltage has disturbance, the UPS starts supplying the load from the batteries via inverter. A block diagram of the off-line UPS is shown in Figure 11.

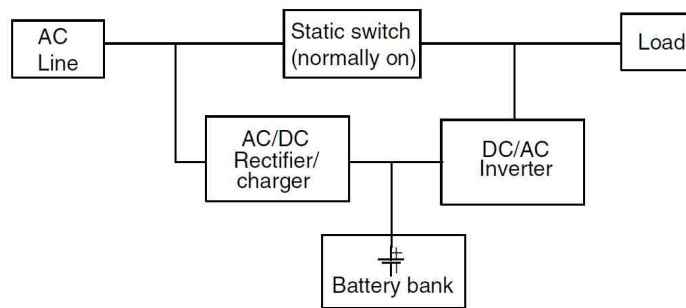


Figure 11: A block diagram of basic off-line UPS [32].

The third configuration of static UPS is the line-interactive UPS. This configuration consists of a static switch, a series inductor, a bidirectional converter, and a battery set. It can operate as an on-line UPS or an off-line UPS. A block diagram of the line-interactive UPS is shown in Figure 12 [32].

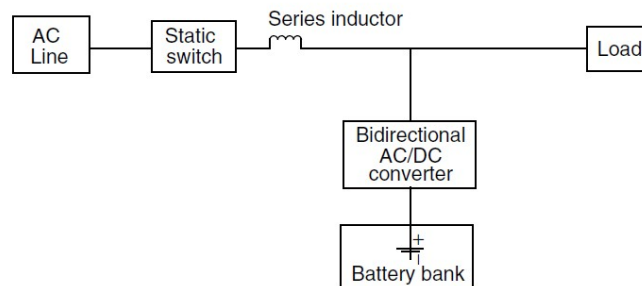


Figure 12: A block diagram of basic line-interactive UPS [32].

This thesis focuses on an on-line double conversion UPS produced by Eaton Power Quality Oy. Figure 13 presents the Eaton 9395 UPS. As the 9395 can provide power from 225 kVA to 1100 kVA, it is commonly used in the large data centers and server farms, financial services or in hospitals. In other words, this UPS model is used to ensure stable power supply to the large systems. Another UPS model used in this thesis project is the Eaton 9155 UPS which can provide power from 8 to 40 kVA, and is mainly targeted to information technology (IT) systems in server rooms, building facilities and production's automation applications. There are also smaller models for consumer markets providing continuous power for personal computers, televisions or other digital devices [33], [34]. However, the smaller devices are not developed in Finland and thus not covered in this thesis.

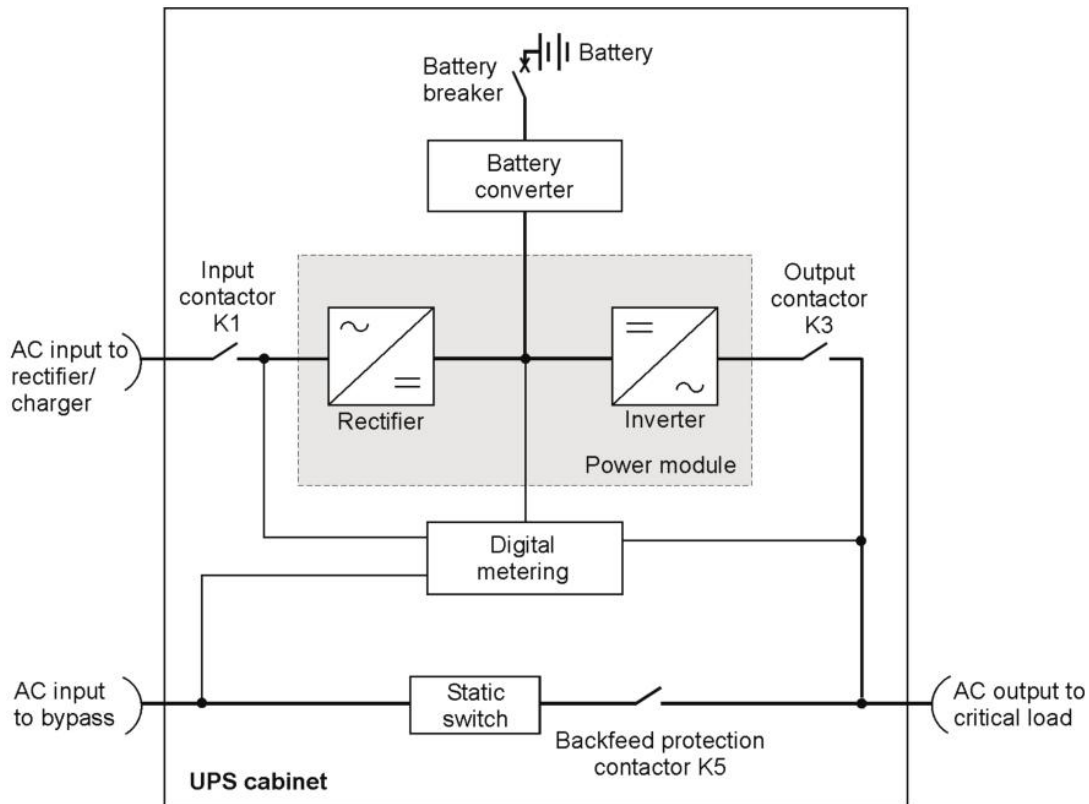


Figure 13: Main elements of the Eaton 9395 and 9155 UPS systems [35].

The larger UPS systems, such as the Eaton 9395, isolates the load equipment from all power problems, including nine problems: power failures, brownouts, sags, surges, overvoltage, switching transients, line noise, frequency variation and harmonic distortion [1]. Whereas the smaller UPS models may protect only from some of these problems, such as power cuts, power sag and power surge.

2.5 International Electrotechnical Commission Standards for UPS

According to International Electrotechnical Commission Standards (IEC) [36], industrial standard is a generally accepted requirement followed by the members of an industry. Standards are needed to ensure the safe and correct functionality of the electrical device. Turning on an electronic device will start a set of invisible events, which make the device work. These events are governed by rules and specifications that help manufacturers design safe and properly working devices.

The rules and specifications are developed with the help of thousands of experts from many organizations all around the world. Experts are working together to accomplish and agree on all the details helping to make products safer and more efficient. An international standard contains these rules for other engineers and future generations to use. Due to standards, future generations do not have to reinvent the wheel.

Standards are needed to ensure that products work together safely and as intended. In test labs, the safety of products are checked according to the industry standard. Governments rely on standards to prevent unsafe products from entering the market.

Many companies try to gain access to enter the global markets. For that, companies need information about differences of individual countries, such as basic voltage of an electric grid and its frequency. This information can be found from the international standards.

However, besides these positive qualifications of the standards, large companies can also use standards as instruments of gaining power. The experts, who were involved in the creation of the standards, can establish costly and complicated rules and specifications that might hinder smaller companies from becoming compliant. This way large companies can rule the markets. These kind of events do not serve the development of technology and are ethically questionable.

The following section describes three standards concerning UPS. These standards have been prepared by the IEC Technical Committee 22 (TC 22): Power electronic systems and equipment, subcommittee 22H (SC 22H): Uninterruptible power systems.

2.5.1 IEC-62040 Standards

The IEC-62040-3 standard [3] contains a method of specifying the performance and test requirements of a complete UPS, not of individual UPS functional units such as inverter or rectifier. The standard applies to movable, stationary and fixed electronic UPS systems delivering under 1000 V AC single or three phase fixed frequency output voltage, and integrating an energy storage system, generally connected into a DC link. The primary function of the UPS, covered by this standard, is to ensure continuity of an AC power source. The UPS may also keep the power source within specified characteristics and hence improves quality of power.

The standard contains requirements for UPS test venue, test instrumentation,

test load, and for different tests, including routine test, site test, witness test and type test. Moreover, requirements for environmental and electrical conditions where UPS should remain functional are described. Environmental conditions include elements, such as ambient temperature, humidity and altitude. Electrical conditions include elements, such as voltage variation and frequency variation.

As described in the standard [3], type tests are a series of tests intended to ensure that identical products become compatible with their specification. The standard describes functional requirements which any UPS should meet. The objective of testing is to determine this with a UPS, which is then representative of all other identical UPS devices.

Type test procedure contains 55 tests related to performance of the UPS. Type tests also include tests related to safety and electromagnetic compatibility described in IEC-62040-1 and IEC-62040-2 standards.

The IEC-62040-1 standard [37] contains general requirements and safety guidelines which any UPS must meet. The IEC-62040-2 standard [38] contains electromagnetic compatibility requirements which any UPS must meet.

The electrical type tests contains measurements of several electrical quantities such as AC/DC voltages and currents, active power, apparent power, power factor and frequency of AC voltage. In adding to these measurements, some tests require observation of voltage waveform and measuring harmonics and THD of input and output voltage and current.

The vision for the desired ATS is that it would execute all of the electrical type tests. However, only the efficiency test and the dynamic output performance test was in the scope of this thesis.

2.5.2 Efficiency and Dynamic Output Performance Tests

In the efficiency test, the UPS' efficiency is calculated from active input and output power, using Equation 1 where P_{out} and P_{in} are sums of all input/output phases' active powers.

$$\eta = \frac{P_{out}}{P_{in}}, \quad (1)$$

In addition, operational and environmental conditions and measurement instruments must fulfil requirements assigned by the UPS standards. The standards also set limit for minimum efficiency depending on UPS power ratings, voltage ratings, load, and efficiency classification. If the UPS has features such as output isolation transformer or input harmonic current filtering, measured efficiency must be decreased by 0.4 to 6.1%, depending on the application, to meet the requirement set by the IEC-62040-3 standard.

In the dynamic output performance (DOP) test, the UPS' output voltage variation is observed with an oscilloscope in different transition situations, such as the changing of the UPS devices state from normal mode to bypass mode, or the changing of UPS' load from 100% to 20%. Output voltage variation is compared limits

set by the UPS standards. In Figure 14 is showed a UPS output voltage curve, containing voltage variation of each phases (thinner lines) and different voltage variation limits (thicker lines). The oscilloscope is set to record the transition event for 1 second and recording is started 30 millisecond earlier than the dynamic event. Oscilloscope sample rate should be $10\mu\text{s}$. The curve is generated using special MS Excel tool from comma-separated values (CSV) file, containing values recorded by the oscilloscope [39]. The test process of DOP test is described more specifically in section 3.4.

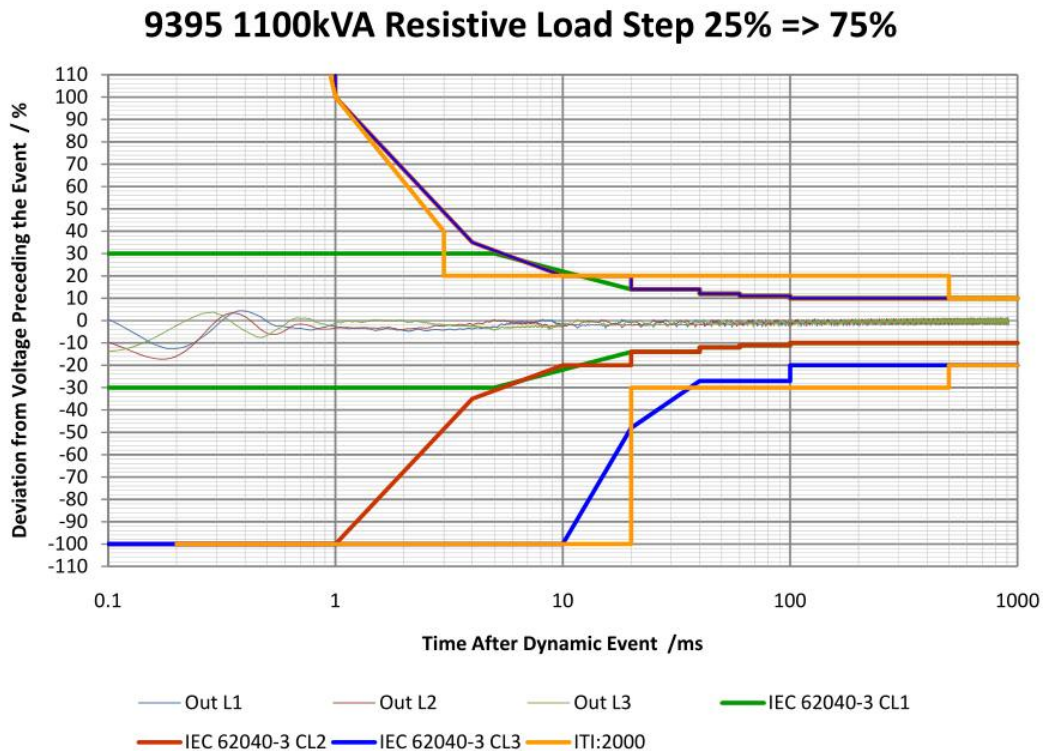


Figure 14: UPS output voltage limit curve [39].

The limit depends on what kind of load is supplied with a UPS. The IEC-62040-3 standard describes three classifications. A classification 1 (green line) is required for sensitive critical loads. A classification 2 (red line) is accepted by most types of critical loads. A classification 3 (blue line) is accepted by general purpose IT loads, such as switched-mode power supplies. Also Information Technology Industry Council (ITI) has specified an AC input voltage envelope, which typical can be tolerated by most IT equipment [40]. This specification is known as ITI (CBEMA) Curve (yellow line).

2.6 Eaton

Eaton Corporation is a international power management company with a mission to provide safe, reliable, efficient and sustainable power management solutions, and a vision to be most admired company in its market. The company was founded 100 years ago in 1911 in New Jersey, United States of America. Today, the company has approximately 73000 employees and customers in more than 150 countries. Eaton's operations are divided into five business units [41]:

- The Automotive unit (the company's first)
- The Hydraulics unit
- The Aerospace unit
- The Truck unit
- The Electrical unit

The largest unit is the Electrical unit covering half of the company's trade. The unit provides a comprehensive portfolio of electrical solutions including equipment used in quality control, distribution and the generation of electrical power, and a wide range of engineering and support services. Furthermore, as a part of the Electrical unit, Eaton's power quality business offers products for monitoring, analyzing, measuring and controlling electrical power with devices such as UPS systems [26].

Eaton is the second largest UPS manufacturer in the world with more than 45 years of experience. This experience is gained from earlier UPS brands such as Fiskars, Exide Electronics, Powerware, Best Power, MGE Protection Systems and Santak. UPS systems are divided into 3-phase systems and 1-phase systems. 3-phase systems are designed and manufactured in three locations, including China, USA and Finland [26].

The UPS factory in Finland is located in Espoo and has operated since 1962. A long history of the factory covers almost all the UPS brands mentioned earlier. Today, the factory's operations includes production and testing of 3-phase UPS systems with power range from 225 to 1100 kVA, and final configuration of UPS systems with power range from 8 to 160 kVA. In addition, the factory can provide customised UPS solutions for specific applications, such as marine and offshore. Furthermore, other parts of the factory's operations include project management and services, providing complete power quality solutions for large data centres [26].

The factory's operations also include the research and development of UPS systems. The primary task of the NPI is to design new products involved with the designing of mechanics, electronics and firmware. NPI researches and develops new technologies that result in new patents. Besides of developing new devices and technologies. Moreover, NPI supports other departments, makes changes and improvements to older devices, gives technical support to marketing, sales and maintenance departments, and production. Another part of the work is also to investigate and solve issues noticed by customer or maintenance workers [42]. During the writing of the thesis, NPI's organization was slightly changed. This change affected also the name, which is now EMEA 3 Phase Engineering.

3 Experimentation

The purpose of the experimentation was to examine automation possibilities of type tests, and clarify the resources, time and effort needed to realize the desired ATS, and also clarify the need for it.

The experimentation was made by developing a functional prototype of the ATS, and demonstrating the main functions required for the ATS. An efficiency test was chosen as a demonstration test for the prototype, since it is the most common type test performed in the NPI department, and a UPS' efficiency is often the most important single technical information for the customer.

This chapter contains a description of the development process of the prototype. Following this, a more specific description of automating the efficiency test is given. This is followed by a section, describing the final prototype specifically.

Another part of the experimentation was to examine the possibility to automate the most complex type test, which is a dynamic output performance test. The results of the experimentation are presented at the end of the Chapter.

3.1 Prototype Development Process

This section introduces a development process of the prototype. A flow chart of the development process is shown in Figure 15.

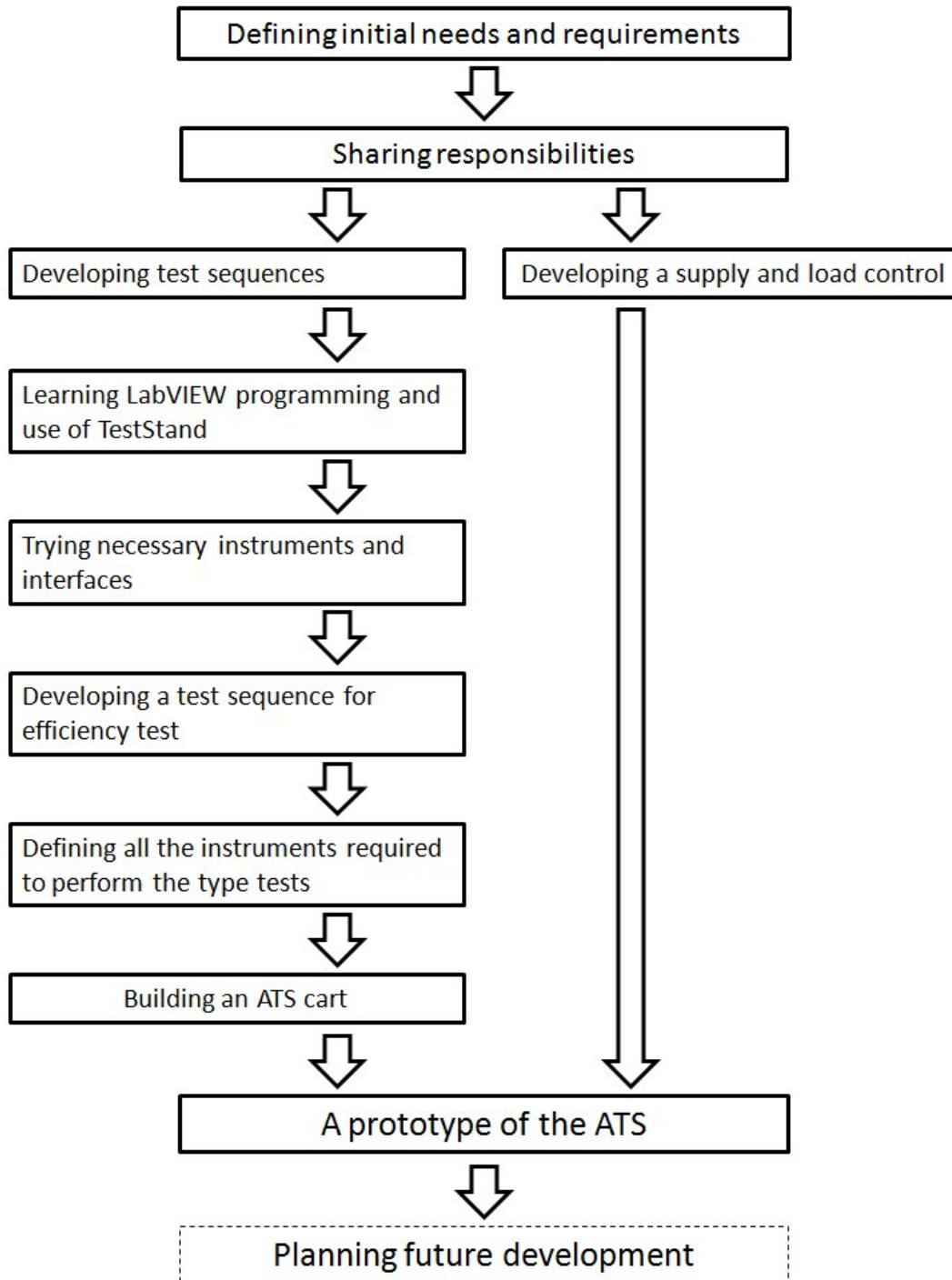


Figure 15: A flow chart of the prototype development process.

The development of the ATS prototype started by defining its initial needs and requirements. The initial requirements are described in section 2.2. The second step was to share responsibilities. Developing test sequences, communication interfaces and a cart was in the scope of this thesis. The supply and load control system was developed in parallel. However, the supply and load control system was developed

by another engineer and it is not in the scope of this thesis, except for the use of the system as a part of the prototype.

After sharing responsibilities, it was decided that developing the test sequences will be started by automating an efficiency test, first for the Eaton 9395 UPS. First, this required learning to use LabVIEW development environment and TestStand software, and second, trying all required instruments and interfaces. When the communication between LabVIEW and the measurement instruments were successfully experimented, the development of a test sequence for an efficiency test was begun.

The test sequence was made with TestStand, invoking programs made with LabVIEW. The next section contains a more specific description of automating an efficiency test. After a test sequence for efficiency test was constructed, it was decided to read through the UPS standard [3] to specify all the instruments required to perform all type tests. The ATS prototype cart was then developed according to this specification. The result of the development process is the prototype of the ATS and final prototype in the context of the thesis project. Finally, a plan for future development will be made. This includes a review of the development process, which is made as a form of this thesis.

3.2 Efficiency Test

An efficiency test was chosen as the first test to be automated. The efficiency test required the building of an interface between a PC and a digital power meter and a UPS. Furthermore, the UPS standard [3] sets requirement, concerning the efficiency test.

An interface between the WT230 power meter and LabVIEW was tested first. NI provides a ready-made LabVIEW driver, consisting of multiple VIs combined into a VI library file, to configure the power meter and to acquire measurement data from it. These VIs were modified and integrated as a part of the test sequence. However, the WT230 was not a suitable power meter for measuring efficiency of a 3-phase UPS as it required two meters to measure both input and output power. The WT1600 power meter was the better option because it had six measurement elements. NI also provided a LabVIEW driver for the WT1600, which was also modified and integrated as a part of test sequence. A GPIB bus was used to communicate between a PC and the WT1600.

Communication between a PC and a UPS was experimented next. One task was to control a UPS using LabVIEW and receive status and alarm information from it, and also the UPS' internal measurement data. An XCP communication protocol enabled all of these actions. As the test system in UPS production contained programs made with LabVIEW, it also contained LabVIEW programs to establish communication with an XCP.

The UPS production's test system also exploits TestStand to execute test sequences. A TestStand test sequence for the Eaton 9395 UPS was used as a template to develop the efficiency test sequence.

The test sequence was developed through a method of trying different features of the TestStand and developing the test sequence piece by piece. Different versions of the test sequence were saved as individual test sequence files. All the sequence files and LabVIEW files were stored to a local network drive.

After all the interfaces between different equipment were successfully experimented and implemented in the test sequence, a test installation was made and the prototype was demonstrated making the efficiency test for the Eaton 9395 UPS. The test installation is shown in Figure 16.



Figure 16: Efficiency test installation for the Eaton 9395 UPS.

A PC laptop was used to execute the test sequence. An output load of the UPS was changed manually from the load and supply control box, controlling the load and supply system of the factory's test bay 6. The system contains a control box switching relays in the relay cabinet, which switches contactors in the load and supply center, located behind the Eaton 9395 UPS. The center provides a supply voltage and an output load for the UPS. The ATS cart holds the WT1600 power meter supplied through an isolation transformer. The test wiring was made as shown in Appendix A.

The first demonstration of the efficiency test was not completely automatic since the load was changed manually. The demonstration also lacked measurements of an input voltage's harmonics and calculation of its THD. The load and supply control was added later to the final prototype, presented in the next section.

3.3 Description of the Developed Prototype

In Figure 17, a block diagram is shown containing all elements of the developed prototype. The software block consists of a PC running TestStand. TestStand executes a test sequence, invoking VIs developed with LabVIEW. The VIs include functions such as: retrieving data from and sending commands to instruments and a UPS; handling of measurement data; and writing measurement data to MS Excel spreadsheet.

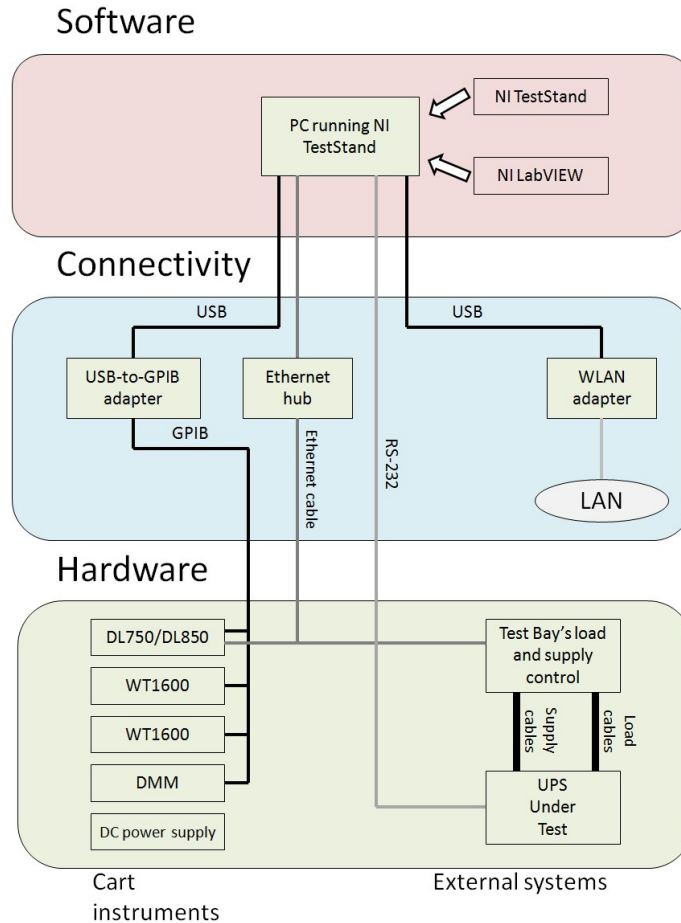


Figure 17: A block diagram of the prototype.

The connectivity block includes communication protocols used in the prototype. Ethernet is exploited to send commands to the load and supply control system, and to receive feedback from it. Ethernet is also exploited to transfer measurement data files from the DL750 and the DL850 oscilloscopes utilizing FTP. The PC communicates with measurement instruments via GPIB bus. Because the PC does not have a GPIB-card, a USB-to-GPIB converter is used to attach the GPIB bus to the PC. XCP communication protocol, utilizing RS-232 interface, is used between the PC and the UPS for sending commands to the UPS and reading alarms, state and internal measurements. The final connection interface in the block is a wireless local

area network (WLAN) interface, which is used for connecting the PC to a local area network (LAN) of the company, containing a network drive, which is used to store LabVIEW VIs, TestStand sequence-files, generated reports, documents related to the prototype hardware and software tools.

The hardware block includes measurement instruments and other equipment incorporated into the prototype cart, the UPS being tested, and the load and supply control system. The control system consists of PLCs. The PLCs are used for switching a supply voltage system and a linear or non-linear load system of one of the factory's test bays for the UPS.

3.3.1 The Prototype Cart

One initial requirement for the ATS was that it should be movable. Due to this, equipment of the prototype were placed into a cart. In Figure 18, the first model of the prototype cart is shown. The cart consists of a wheeled frame holding two drawers, a shelf and top plane. The cart also had an extension socket with eight plugs and one plug isolated with an isolation transformer for an oscilloscope. However, after specifying all of the equipment needed to perform all of the type tests, it was realized that the cart is not large enough to fit everything. A cart must include following equipment:

- Oscilloscope
- PC
- PC display
- Shelf for keyboard
- WT230 power meter or WT1600 power meter
- Another WT1600 power meter
- Digital multimeter
- DC power source
- Holder for cables
- Extension socket
- One plug isolated with isolation transformer



Figure 18: The first cart model.

A suitable cart fulfilling the requirements was ordered from Schroff company. Before ordering, a suitable cart was carefully selected and a three-dimensional model, shown in Figure 19, was created with correct dimensions to ensure that all equipment can be fitted to the cart.

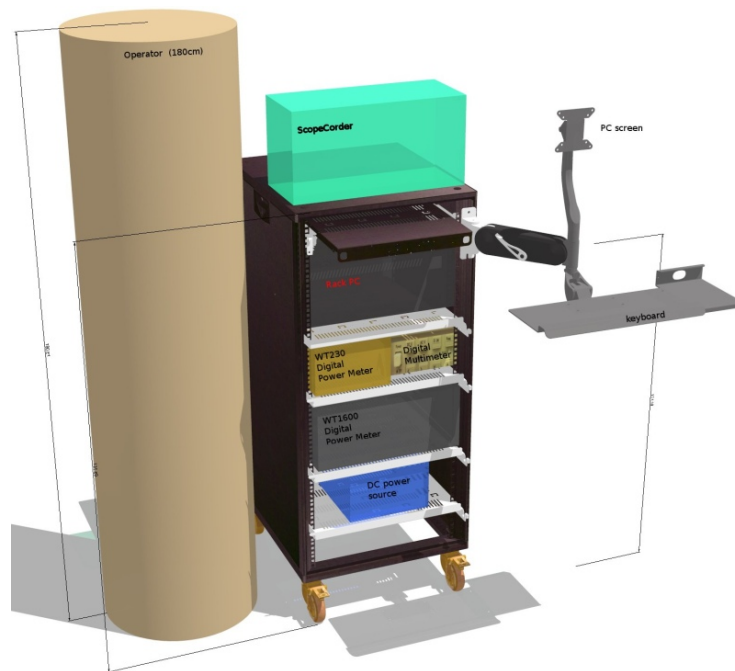


Figure 19: A 3D-model of the final cart.

In the 3D-model, all dimensions are proportional to real physical dimensions. The cart holds an oscilloscope, a rack mounted PC, a WT230 power meter, a digital multimeter (DMM), a WT1600 power meter and a DC power source. A supporting

arm, holding a PC display and a keyboard and a mouse, was planned to fit to the cart. However, the supporting arm in the 3D-model was too expensive and thus not purchased. A brown pillar acts as a 180 cm long operator and is added to Figure for a better perceiving the size of the cart in the real world.

In Figure 20, the final prototype cart is shown holding all of the necessary instruments needed to perform all of the type tests. Instruments are the DL850 oscilloscope, two WT1600 power meters, one digital multimeter, DC power source, and a rack mount PC plus a PC display. Furthermore, the cart has an extension socket providing power for each device, and an isolating transformer for an oscilloscope, separating it from the voltage potential of the DUT. Moreover, the cart is movable and has one telescope shelf for keyboard and mouse, or for use as a writing pad.

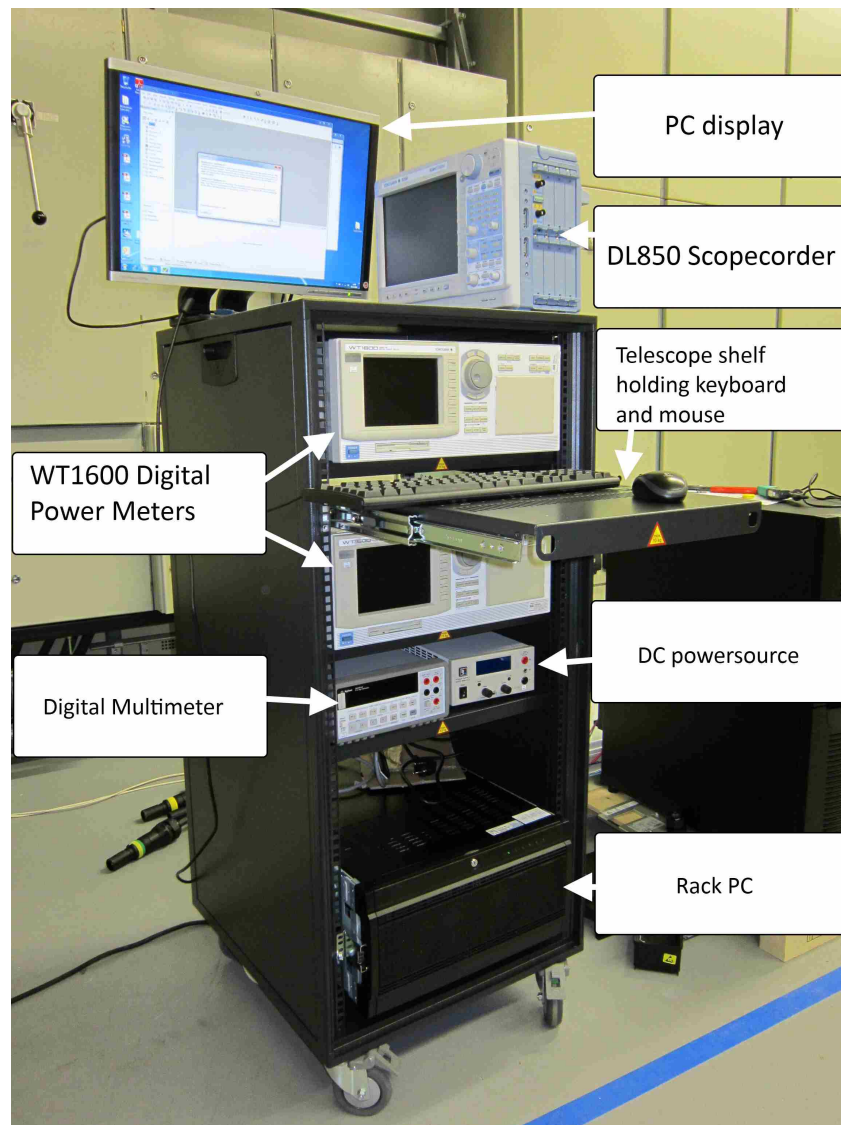


Figure 20: The final prototype cart.

3.3.2 Load and Supply Control System

The load and supply control system controls the load and supply center, which works as a stimulus subsystem for the prototype. A stimulus subsystem, introduced in section 2.1.6, was automated using PLCs shown in Figure 21. PLCs can be controlled via Ethernet using a PC.

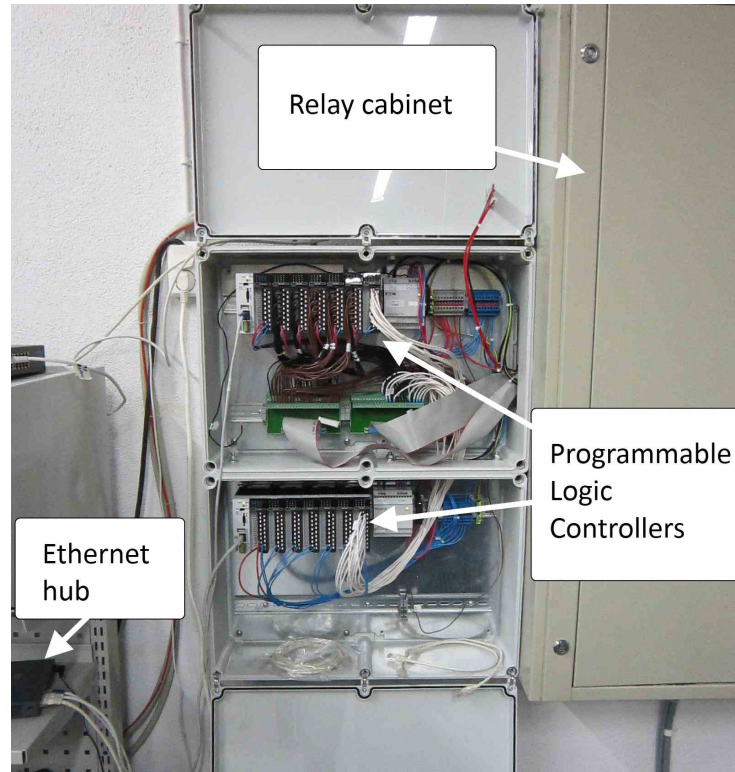


Figure 21: Load and supply control system.

3.3.3 Operator Interface

NI TestStand provides a ready-made user interface (UI) for executing test sequences. The UIs made with different programming languages, including C#, C++, LabVIEW, LabWindows CVI and Visual Basic .NET, are provided. In Figure 22, a user interface made with LabVIEW is shown.

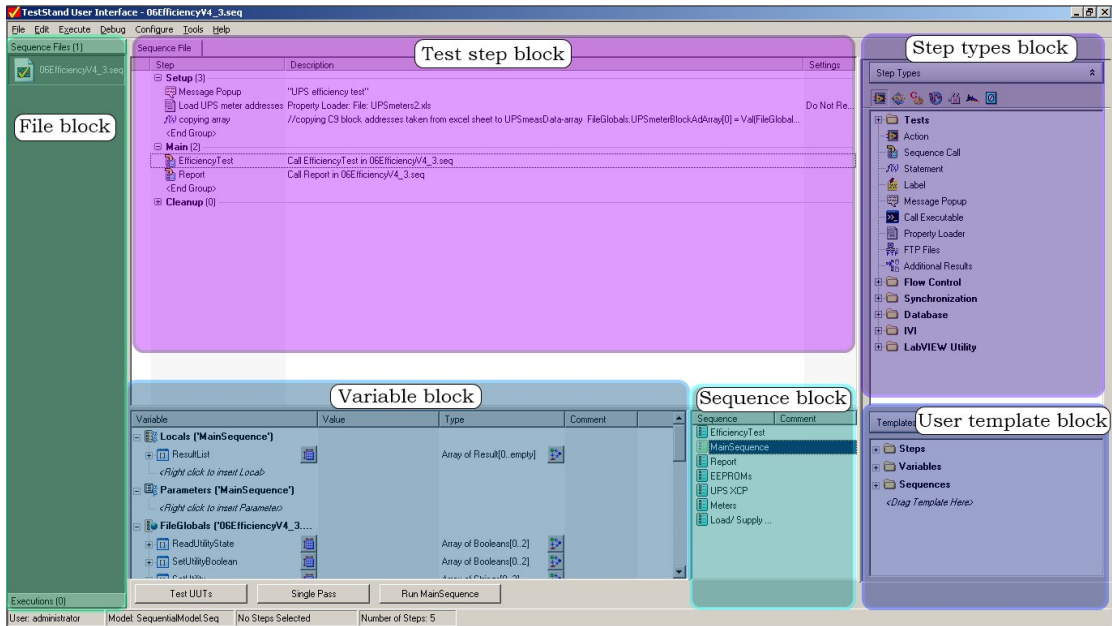


Figure 22: A user interface.

The file block contains a TestStand sequence file. The file contains a main sequence and subsequences shown in the sequence block. The test step block, shows the content of a selected sequence, in this case the MainSequence. The step types block contains actions, which can be dragged to the test step block to a part of the test sequence. The variable block contains local and global variables, which for example can be used for storing measurement data from a power meter. The user template block contains the user selected steps, variables and sequences.

3.3.4 Operation of the Prototype

The prototype performs an efficiency test for a UPS. This was demonstrated by using the prototype to perform an efficiency test for the Eaton 9155 UPS, which is a 1-phase UPS with a maximum output power of 10 kVA. An installation of the efficiency test is shown in Figure 23.

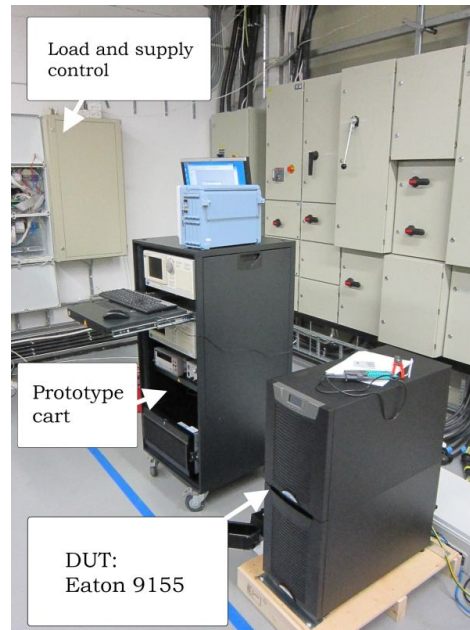


Figure 23: Efficiency test installation for Eaton 9155 UPS.

In Figure 24, a wiring circuit of the efficiency test installation is shown.

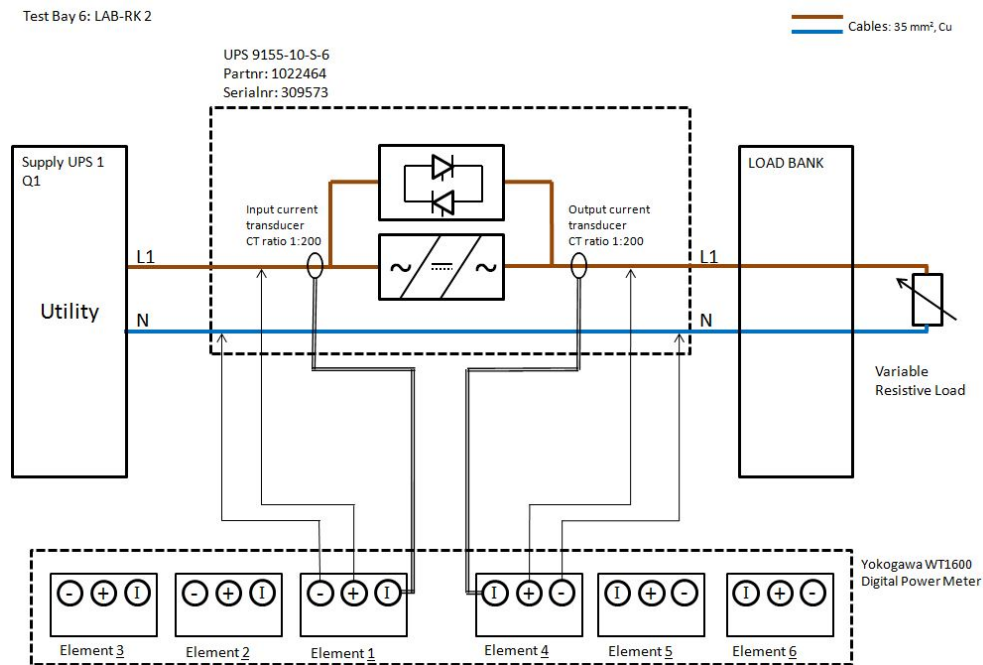


Figure 24: A wiring circuit of the efficiency test.

In Figure 25, a TestStand sequence of the efficiency test is shown. Test execution is divided into three groups: the Setup, the Main and the Cleanup. In the setup step group, a WT1600 power meter is initialized by invoking LabVIEW VI -file "InitializeWT1600.vi". The main step group contains actual steps included in the efficiency test. The "Utility ON" -step is a pop-up notice for the operator. After closing the notice, "Utility on" -action step calls "Write Load (Boolean)2.vi", which sends a command to close a utility contactor to an OPC server. The OPC server passes the command to a PLC via Ethernet and in the end to the utility contactor.

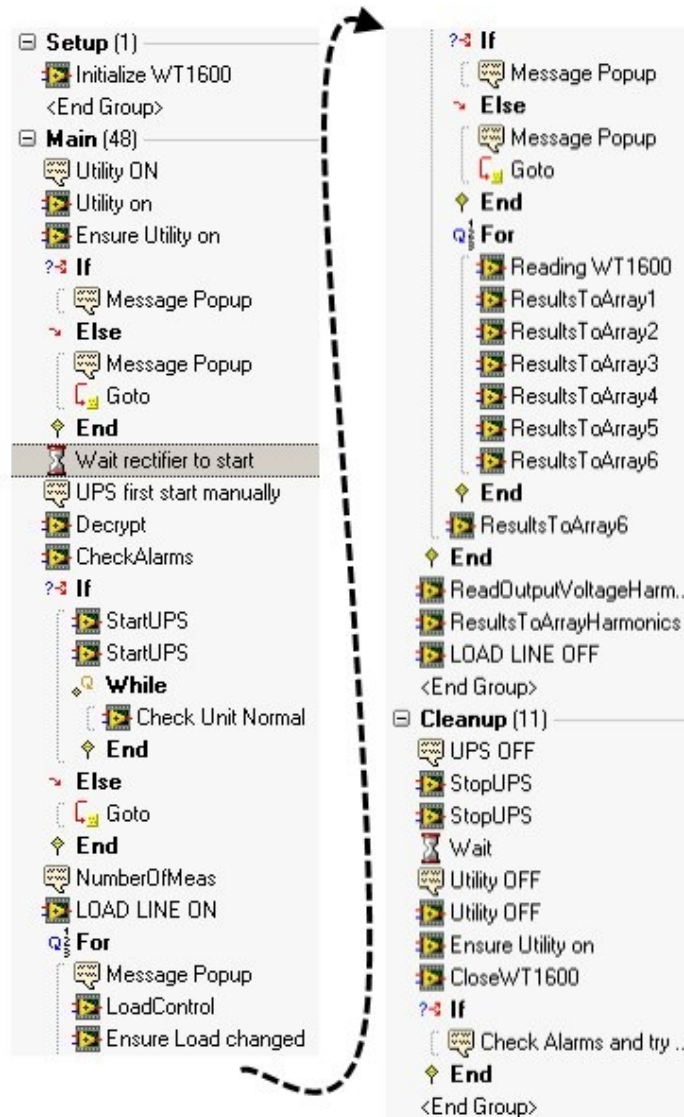


Figure 25: A TestStand sequence of the efficiency test.

"Ensure Utility on" -action step calls "Read Boolean Data Final.vi", which reads the state of the PLC. The following If-statement gives a pop-up notice, informing whether or not the utility was set successfully. In case the utility set was unsuccessful, execution jumps into the cleanup step group.

The "Waiting rectifier to start" -step stops the execution for 70 seconds which is the usual time required to start a rectifier of the Eaton 9155 UPS. The UPS must be first started manually from the device's user panel before it accepts any XCP commands.

A "UPS first start manually" -pop-up notice informs this. After starting the UPS, meaning that the UPS goes to the on-line state, "Decrypt" -action step calls "TS Encryption.vi" which enables the XCP communication between the PC and the UPS. The "CheckAlarms" -action step asks whether or not the UPS has any alarms. If alarms are not detected, "StartUPS" -action step sends "to on-line" -command to the UPS twice for successful transmission.

The "Check Unit Normal" -action step calls "TS Status.vi" which checks whether the UPS is on the on-line state or not. The status check is inside a while-loop which, is stopped when the UPS state is on-line. If alarms are detected, the execution moves to the cleanup step group. Following a pop-up notice "NumberOfMeas" requests the number of measurement samples taken with each load. The "LOAD LINE ON" -action step calls again the "Write Load (Boolean)2.vi", which this time closes the load contactors.

The following for-loop is executed 10 times and the load is changed in each cycle, starting from 100% resistive load (value of the power factor is near 1) and ending to 0% resistive load. An operator is notified with a pop-up notice and when the operator closes the pop-up "LoadControl" -action step is executed. The action step calls the "WriteLoadValue.vi" which changes the load value by sending command to the OCP server which passes it to the PLC via Ethernet.

The PLC switches the contactor which connects 100% load to the UPS' output, which is in the case of 10 kVA UPS about 5.4Ω when $U_{output} = 225.6VAC$ and $I_{output} = 41.83A$. The load change is ensured by calling the "ReadLoadValue.vi". Once again, if the load is not changed correctly, execution moves to the close step group.

Next the for-loop will be executed until variable "FileGlobals.i" reaches the value defined by the operator in the step "NumberofMeas". Inside the for-loop, the WT1600 power meter's measurements from the UPS' input and output are read by calling the "ReadWT1600_v7_only2elem.vi". The measurements contains value of six quantities, including AC voltage and current, active power, apparent power, power factor and AC voltage's frequency.

The measurement values are stored into the "FileGlobals.Results_2.Element1_All" and "FileGlobals.Results_2.Element2_All" variables. The following "ResultsToArray" -action steps calls the "ColumnsToArray_v2.vi", combining the results of each element into a two dimensional array. Results from all six elements are combined although only two elements are used here. This is done because most of the UPSs tested in the NPI are 3-phase devices.

After the for-loop, combined results of each element are combined into a two dimensional array, now containing all of the measurements from all of the elements. After all 10 load steps are executed, the "ReadOutputVoltageHarmonics" -action step calls "WT1600Harmonics.vi" which measures harmonics of the output voltage and calculates a THD. However, this step is not working properly and was left

unfinished because it is not essential in the context of the prototype.

The "ResultsToArray" -actions step calls "ColumnsToArray_Harmonics.vi" which stores measured values to "FileGlobals.Results_2.Harmonics_All" variable. The "LOAD LINE OFF" -action step calls the "Write Load (Boolean)2.vi", detaching the load system from the UPS' output.

The cleanup step group contains actions for ending the efficiency test. First the operator is noticed with a pop-up "UPS OFF" and after an operator closes the notified with a "StopUPS" -action step calls the "Create and Send XCP command_visa.vi", commanding the UPS to turn off. This is done twice for successful transmission.

Execution stops for seven seconds, until the UPS is shut off. After this, a pop-up notice informs of detaching utility from supply of the UPS. The "CloseWT1600" -action step closes the GPIB connection to the WT1600. An If-statement in the end gives a pop-up notice if UPS alarms are detected.

After executing of the efficiency test sequence, Report -subsequence is called. This sequence contains only one step "Values to Excel all measures" which calls the "Excel_report6_2.vi", storing the values in array variables "FileGlobals.Results_2.Harmonics_All" and "FileGlobals.Results_2.AllMeasures" to the MS Excel sheet. The MS Excel sheet is included in appendix B.

3.3.5 LabVIEW Virtual Instruments

In this section, the LabVIEW VIs invoked in the test sequence are introduced more specifically. Together, 16 VIs are called in the test sequence and these VIs contains multiple subVIs. The efficiency test employs, together, 79 VIs. These are listed in Appendix C.

The LabVIEW VI "InitializeWT1600.vi" is modified from NI's WT1600 LabVIEW driver example. The VI first opens a GPIB communication, and then sends configuration commands to the power meter. The configurations include a selection of wiring type, voltage range, current range, number of values shown in the power meter's display, current transformer (CT) ratio and measurement update rate. In Figure 26, the hierarchy of the "InitializeWT1600.vi" VI is shown.

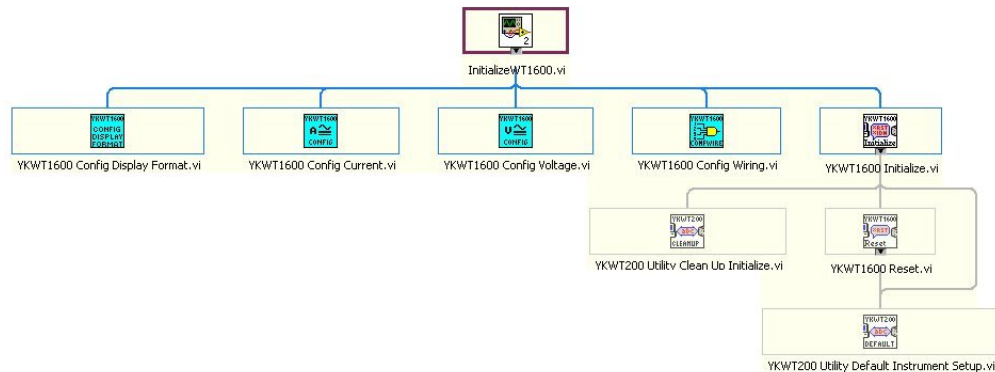


Figure 26: VI hierarchy of "InitializeWT1600.vi".

- **Write Load (Boolean)2.vi.** This VI commands the PLCs controlling supply, linear load and non-linear load contactors. Commands are sent by writing specific CoDeSyS OPC server item either one or zero. The OPC server passes the information to the PLCs via Ethernet.
- **TS Encryption.vi.** This VI calculates and saves an authorization code for enabling the XCP communication between the PC and the UPS.
- **CheckAlarms.vi.** This VI checks active alarms of the UPS and returns a string containing the number of each active alarm, and an alarm detected bit.
- **Create and Send XCP command_visa.vi.** This VI creates an XCP command, described earlier in Figure 4, and sends it to the UPS. The command can be selected from "Command" -menu or write in "Command 0x" -string control. If the command requires an authorization code, for example if the UPS start command requires it, the "Send authorization code" -button must be selected. The COM port where RS-232 is connected can be chosen from "Visa" -menu. The "Concatenated String" -string shows the whole XCP command. "Command out" -string shows a command part of the whole XCP command. "Start time of send" -number shows a elapsed time before the command is sent to the UPS. "PASS" -variable is true if the XCP command was successfully sent.
- **TS Status.vi.** This VI requests the status of the UPS via XCP. VI returns "Responce" -string containing a number of status and a "Report Text" -string containing status description.
- **WriteLoadValue.vi.** This VI changes an output load of the UPS by sending command to the OPC server. The OPC item responsible for changing the load is written in "Item" -string and the desired load value in kilowatts is written into the "Load Value" -variable. It is possible to change the load either in one output phase or each output phases of the UPS.
- **ReadLoadValue.vi.** This VI reads the current output load value of the UPS from the OPC server. The OPC item responsible for changing the load is written into the "Item to read" -string and the VI returns the "Kw arvot" -variable containing a present load value in kilowatts. It is possible to check the connected load either in one output phase or each output phases of the UPS.
- **ReadWT1600_v7_only2elem.vi.** This VI reads measurement data from the WT1600 power meter via GPIB. The VI returns measurements from each elements of the WT1600, including RMS value of AC voltage, RMS value of AC current, reactive power, apparent power, power factor and voltage frequency. The VI returns an array from each element's measurements. Additionally, in case of three-phase UPS, the "SigmaA" -array contains an average RMS value of input voltages and currents, and a sum of input active powers and apparent powers. "SigmaB" -array contains same values but from output of the UPS.
- **ColumnToArray_v2.vi.** This VI combines measurement values from individual measurement events. It is used separately for the each WT1600 element.
- **ColumnToArray_v3.vi.** This VI combines all measurement values to the final form given to the "Excel_report6.2.vi", generating a test report.

- **WT1600Harmonics.vi.** This VI reads voltage harmonics from one input phase of the UPS. It first configures the WT1600 to harmonics measurement mode. However, this VI does not read harmonics correctly. The VI was left unfinished because it was not thought essential in the context of the prototype.
- **ColumnsToArray_Harmonics.vi.** This VI combines measurement values from the individual harmonics measurement events.
- **Read Boolean Data Final.vi.** This VI reads state of the utility contactor from the OPC server. OPC items responsible for controlling utility contactors are given to "Luettavat Itemit" -string array. "Boolean data out" -array contains state of the contactors which is either false, meaning that the contactor is open, or true, meaning that the contactor is closed.
- **CloseWT1600.vi.** This VI closes the GPIB connection between the PC and the WT1600 and performs an error query to the meter. Possible errors are stored in "Error" -and "Error Message" -variables.
- **Excel_report6_2.vi.** This VI generates an Excel spreadsheet and stores values from given input arrays "array 1", "array 2", "array 7" and "array 8" to the spreadsheet. An Excel spreadsheet is generated according to Excel template "template4.2.xltx" containing named cells. Arrays are copied into the spreadsheet according to these named cells.

3.4 Dynamic Output Performance Test

Observing voltage waveforms with an oscilloscope is a pertinent part of the DOP test. For automating the test, the oscilloscope needs to be configured automatically and recorded waveform data needs to be transferred to the PC.

The test contains actions including changing the state of the UPS, and changing output load of the UPS. These actions must be done at exactly right moment, complicating test performance and automating the test.

3.4.1 Test Process

Test installation requires a DL750 or DL850 oscilloscope to observe voltage waveforms. The oscilloscope's voltage probes are connected to each input/output phase of the UPS. A current probe is connected to one output phase. The oscilloscope is initialized to trigger to this current. Moreover, the oscilloscope's sample rate is set to 100 kilo samples per second, and the start point of the recording is set to 30 milliseconds before the triggering point. The DOP test includes five dynamic events:

1. From normal mode to battery mode with a full load
2. From battery mode to normal mode with a full load
3. From normal mode to bypass mode when overload is applied
4. Load step in normal mode
5. Load step in battery mode

Changing the UPS state from normal mode to battery mode must be timed exactly when the input voltage waveform passes through zero and again when input voltage waveform is at its peak. In this case, the input supply of the UPS is interrupted for a minimum of one second, causing a shift from normal state to battery state. However, due to delays caused by different interfaces, the correct timing for sending the command must be explored and ensured manually. After this the waveform can be saved and transferred to the PC, using the developed LabVIEW VIs.

In the case of changing UPS state from battery to normal mode, in other words returning the input supply, the input voltage waveform can be at any angular position. The same rule holds true also in the case of changing UPS state from normal to bypass by applying an overload to the UPS.

In the case of load step, the UPS must be in normal state with a full load and load is reduced to 20% at the same time when the output voltage is at its peak value. This is repeated with UPS on battery mode.

Three major challenges make automating the DOP test difficult and time consuming. The first challenge is the changing state of the UPS and making the load step at the right angle of input voltage. The second challenge is that the successful load step requires two parallel load systems. Only one load system was made controllable with LabVIEW during the thesis project. The third challenge is to automatically compare the voltage variation caused by dynamic event, to limits defined

by the UPS standard. Due to these challenges, automating the DOP test requires more time and resources than would be saved through automation, and thus it is not valuable to automate the DOP test.

In Figure 27, a process of the DOP test is shown.

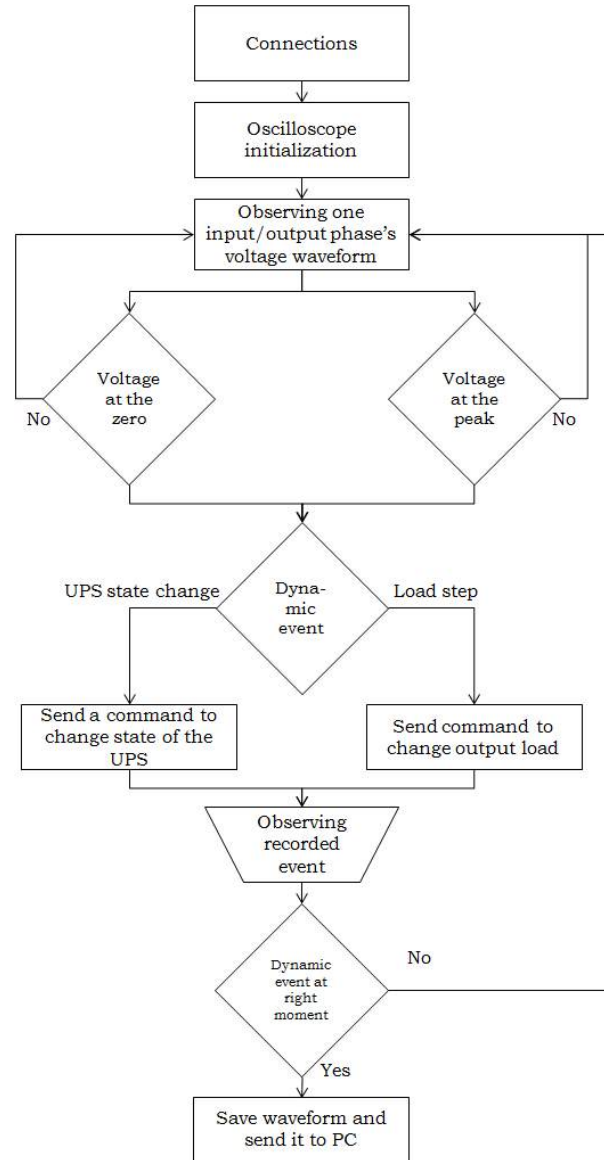


Figure 27: Process of the DOP test.

3.4.2 LabVIEW Virtual Instruments

Experimenting the DOP test resulted a communication interface between a LabVIEW VI and a Yokogawa DL750 and a DL850 oscilloscopes. The commands and responses are transferred via GPIB bus and larger measurement data files are transferred via Ethernet. The following six VIs were made for transferring data between a PC and the oscilloscopes:

- **InitDL750.vi**. This VI initializes the DL750 or DL850 oscilloscope. It opens a GPIB communication to the PC, sets timebase and configures display of the oscilloscope.
- **Aquisition.vi**. This VI sends a GPIB command to the DL750/DL850 to start acquisition. With input parameters, it is possible to choose which channels are used, and trigger mode and its source signal.
- **DL750image_v2.vi**. This VI retrieves a display image of the DL750/DL850 via GPIB. The location of the retrieved image is defined as the input parameter.
- **CloseDL750.vi**. This VI closes the GPIB communication and performs an error query to the DL750 or the DL850.
- **SaveWVF.vi**. This VI sends a GPIB command to the DL750/DL850 to save recorded waveforms into a CSV-file and store it into the hard drive. The name of the CSV-file is defined as the input parameter.
- **DL750FTP_v3.vi**. This VI retrieves a CSV-file from the hard drive of the DL750/DL850 via Ethernet using FTP. The path of the CSV-file and IP address of the DL750/DL850 is defined as the input parameters.

3.5 Results

The experimentation resulted a functional prototype executing the efficiency test automatically. The prototype can be used only for indicative measurement of UPS' efficiency because it does not fulfil the requirements set by the UPS standard. At least the measurement of input voltage harmonics and THD, and assessment of measurement uncertainty is needed to fulfil the requirements.

Via making the prototype and examining the DOP test, interfaces between the following equipment were experimented:

- PC - WT1600
- PC - WT230
- PC - DL750
- PC - DL850
- PC - UPS
- PC - Load and supply control system

These experimented interfaces will be useful in the future testing. However, some work is still required to integrate these interfaces as a part of another test.

The examination of the DOP test resulted a test process description. However, automating the DOP test was found to consume more time and efforts than would be saved through automation and thus it is not valuable.

The experimentation proved that automating even one type test requires a lot of time and resources. Due to this, an ATS for type test is not the best solution for reducing time and resources consumed by testing.

4 Conclusions and Future Work

The aim of this thesis was to clarify the need for the automatic test system for type tests of the UPS, and clarify the requirements needed to realize it. The ATS was considered as a solution to reduce time and resources consumed by testing processes made in Eaton Power Quality Oy's product development department.

In Chapter 2, an automatic test system was reviewed based on the descriptions of earlier publications. A basic element of an ATS was introduced and compared against to the developed prototype.

Preliminary requirements for the ATS, as specified before starting the thesis project, were also reviewed. The prototype was then based on these requirements. However, the requirements were treated more as a guide than being strictly followed.

The life cycle of the ATS was reviewed, along with three methods helping to extend this life cycle. The motivation behind this was that the previous ATS was obsolete and discarded as it was unused by employees, and also neither documents nor instructions existed on how to use it. The earlier ATS lacked a life cycle management plan and when the engineer who developed the system left from the company the system was not maintained any more.

UPS and IEC standards, concerning the UPS, were introduced. The chosen type tests, the efficiency test and the dynamic output performance test, were reviewed. At the end of the Chapter, Eaton Corporation and its product development department in Finland was introduced.

The experimentation made for clarifying the need for the ATS and the requirements necessary to realize it were presented in Chapter 3. This was done through the prototype described in the Chapter, and also the development process of the prototype was described.

Additionally, a closer examination of the dynamic output performance test was made. Furthermore, the experiment conducted to automate the test resulted in a conclusion that it is not sensible to automate the test. However, as a result of the experiment an interface between a PC and the DL750 (and the DL850) was attempted and LabVIEW programs were made for transferring and receiving data between them.

Completed reviews and the experimentation conducted lead to a conclusion that the realization of an automatic test system that is able to perform all the type tests, requires a large amount of time and resources. Due to this, the automatic test system for type tests is not considered as the best solution to reduce the time and resources consumed by testing. However, this does not mean that the work completed was in vain. Performing an efficiency test with the prototype is now faster than executing it manually. Although the prototype cannot be used to perform an official efficiency test for the UPS, it is still valuable in indicative tests. The prototype cart works as a definitive place for equipment and tools used in different tests. The rack PC in the cart can be used for developing LabVIEW programs and TestStand test sequences, and executing other utility software that help in UPS testing processes. Documents related to testing, such as test results and test instructions, can be stored on the PC.

The thesis meets the initial aim well. However, the aim has changed during the project significantly. At the beginning of the project, the aim of the thesis was to make a TestStand test sequence for each of the electrical type tests. However, this was soon found to be too large of a task for the thesis and the work was then limited to two type tests. The new aim was to make an ATS able to perform the efficiency test and the DOP test. However, as mentioned before automating the DOP test is not sensible. Due to this, the whole ATS for the type tests beginning to appear as too large of a project to be beneficial realized at all. This resulted in changing the aim of the thesis to what is seen in its final form. The unsuccessful specification of the aim in the beginning of the thesis project resulted in extended writing process for the thesis.

Questioning the need of the ATS resulted in the examination of other solutions to the initial problem. In the following section, suggestions for future development and scenarios are discussed.

Future Development

The conclusion that it is not beneficial to realize the ATS for type tests led to other suggestions to solve the initial problem. Besides the type tests it would be more beneficial to automate a regression DVT test for the new UPS under development. The test consists of basic actions such as commanding the UPS on and off, and switching utility on and off. These actions can be automated with little effort. The regression DVT test is performed each time than a new firmware version is released to the UPS to check that the UPS' basic functionality has remained intact.

It would also be beneficial to consider the possibility to automate or assist performance of forthcoming design verification and design validation tests for the new UPS. The tests include most typical tests for the UPS and thus would save time if automated. Each test should be documented, and if possible make a step-by-step instruction of how the test is performed.

For better exploitation of the prototype, the storing of measurement data to an Excel spreadsheet should be improved. Currently, the data is stored to an Excel spreadsheet in the end of the efficiency test sequence. The data is lost if the execution of the test sequence is stopped for some reason. A better solution is to write the data to the Excel spreadsheet right after it is received from a measurement device. The action of receiving data from a measurement device and storing it to an Excel spreadsheet is one of the most common actions and thus it must be improved such a level that anyone involved in the product's development can do it.

Through the making of LabVIEW VIs for the prototype, it was found that LabVIEW is a handy tool for making small utilities aiding in different test processes. For better management of the utility software development, a software versioning and a revision control system should be used and its structure should be determined. Also, a common programming style should be agreed upon before developing a new LabVIEW programs. NI provides best practises for TestStand [43], [44] and Labview [45], [46] programming.

A life cycle management process should be considered in case of each equipment use in test processes including the prototype, measurement devices, assistance tools, and utility software. The methods described in Section 2.3 can help in this task. One practise for managing life cycles is to organize a team responsible for developing and managing the equipment. The team should use an issue tracking system for better management of issues in the testing processes. The Atlassian JIRA [47], which is already used in other projects in the product development department, could be used also for this purpose.

These aforementioned concrete suggestions should be taken into consideration when deciding upon a next objective for resolving the initial problem by improving the testing processes.

References

- [1] Eaton Corporation. "The Nine Power Problems", Internet: www.switchon.eaton.com/resources/power-101/nine-power-problems.aspx, 2011 [Nov. 12, 2011].
- [2] Cooper, R.G. *Winning at New Products: Creating Value Through Innovation*. 4th ed., Basic Books, 2011, ISBN: 0465025781.
- [3] International Electrotechnical Commission. "IEC 62040-3 Uninterruptible power systems (UPS) - Part 3: Method of Specifying the Performance and Test Requirements." IEC Standard 62040-3/Ed.2, Mar. 14, 2011.
- [4] Kokkonen, P. "UPSin tyyppitestauksen automatisointi." B.Sc. thesis, Espoo - Vantaa University of Applied Sciences, Espoo, Finland, 1997.
- [5] Greenspan, A.M. "Automatic Test Systems Dedicated or Integrated." IEEE Transactions on Instrumentation and Measurement, vol. IM-20, no. 4, pp. 191-198, Nov. 1971.
- [6] Bakshi, U.A., Bakshi, A.V. *Electronic Instrumentation*. Technical Publications, 2009, 492p, ISBN: 8184314469
- [7] Mendes L.A., Back N. and Oliveira G.H.C. *Designing Automated Test Systems: An Adapted Methodology Inspired on Pahl and Beitz's Systematic Approach*. Mechatronics Engineering Department, Pontifical Catholic University of Paraná, Curitiba, PR 81611-970, Brazil, DOI: 10.1016/j.rcim.2009.04.006, 2009.
- [8] Flynn, M.J. "Regression Analysis of Automatic Measurement Systems." D.S. dissertation, George Washington University, USA, 2009.
- [9] Josifovska, S. "The Father of LabView." IEE Review, Vol. 49, no. 9, pp. 30-33, Sept. 2003.
- [10] National Instruments Corporation. "The Benefits of Programming Graphically in NI LabVIEW." Internet: www.ni.com/labview/whatis/graphical-programming/, 2012 [Jan. 30, 2012].
- [11] Mackin, S. "A test Engineer's Evaluation of Graphical Programming". Internet: <http://www.home.agilent.com/agilent/editorial.jsp?cc=IN&lc=eng&ckey=1000001168:epsg:tcn&nid=-536900139.0.00&id=1000001168:epsg:tcn>, [Jan. 30, 2012]
- [12] Agilent Technologies. "Agilent VEE 9.3 Brochure." Internet: <http://cp.literature.agilent.com/litweb/pdf/5989-9833EN.pdf>, Oct. 27, 2011 [Mar. 12, 2012].

- [13] Agilent Technologies. "HP VEE 5.0 Brochure." Internet: http://www.home.agilent.com/upload/cmc_upload/All/EPSPG086072.pdf?&cc=NL&lc=dut, Apr. 1998 [Mar. 12, 2012].
- [14] National Instruments Corporation. "NI TestStand: TestStand 2010 Evaluation Guide." Internet: www.ni.com/pdf/manuals/350863g.pdf, Oct. 2010 [Jan. 31, 2012].
- [15] National Instruments Corporation. "TestStand Benefits." Internet: zone.ni.com/devzone/cda/tut/p/id/4914, May 24, 2010 [Jan. 31, 2012].
- [16] Yokogawa Electric Corporation. "WT210/WT230 Digital Power Meter User's Manual." 2009.
- [17] Yokogawa Electric Corporation. "WT1600 Digital Power Meter User's Manual." 2009.
- [18] Yokogawa Electric Corporation. "DL750 Digital Power Meter User's Manual." 2009.
- [19] ICS Electronics. "GPIB 101 - A Tutorial About the GPIB Bus." Internet: http://www.icselect.com/pdfs/ab48_11.pdf, Oct. 12, 2009 [Feb. 26, 2012].
- [20] Sethunadh, R. "Using New Instrument Interface Standards to Increase Automatic Test System Performance." *Autotestcon*, IEEE, pp. 677-682, 26-29 Sept. 2005. doi: 10.1109/AUTEST.2005.1609216.
- [21] Spurgeon, C.E. *Ethernet: the definitive guide*, O'Reilly Media Inc., 498 pages, 2000, ISBN: 1565926609.
- [22] Eaton Corporation. "X-format Communications Protocol (XCP) Specification." Internal document of Eaton Corporation, Rev. C, 2001.
- [23] Eaton Corporation. *XCP Protocol Development Suite*. Internal document of Eaton Corporation, Rev. D0, 2005.
- [24] Eaton Corporation. "MX: Instructions for Modifying a 9395 so that It May be Used as an Adjustable Power Supply." Internal document of Eaton Power Quality Oy. Document name: MX.v3.pdf, 2008.
- [25] Eaton Corporation. "Factory Acceptance Testing, Future Facilitates and Green Load Concept." Internal document of Eaton Power Quality Oy. Document name: HPO Test Floor - Green (Electronic) Load -Rev B.ppt. 15 Oct. 2008.
- [26] Eaton Power Quality Oy. "Presentation: UPS Factory in Finland." Internal document of Eaton Power Quality Oy, Company's Intranet: [/Yritysesitykset/EatonHPOfinal10112011.ppt](#), Nov. 10, 2011 [Jan. 13, 2012].

- [27] Rask, S. "System Requirement Specification (SRS): Data Acquisition and Automated Test Systems: NPI/LSG." Internal document of Eaton Power Quality Oy, 2010.
- [28] Liosis, A.C. "A Prime Contractor's Perspective on Total ATS Development and Life Cycle Cost (LCC) Support Responsibility." Autotestcon Proceedings, IEEE Systems Readiness Technology Conference, pp.313-318, 2001.
- [29] Calhoun, C.C. "Applying Independent Verification and Validation to the Automatic Test Equipment Life Cycle." Aerospace and Electronic Systems Magazine, IEEE, vol. 13, no. 7, pp.37-42, Jul., 1998.
- [30] Dustin, E., Rashka, J., Paul, J. *Automated Software Testing: Introduction, Management, and Performance*. Addison-Wesley Professional, pp. 7-14, 1999, ISBN: 9780201432879.
- [31] Kusko, A., Thompson, M.T. *Power Quality on Electrical Systems*, McGraw-Hill Professional Publishing, Blacklick, OH, USA, 05/2007, ISBN: 9780071470759.
- [32] Emadi, A., Nasiri, A., Bekiarov, S.B. *Uninterruptible Power Supplies and Active Filters*. CRC Press, 2005, ISBN: 9780849330353.
- [33] Eaton Corporation. "Eaton 9395 225-110 kVA Brochure." Internet: <http://powerquality.eaton.com/Products-services/Backup-Power-UPS/9395.aspx?cx=79>, 2011 [Sept. 27, 2011].
- [34] Eaton Corporation. "Eaton Protection Station Datasheet." Internet: <http://powerquality.eaton.com/Products-services/Backup-Power-UPS/Protection-Station.aspx?cx=79>, 2011 [Sept. 27, 2011]
- [35] Eaton Corporation. "Eaton 9395 UPS, 225-275 kVA / 300kVAPF0.8: User's and Installation Guide." Internet: <http://powerquality.eaton.com/Products-services/Backup-Power-UPS/9395.aspx?cx=79>, 2011 [Feb. 21, 2012].
- [36] International Electrotechnical Commission. "Information About Standars for General Public." Internet: http://www.iec.ch/perspectives/general_public/, 2012 [Jan. 7, 2012].
- [37] International Electrotechnical Commission. "IEC 62040-1: Uninterruptible Power Systems (UPS) - Part 1: General and Safety Requirements for UPS." IEC Standard 62040-1/Ed.1, June 11, 2008.
- [38] International Electrotechnical Commission. "IEC 62040-2: Uninterruptible Power Systems (UPS) - Part 2: Electromagnetic Compatibility (EMC) Requirements." IEC Standard 62040-2/Ed.2, Oct. 19, 2005.
- [39] Uusitalo, J. "UPS Output Dynamic Performance Evaluation Tool, Ver 1.04." Internal document of Eaton Power Quality Oy. Document name: UPS Output Dynamic Performance Evaluation Tool.pdf. Apr. 27, 2011.

- [40] Information Technology Industry Council. "ITI (CBEMA) Curve Application Note." Internet: <http://www.itic.org/clientuploads/Oct2000Curve.pdf>, 2005 [Mar. 15, 2012].
- [41] Eaton Corporation. "Our Company." Internet: www.eaton.com/Eaton/OurCompany/index.htm, 2012 [Feb. 6, 2012].
- [42] Karola R. "Presentation: NPI Engineering". Internal document of Eaton Power Quality Oy, Company's Intranet: [/Perehdytys/NPI.ppt](#), Feb. 5, 2008 [Jan. 13, 2012].
- [43] National Instruments Corporation. "About the TestStand Process Models." Internet: <http://zone.ni.com/devzone/cda/tut/p/id/2694>, Sept. 6, 2006 [Feb. 26, 2012].
- [44] National Instruments Corporation. "Best Practices for NI TestStand Process Model Development and Customization." Internet: <http://zone.ni.com/devzone/cda/tut/p/id/7958>, Sept. 26, 2008 [Feb. 26, 2012].
- [45] National Instruments Corporation. "Software Engineering with LabVIEW." Internet: <http://zone.ni.com/devzone/cda/tut/p/id/7117>, May 2, 2011 [Feb. 26, 2012].
- [46] National Instruments Corporation. "Best Practices for Managing NI LabVIEW Applications Using the Project Explorer." Internet: <http://zone.ni.com/devzone/cda/tut/p/id/7197>, Dec. 6, 2011 [Feb. 26, 2012].
- [47] Atlassian Corporation. "JIRA Project Tracking Tool Overview." Internet: <http://www.atlassian.com/software/jira/overview>, 2012 [Feb. 26, 2012].

Appendices

A Efficiency Test Wiring Diagram

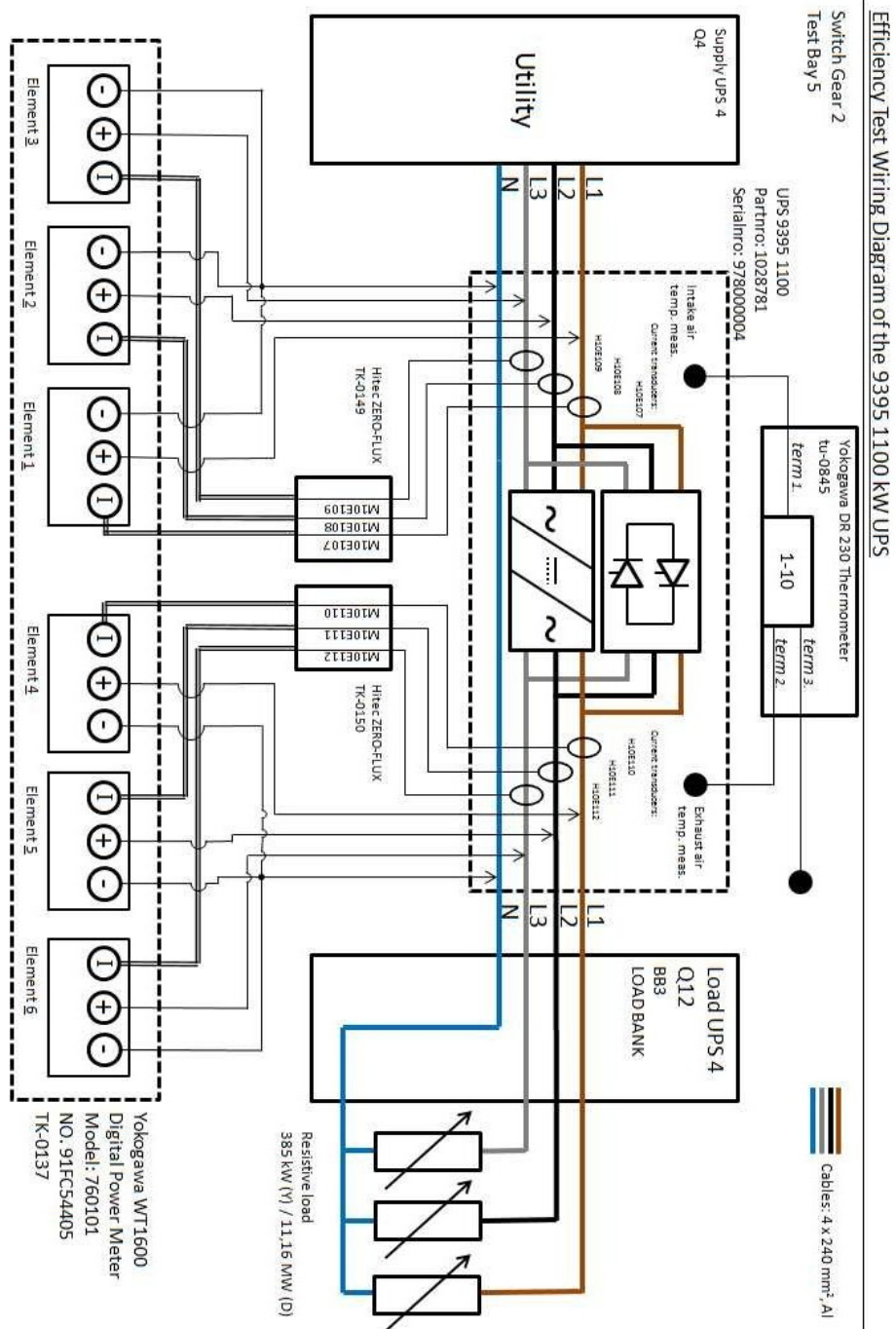


Figure A1: Efficiency test wiring diagram.

B Report of the Efficiency Test

		Resistive load									
		100 %	90 %	80 %	70 %	60 %	50 %	40 %	30 %	20 %	0 %
U_input	L1	234,27	234,15	234,72	234,72	234,90	234,61	234,93	234,78	235,09	235,53
	L2										
	L3										
I_input	L1	45,07	40,82	36,51	32,49	28,11	24,06	19,87	15,92	11,87	5,10
	L2										
	L3										
P_input	L1	10513,00	9503,00	8507,33	7558,00	6518,00	5541,00	4536,00	3559,00	2553,00	558,00
	L2										
	L3										
	total	10513,00	9503,00	8507,33	7558,00	6518,00	5541,00	4536,00	3559,00	2553,00	558,00
S_input	L1	10557,00	9558,00	8569,00	7625,00	6604,00	5645,00	4668,00	3738,00	2790,00	1202,00
	L2										
	L3										
	total	10557,00	9558,00	8569,00	7625,00	6604,00	5645,00	4668,00	3738,00	2790,00	1202,00
pf_input	L1	1,00	0,99	0,99	0,99	0,99	0,98	0,97	0,95	0,92	0,46
	L2										
	L3										
	average										
f_input	L1	50,02	50,02	50,02	50,02	50,02	50,01	49,98	50,02	49,96	49,96
	L2										
	L3										
	average										
U_output	L1	225,60	225,99	226,37	226,77	227,03	227,42	227,81	228,14	228,50	229,63
	L2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	L3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
I_output	L1	41,83	37,71	33,51	29,53	25,20	21,04	16,79	12,78	8,50	0,00
	L2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	L3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
P_output	L1	9437,00	8523,00	7586,67	6696,00	5721,00	4785,00	3824,00	2915,00	1942,00	0,00
	L2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	L3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	total	9437,00	8523,00	7586,67	6696,00	5721,00	4785,00	3824,00	2915,00	1942,00	0,00
S_output	L1	9437,00	8523,00	7586,67	6696,00	5722,00	4785,00	3824,00	2915,00	1942,00	0,00
	L2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	L3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	total	9437,00	8523,00	7586,67	6696,00	5722,00	4785,00	3824,00	2915,00	1942,00	0,00
pf_output	L1	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	#DIV/0!
	L2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	L3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	average	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
f_output	L1	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!
	L2	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	L3	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
	average	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
U_battery											
I_battery											
P_battery											
Efficiency		0,90	0,90	0,89	0,89	0,88	0,86	0,84	0,82	0,76	0,00

Figure B1: Efficiency test report.

Create and Send XCP command_ visa.vi		
TS Status.vi	C9-string to Unsigned Word (U16).vi Read XCP data.vi Floating point SGL.vi C9-string to 32.vi Get string from data.vi Get XCP data from offset.vi Alarm map offset.vi Map Format.vi Meter map offset.vi XCP build send receive decode.vi Com open.vi Hex to String.vi Decode XCP string.vi clear buffer.vi wait.vi Create and Send XCP command_ visa.vi clear buffer no read.vi Build C952 string.vi Status.vi Out of time.vi XCP check sum.vi Unsigned Long (U32) to C9-string.vi Unsigned Byte (U8) to C9-string.vi	2 2 2 2 2 2 2 2 2 3 3 3 3 3 4 2 3 3 3 3 3 3
WriteLoadValue.vi	Trim Whitespace.vi whitespace.ctf	2 2
ReadLoadValue.vi	Trim Whitespace.vi whitespace.ctf	3 3
ReadWT1600_v7_only2elem.vi	ReadWT1600sigmas_v2.vi ReadWT1600OutputElements_v2.vi ReadWT1600InputElements_v2.vi WT1600ConfigDisplaySignalItems.vi WT1600ConfigDisplayOutputItems.vi YKWT1600 Read Numeric Normal.vi WT1600ConfigDisplayInputItems.vi YKWT1600 config Numeric Normal.vi	
ColumnToArray_v2.vi		
ColumnToArray_v3.vi		
WT1600Harmonics.vi	YKWT1600 Config Display Numeric Harm List.vi YKWT1600 Config Display Numeric Harm.vi YKWT1600 Read Numeric Harmonics.vi YKWT1600 Config Numeric Harm.vi YKWT1600 Config Display Format.vi YKWT1600 Config Harmonics.vi	
ColumnsToArray_Harmonics.vi		
Read Boolean Data Final.vi	Trim Whitespace.vi whitespace.ctf	4 4
CloseWT1600.vi	YKWT1600 Close.vi YKWT1600 Error Query (multiple).vi YKWT1600 Error Query.vi	
Excel_report6_2.vi	MS Office Report.vi	
Number of VI	79	

Figure C2: ATS virtual instruments continue.