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OiTec Oy Safety Power Distribution Unit Tester

Metropolia University of Applied Sciences

Bachelor of Engineering

Electronics

Bachelor's Thesis

31 January 2021

Author Title Number of Pages Date	Julien Tenkanen OiTec Oy Safety Power Distribution Unit Tester 38 pages + 2 appendices 31 January 2021
Degree	Bachelor of Engineering
Degree Programme	Electronics
Professional Major	Electronics
Instructors	Jussi Tuppurainen, Project Manager Anssi Ikonen, Head of Degree Programme

The goal of this thesis work was to design the hardware and software for a functional PDU Tester and fabricate it. The Tester hardware consists mainly of relays and DAQs to control the switching mechanism of the relays as well as read analog and digital signals coming from the PDU. A set of cables connecting the Tester and the PDU are the main method of sending and receiving signals between the two devices.

Since there was a need to automate the testing process, as well as create detailed documentation of the results, a test sequence was made with TestStand to operate the DAQs digital and analog input and output. TestStand will also compile a report with detailed pass/fail results for each measured element that is to be tested in the PDU. The main goal of this is to streamline the process of finding the faulty connections within the PDU so that the exact problem points can be pinpointed at a cursory glance.

Because the Tester functionalities are, for the most part, independent from each other, it is easy to add and remove elements without disturbing the overall functionality of the device. The purpose of this is that it will be easy to match updated hardware or software specifications, should OiTec's PDU design get updated.

The result is a Tester device that can perform accurate and fast measurements of the PDU's PLC while giving a detailed report that is easy to use to identify any faults in the PDU, should they exist. This also shows the value of investing in automated testing processes as the current PDU Tester can do a full scan of a PDU PLC's functionalities within a few seconds, whereas it would take a lot longer to do it manually.

Keywords	PDU, Tester, LabVIEW, TestStand, Relay, DAQ, PLC

Tekijä Otsikko Sivumäärä Aika	Julien Tenkanen OiTec Oy Turva Virranjakoyksikön Testeri 38 sivua + 2 liitettä 31.1.2021
Tutkinto	insinööri (AMK)
Tutkinto-ohjelma	Elektroniikka
Ammatillinen pääaine	Elektroniikka
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Opinnäytetyön tarkoitus oli suunnitella laitteistoa sekä ohjelmistoa funktionaaliselle PDU-Testerille ja rakentaa se. Testerin laitteisto sisältää suurimmaksi osaksi releitä sekä DAQ:eja, joilla ohjataan releiden kytkentämekanismia. DAQeilla luetaan myös analogisia sekä digitaalisia signaaleja, jotka tulevat PDU:sta. PDU ja Testeri yhdistetään erilaisilla kaapeleilla, jotka välittävät signaaleja molempien laitteiden välillä.

Koska on tarve automatisoida testiprosessia, sekä luoda yksityiskohtaista dokumentaatiota testituloksista, TestStandilla luotiin testisekvenssi. Sillä operoidaan DAQ:ejen digitaalisia sekä analogisia syöttöjä ja antoja. TestStand kokoaa raportin, jossa jokainen mitattu elementti saa tuloksesi onnistumisen tai epäonnistumisen tuloksen. Tämän tavoitteena oli tehostaa prosessia, jolla löydetään virheellisiä kytkentöjä PDU:n sisältä, jotta tarkat viat löytyisivät nopealla tarkastuksella.

Koska testerin funktionaalisuudet ovat suurimmaksi osaksi toisistaan riippumattomia, on helppoa lisätä tai poistaa laitteen toimivuutta. Tämän tarkoitus on, että testeriä olisi helppoa päivittää, jos OiTecin PDU:hun tulisi päivitetyksi.

Tuloksena on testerilaite, joka pystyy tekemään sujuvaa ja virheetöntä mittausta PDU:n PLC:stä sekä samalla antaa yksityiskohtaisen raportin, jota on helppo lukea ja joka tunnistaa virhekohdat, jos niitä on. Tämä insinöörityö myös osoitti automatisoidun testausprosessin arvon, sillä nykyinen PDU-testeri pystyy tekemään kokonaisen skannauksen PDU:n PLC:n funktionaalisuuksista muutamien sekuntien sisällä. Jos sen tekisi manuaalisesti, aikaa kuluisi paljon enemmän.

Avainsanat	PDU, testeri, LabVIEW, TestStand, rele, DAQ, PLC

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Appendices

List of Abbreviations

AC	Alternating Current.
AI	Analogue Input.
AO	Analogue Output.
COM	Common.
DAQ	Data Acquisition. A device used to measure things such as voltages, resistances, and currents.
DC	Direct Current.
DIO	Digital Input/Output.
GND	Ground.
HW	Hardware.
I/O	Input and Output. The directions of signals within a given device.
LED	Light-Emitting Diode. A diode that emits light when powered up.
Modbus	A communication protocol for programmable logic controllers.
NC	Normally Closed.
NI	Formerly known as National Instruments.
NO	Normally Open.
PC	Personal Computer.

PDU	Power Distribution Unit. A device that converts AC to DC and distributes the power to other electronic devices. Usually mounted on racks with several other devices that the PDU provides power to.
PE	Protective Earth.
PLC	Programmable Logic Controller. A device that can be programmed to give specific logic-based commands for how its inputs and outputs operate.
USB	Universal Serial Bus. One of the most common communication protocols used today to connect electronic devices with each other.
UI	User Interface.
V	Voltage.
VI	Virtual Instrument.
Z	Impedance.

1 Introduction

OiTec Oy has created its own safety PDU that it offers to its customers as an alternative, ready-made solution. OiTec's PDU's design is flexible and may be customized to fit any kind of testing system. All products must have their safety and functionality tested before the they can be shipped off to customers. Since the PDU is only part of a larger whole, and testing the entire product takes time, there is a need to streamline and automate every aspect of the testing process to increase production speed. For this purpose, a Tester device was designed and created for OiTec Oy's PDU. This work will cover both the hardware and software aspect of such a product.

1.1 OiTec History

OiTec Oy was established in 2013 by Pekka Oinonen. The company offers a diverse set of services in research & development; mechanical, layout, hardware and software design and implementation for electronics testing devices. OiTec Oy currently employs about 20 test designers and some test assemblers.

1.2 Objectives

The main objectives of this thesis were to create a functioning tester device while learning how to use the tools employed at OiTec Oy in software and hardware design. This mainly concerns the use of EPLAN's Electric P8 and NI's TestStand and LabVIEW. The final objectives were becoming familiar with all the steps of making an electronic product from start to finish, as well learning basics of designing a tester for an electronic device.

1.3 Power Distribution Unit

Since this thesis is not focused on the PDU but its tester, a cursory glance of what a PDU is, instead of going too deep into its designs will be sufficient. A PDU is a device that distributes electrical power to other electrical devices. Within the PDU is a PLC that runs on independent software. The PLC handles and oversees the PDU’s safety functionality, making it the most crucial part of the device. For this purpose, the PLC will be one of the main things to be measured with the PDU Tester. The PDU serves to protect electric devices from electrical surges or power outages with its protective switching circuitry. OiTec’s PDU is rack-mountable, as seen in Figure 1, and one of its uses is powering larger test stations, for example, ones that test frequency boards used in motors.

Figure 1. OiTec Oy’s PDU mounted on the test station rack.

2 Product testing and its automation

2.1 The importance of product testing

Product testing plays an important role in product development. Every company wants to guarantee the working condition of its products. Each company is responsible for the product, and thus image of themselves that they put out. A series of poorly made and broken product could lead to financial ruin and a loss in faith in the companies putting out faulty products. In some cases, there may even be legal obligations for companies to prove, for example, that a product they sell meets the safety standards and will not, at the worst case, lead to death of a person. For these reasons, the testing process itself is as equally important as making the product itself.

Industry veterans tend to agree on the advantages of well-done testing and argue that they lead to benefits such as a decrease in production time, an increase in customer confidence and a reduction in company costs, among other positive aspects, which lead to an increase in company profitability [1].

2.2 Problems and solutions in product testing

One of the challenges is that testing itself can also be faulty and lead to accidental erroneous results, especially if it is done manually. The most reliable solution for this problem is to create a well-designed automated process to handle as much of the product testing as possible to mitigate man-made mistakes. Industry standard solutions for automation typically lie within the use of NI's LabVIEW and TestStand software as they provide the tools to create automatic systems. The know-how to use such programs are industry wide and both programs offer a high level of integration with a large selection of devices.

With the tools and experience to use them being readily available, the question in testing usually ends up lying in what to test and how to implement it. Testing itself is a complex subject as it can be broken down into multiple subtypes, depending on what is to be tested, what are the properties to be measured and in what manner are the tests to be carried out. Some of the categories for electronic devices have been suggested as Memory, Cable/interconnect, and Communication interface testing [2].

This thesis is concerned with what can be called Cable/interconnect and Memory testing. The former is defined as test as a method of ensuring that cables connected to other cables are correct and is used as a way of finding and eliminating different sources of errors, for example short circuits and disconnected wiring. The latter method is to check that all data that is read from or written into a device that has memory, such as flash memory, is done without errors or changing its behavior [2].

Once the focal point or points that need to be tested to guarantee product reliability have been determined, the process of building a testing system becomes a series of questions that each need to be answered with a solution, until every question has an answer.

2.3 OiTec Oy's product problem and solution process

Currently OiTec Oy does all its PDU testing by hand. The inherent weaknesses of doing the testing by hand is not only the fact that it is a much slower process but that doing things by hand can lead to a myriad of man-made mistakes as well whereas a well automated system would be less prone to making such mistakes.

PDU testing, as does the process of all device testing, pays itself back when the testing is done properly the first time and does not need to be redone later should the product be found to be faulty. This puts pressure on companies to do testing correctly the first time, thus the increasing need to streamline this process. OiTec Oy's customers rely on the testing stations assembled by OiTec Oy and are always in need of buying more as fast as possible. This thesis will concern itself on the Safety PDU part of testing station quality assurance. The solution that OiTec Oy has chosen for its problem is to create a companion device, a tester with its own hardware and software tailored specifically to test the functionality of its safety PDU products.

The first step is to examine the PDU and determine what are the key points within that should be tested to determine product reliability. The PDU has a PLC component that controls the safety logic functionality of the PDU. It receives inputs based on external and internal contact states, such as if a station cabinet's fixture is closed or if certain fuses are on or off, that inform the PLC of what kind of logic states it needs to in order to allow the PDU to divert power safely to the other devices it is connected to. All functionality goes through the PLC and because of this it is easy to see that it is the critical component to be tested.

Now that the focus of the tester has been identified, a way to test its functionality needs to be found. Since the PLC has several logic inputs that need to be triggered individually for accurate test results, as individual input tests will reveal with more specific accuracy where an error would be located, some kind of switching mechanism would be perfect for purpose of this kind of testing. With a switch that can be turned on and off the test device could have absolute control over which PLC inputs are being triggered, and when. An electromechanical relay has one or more input ports with NC and NO output channels for each input. With this the tester is able to control when a trigger signal is fed to the PLC's input or not.

The next issue has to do with the switching mechanism of the relays. If a relay's Positive and Negative terminals are wired normally to, for example, +24VDC and Ground, it will switch on and always be in its NO state. This is due to the electromechanical nature of the relay as when there is a current going through its internal coil it will switch on, and if there is no current then it will switch off. For the purposes of the tester the relays need to be able to have both NO and NC states accessible on demand. The goal here, then, is to have a way to power up the relay without automatically putting it in the NO state. For this purpose OiTec Oy has created its own circuit card specifically for electromechanical relays with the capability to interrupt current flow on demand. By wiring the relay's Negative terminal to the card it is now possible to power up the relay in a way that the current does not flow through its internal coil. With this setup the relay can be powered on without switching immediately into its NO state.

The final steps left to be solved are how to control the relay switching mechanism as currently it is only capable of being in its NC state while being powered on and how to automate the switching process with software. A NI USB DAQ fulfills this role as the last key component. The aforementioned circuit card deisgned by OiTec Oy uses a NUD3160 semiconductor that acts as a sort of switch by itself, controlling the current flowing through it. It has a Drain that flows to its Source port, but only if the Source is closed by sending a digital signal to its Gate port. By connecting Drain to the relay's Negative terminal, Gate to a DAQs digital output and Source to Ground, the tester is now capable of switching the relay between its NC and NO states. When the relay is grounded it will allow current to flow from the Positive terminal through its coil, switching to the NO state. When the DAQ stops sending its digital signal to the semiconductor's Gate terminal it opens the Drain terminal, cutting off the relay from its Ground, blocking the current from flowing through the coil and forcing the relay back into its NC state. With this final step the device is now capable of using relays to send and cut trigger signals to the PDU's PLC on demand.

The NI USB DAQ also has native support with NI's own software, LabVIEW and TestStand. Both software will be needed to create the automation part of the tester device. TestStand is used to create sequences of automatic tests using hardware drivers created with LabVIEW to connect and control DAQ functionality, allowing the software to drive the tester hardware and automatically manipulate the relays based on the specific commands created in TestStand.

2.4 OiTec Oy's Safety PDU's full testing process and future plans

There are several other tests that are done to the PDU, but they are not covered in this thesis as the PLC testing itself is a large and diverse enough subject to serve as the focus. Each electrical device within the PDU is tested to ensure that they meet the safety standards, meaning that the PDU is subjected to Earth continuity, insulation resistance and loop impedance tests, among others.

There are already plans to implement more Tester functionality as well, such as a way to measure the current and voltage output by the PDU in order to ensure that they are within the promised values of the power units used within the PDU.

3 PDU Tester Hardware

3.1 Components

This chapter will go over the critical components and devices needed in order to create the PDU Tester hardware, as well as briefly reason why some of the devices were chosen.

The PDU Tester was made up of pre-existing components, as there is no need to make anything specifically for this project. There are two circuit cards designed by OiTec Oy that are being reused, as their functions cover the needs of the Tester.

3.1.1 Relay

A relay is a switching device used to regulate power flow within circuits. Unlike regular mechanical switches, relays operate electrically by feeding power into them to open and close their gates.

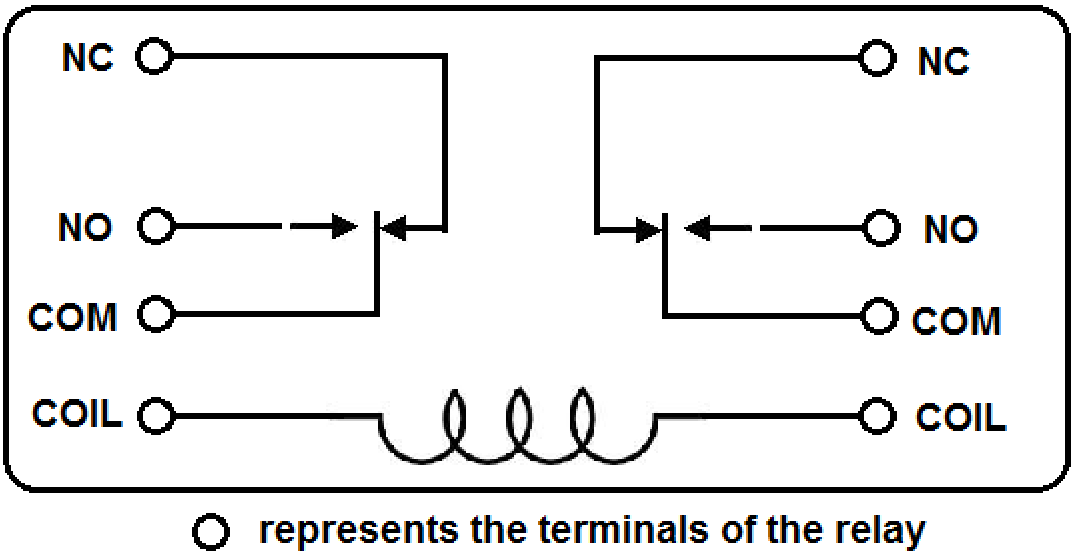


Figure 2. 2 Pole Electromechanical Relay Diagram. [3]

By feeding a voltage through the coil ports, as seen in Figure 2, the electromagnet creates a magnetic field that will cause the COM ports to switch from their NC states to their

NO states. Powering the relay down will revert the COM ports back to their original NC states. The model of this diagram is a 2 Pole relay, meaning it has two COM ports.

3.1.2 Relay Drive Board

Since there is a need to control the switching of the tester relays with digital signals using a NI USB-6001 DAQ, a circuit board with semiconductors that can be used to control the relay switching is a key component for the overall design of the tester. OiTec has its own design for such a circuit board.

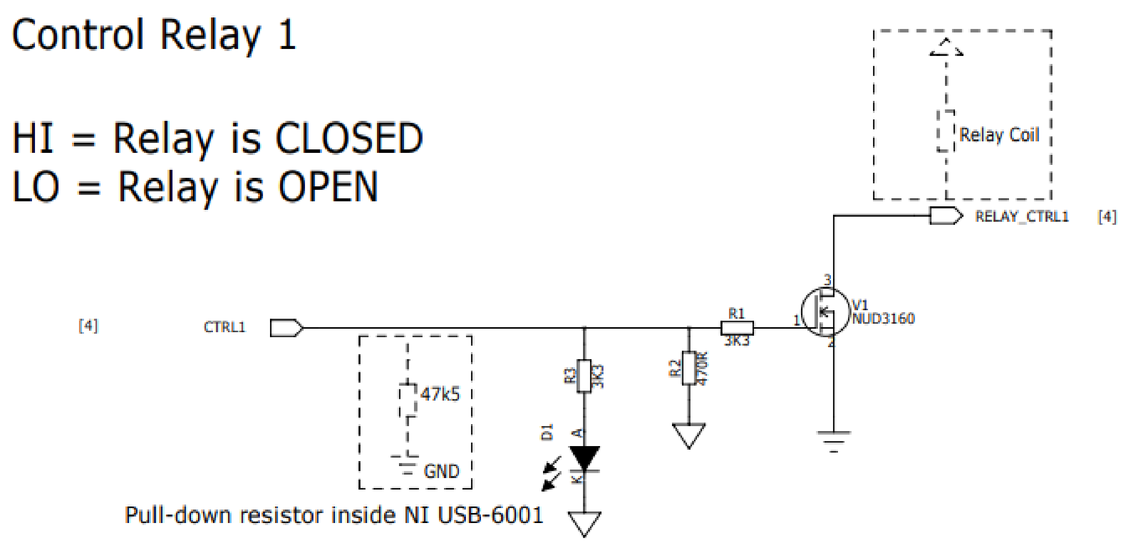


Figure 3. Relay Drive Board circuit designed by OiTec.

Feeding a DAQ signal via the CTRL1 pin into the semiconductor will open and close its gate (depending on if the signal is high or low), which in turn affects the switching state of the relay. Each board has four identical channels as seen in Figure 3, being capable of operating four relays per board.

3.1.3 Voltage Divider Board

Since the NI USB-6001 DAQ used in the Tester can only take input voltages at +/- 10VDC and the voltages coming from the PDU go up to 24VDC, it is imperative to have some way of lowering the incoming voltages to protect the DAQs from breaking. A circuit that cuts incoming voltage to a third of its original amount has been designed by OiTec and can be repurposed for the benefit of the PDU Tester.

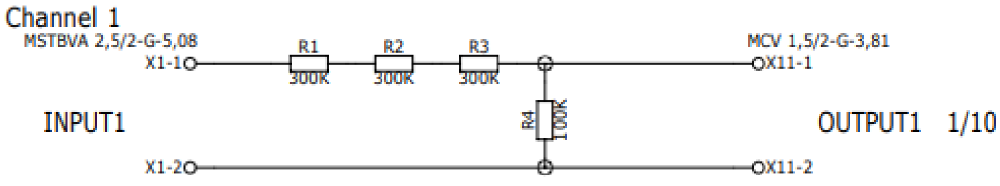


Figure 4. Pin layout for NI USB-6001 DAQ.

There are ten channels in the board, all of them similar to the one channel seen in Figure 4.

The equation for voltage division is:

$$Vout = \frac{R4}{R1+R2+R3+R4} \times Vin \qquad (1)$$

3.1.4 NI USB-6001 DAQ

A device that can measure different physical properties such as Voltages, Currents, Resistances as well as output digital signals. Its usefulness and popularity come from its flexibility in electronic applications as it has multiple channels for AIO, DIO, +5 VDC and GND, as seen in Figure 5.

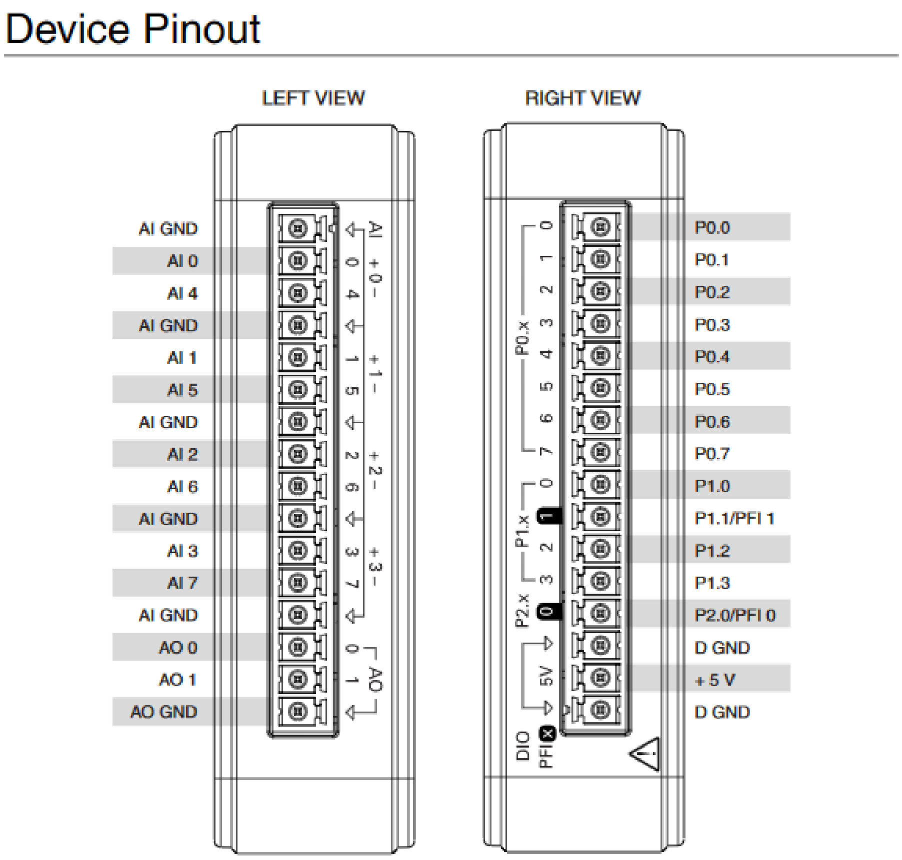


Figure 5. Pin layout for NI USB-6001 DAQ. [4]

The other strength of this DAQ is its ease of use. It connects to PCs via USB and is natively supported by LabVIEW, allowing users to create powerful LabVIEW VIs for this device extremely fast and easily.

3.1.5 Distribution Block

A distribution block is a multi-channeled device used to distribute power to multiple devices or circuits. It is a useful device that helps streamline signal distribution within electric circuits. Distribution Blocks are flexible and can even be used to for grounding purposes as well.

Figure 6. Phoenix Contact's 18 channel distribution block. [5]

In Figure 6 the largest port is the input port of the distribution block and where signal that is to be distributed is fed into. The channels with smaller ports are the output ports from which the input signal is distributed to other electrical devices or circuits.

3.1.6 Circuit Breaker

A circuit breaker is a switch that is used to protect electrical circuits or devices from surges or short circuits. It activates automatically by opening its internal circuit via a switch, protecting electrical circuits from damage if the input currents go beyond the breaker threshold.

Figure 7. 2 Pole Circuit Breaker by ABB.

As seen in Figure 7, the circuit breaker has a mechanical latch that changes its state between NO and NC when it is activated. Normally it will be in the NC state, but it will switch to the open state for protective purposes, blocking the current from flowing into the rest of the circuitry. Regular fuses need to be replaced after they have activated once as they burn themselves out, but circuit breakers only need to have the latch set back to its NC state to resume operations.

3.1.7 Step Power Supply

This power supply unit is the main source of power for the PDU Tester as it is used to power everything within the Tester, except the DAQs.

With an input of 100-240VAC it outputs a single phase 24VDC at 0.75 amperes, as seen in Figure 8. On its own it only has two channels to output this DC Voltage, which is why the distribution blocks are needed for sharing the power with the many other devices used within the Tester.

Figure 8. Phoenix Contact 24VDC/0.75A PSU. [6]

3.1.8 Light-Emitting Diode

A LED is an electric component that lights up when voltage is fed into it. Each relay will be assigned its own LED that will be fixed onto the Tester's front panel. Their purpose will be to give a visual indication of the switching state of the relay connected to it.

This is more of a planned feature for the future as this will not be done for the thesis itself.

3.1.9 USB-HUB

A hub is a multi-port device used to split a single port. For example, a device may only have one extra port available, so with a single hub device it is possible to connect more devices into the single available port. The UPort 404 Series device in Figure 9 can split and share a single USB port with up to four other devices.

Figure 9. MOXA UPort 404 Series. [7]

In the case of the PDU Tester, the UPort Series 404 USB-HUB is connected to a PC USB port, which will share the USB port with four other devices that require a USB connection. This is done to streamline the connectivity of the USB devices within the tester but is also crucial in case more than one USB port is not available for use. The PDU Tester uses three NI USB-6001 DAQs, therefore this hub is crucial to ensure their connectivity.

3.1.10 Connectors

In order to test the PDU's functionality there needs to be a connection between it and the Tester. For this purpose, the Tester will be using the same connectors as the PDU. There will be four 4-potential and two 6-potential connectors, like the one in Figure 10.

The measurements in these connectors will be for the general voltage functionality of the PDU.

The 37-potential interface module of Figure 11 will connect to the PDU’s PLC which will measure the correct functionality of the PDU’s logic controls.

Figure 10. Phoenix Contact’s Printed Circuit-board connector. [8]

Figure 11. Phoenix Contact’s interface module with a D38 connector. [9]

4 Software

This chapter will introduce the software used to design and create a PDU Tester followed by an overview of the LabVIEW VI, TestStand test sequences and EPLAN schematics that were created for the project.

4.1 LabVIEW

LabVIEW is a graphical programming environment developed by NI. It allows the user to create programs, called VIs in LabVIEW, with speed and agility that is not normally possible in typical text-based programming languages. LabVIEW has native support for a large pool of different hardware-based drivers, granting users easy interfacing with hardware devices. If a hardware driver does not exist, it is quite easy to create new ones with LabVIEW.

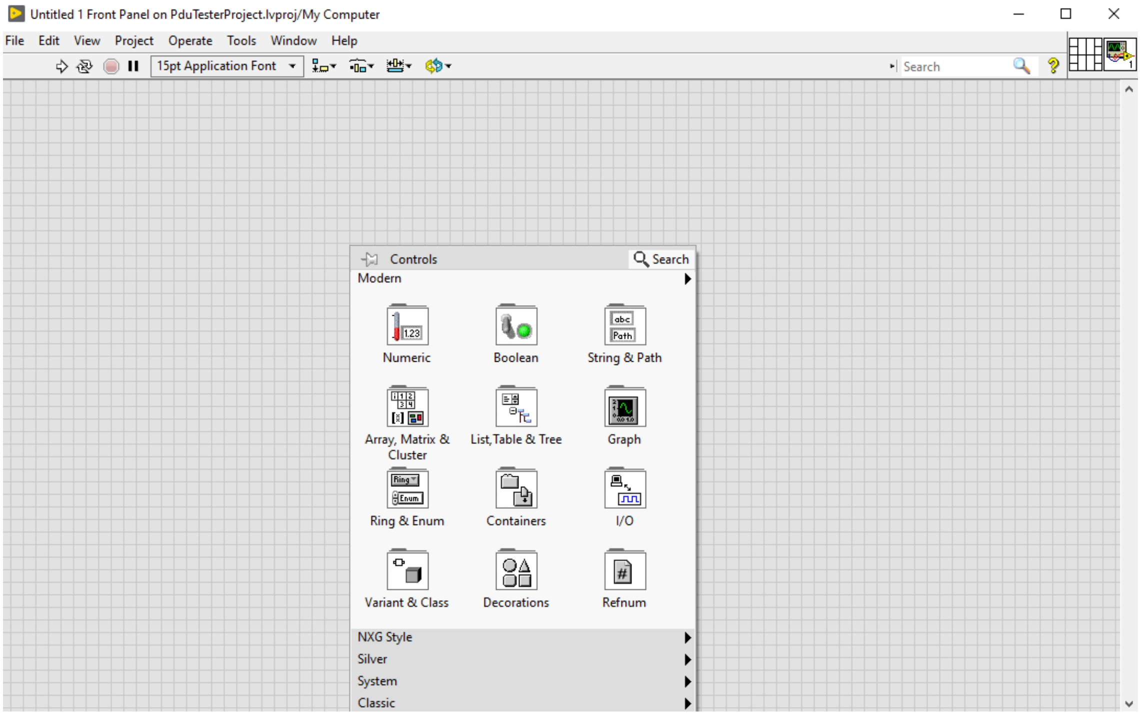


Figure 12. LabView's main screen with the Controls panel open.

Programming in LabVIEW is done by simply dragging-and-dropping blocks, which can be found in the Controls panel seen in Figure 12, and connecting them to each other with wires. The different colored wires all represent the different types of data that the blocks input or output, such as green for Boolean and pink for character strings. This streamlined experience or development also extends to UI creation, where making the UI is as easy as dragging and dropping the different elements into place.

LabVIEW is an industry standard tool that is used by most companies who work within the field of electronics but is not strictly confined to that field alone.

4.2 TestStand

TestStand is a sequencing tool allowing users to create test sequences for hardware testing purposes. As the program is made by NI, it has LabVIEW integration, allowing users to create VIs with LabVIEW that perform specific functions, and then create a sequence in TestStand to activate these VIs. The VIs can be independent from each other but brought together with TestStand, which allows users to create test sequences in a more modular fashion.

Although it supports streamlined LabVIEW support, in no way is TestStand dependent on it, and can be operated using the scripting tools within the program itself.

TestStand is another industry standard tool for engineers who are especially concerned with device testing as it provides an agile and streamlined environment for developing test sequences, as seen in Figure 13.

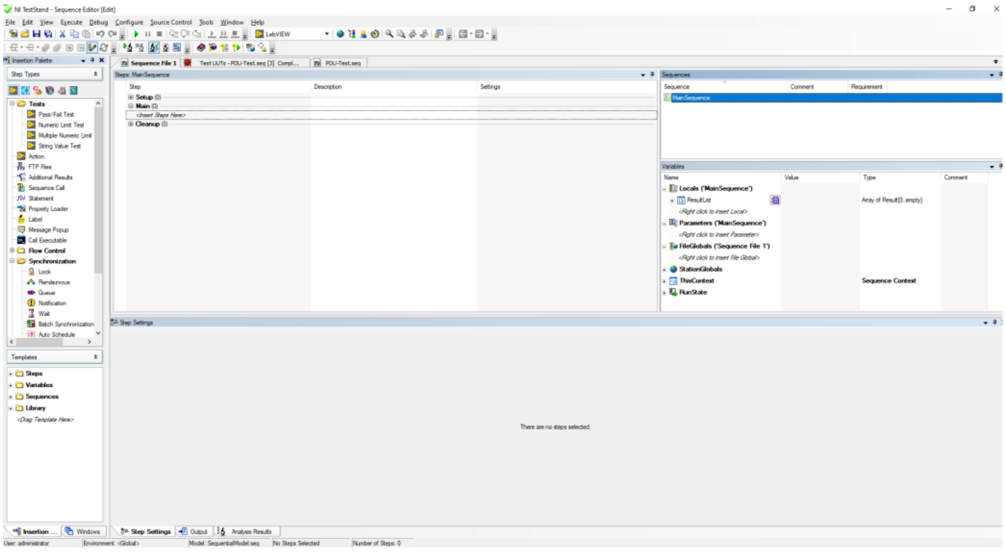


Figure 13. The main screen in NI TestStand.

4.2.1 Device Drivers

Device drivers are software that establish a connection between a device and a computer as well as control its functionality. The Tester uses OiTec's in-house drivers created for DAQs so that their functionality can be activated or deactivated during the test sequences created to test the PDU. They are the core building blocks for the PDU Tester's sequences. Since NI TestStand has LabVIEW integration, these drivers have been created using the LabVIEW programming environment.

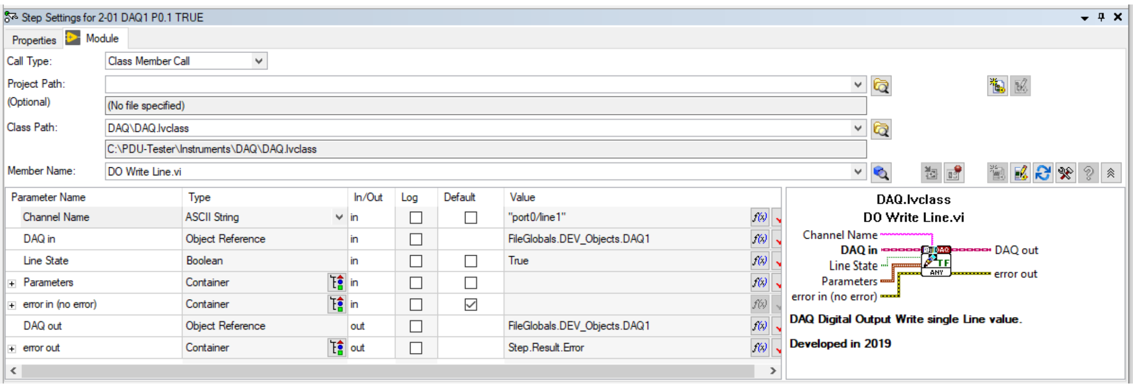


Figure 14. A DAQ device driver.

The right side of Figure 14 shows the block diagram of driver created in LabVIEW, giving ease of understanding of how the LabVIEW VI inputs and outputs operates. This example sets the P0.1 pin a DAQ to True, meaning that it will output a Boolean 1. Should the Value for the Line State be given False then it would output a Boolean 0. In this way the test sequence will switch the relays on and off as each DAQ pin will have its own designated relay that the sequencing will determine to activate or deactivate.

4.2.2 Test Sequence

Much like LabVIEW, TestStand has an easy-to-use interface where actions can be dragged from the side bars on the left or right and dropped in the middle panel to start building a sequence. In Figure 15 on the top of the left panel are all the basic building blocks that make up most sequence steps made in TestStand.

As OiTec has its own in-house libraries with all the necessary device drivers (LabVIEW VIs), creating the test sequences for the PDU Tester is a simple matter of applying the correct sequence actions and drivers with the appropriate pass and fail thresholds.

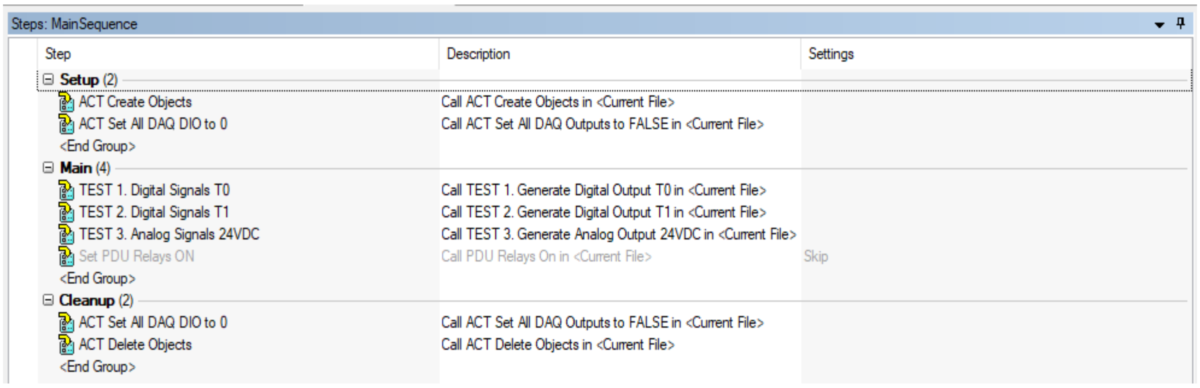


Figure 15. The MainSequence for the PDU Tester.

The main screen only includes Sequence Calls, a function that calls another sub-sequence. Each sub-sequence will have its own list of functions. This way the test sequences can be created in smaller, more manageable parts. It helps with the overall readability of the sequence itself, but also with the end report that TestStand generates at the end.

The Setup phase includes drivers to create the instances of the DAQs that will be used in the tests themselves and the Cleanup phase has the drivers to close these DAQ instances. Both phases also have a sequence step to set all the DAQ DIOs to 0 to ensure that nothing is on before or after the testing is done. If even a single DAQ's DIO port was outputting a digital 1 it would give the entire test the wrong result.

The Main step of the MainSequence is where all the actual PDU tests take place. TEST 1 through 3 will test the functionality of the PDU's PLC, and has been divided into three separate parts, for the different signals used to trigger the PLC's functionality.

The greyed-out sequence called Set PDU Relays ON is skipped for now and not covered by this thesis.

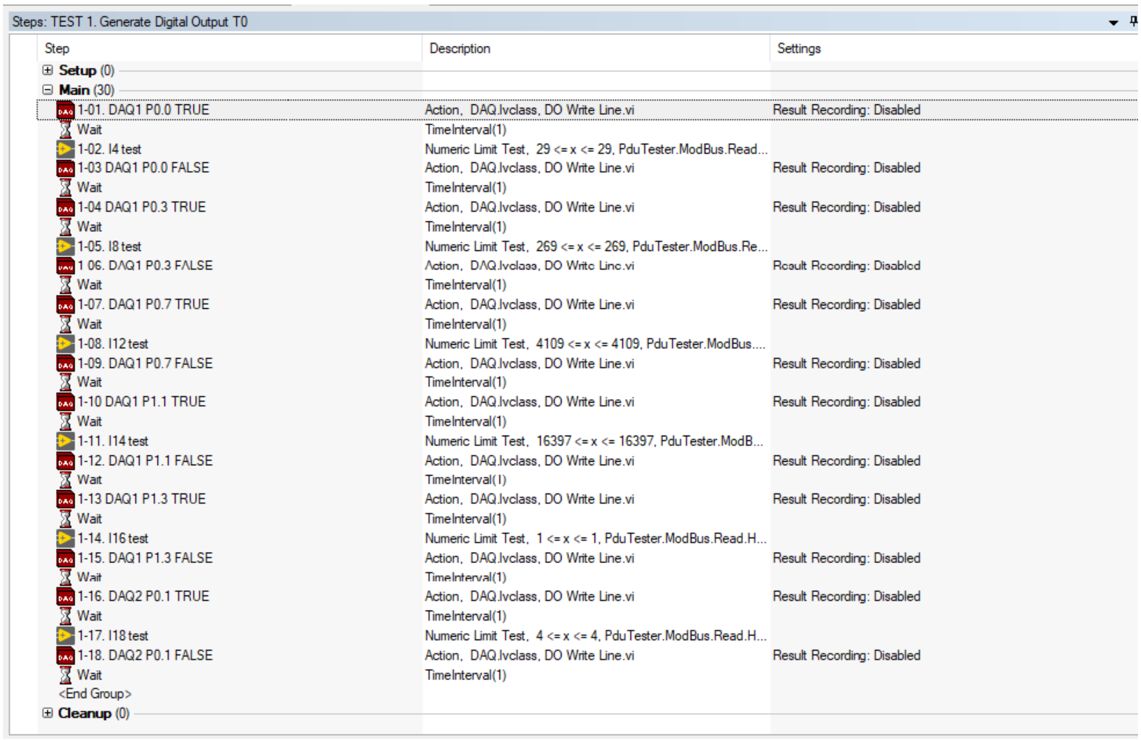


Figure 16. The TEST 1. Digital Signals T0 sub-sequence.

In this sub-sequence, Figure 16, the functionality of the PDU PLC's T0 signal dependent inputs will be measured. This is done by setting the appropriate DAQ pins to output a Boolean 1 in order to switch on its designated relay, which will forward the T0 signal taken from the PDU back into the specific PLC input that gets triggered by the signal.

After this step we use a Modbus driver to send the PDU Modbus a value of 31233 or 31234 (for tests I16 and I18). With this number we set the Modbus to output register values based on the PLC's logic state.

During the next step the DAQ pins output is set to False, turning the relay back to its default state, closing off the T0 signal from entering the PLC. Since computers will run the test sequences faster than the relays mechanical switching can keep up with, which would cause errors in the testing process, it was necessary to add a 1 second delay between each of the relays switching steps to ensure that they have the correct state before the computer will read the output values.

This process is repeated for each input in the PLC that is critical for the functionality of the PDU.

4.3 EPLAN Electric P8

Electric P8 is a hardware schematic creation environment in which one of its core features is how it creates detailed and automatic documentation. For example, it will generate a bill of materials as the user places components, defines the connections (defining wire thickness, color and length) and so on. The software can be used to design the schematics for singular devices, or even larger scale factory operations.

Electric P8 supports a vast library of hardware components by most of the common vendors and manufacturers, but if a component or device cannot be found, making your own via macros with their own symbols along with adding the hardware specifications into the component library ends up being a relatively easy and fast task to accomplish.

Within this chapter we will go through the hardware schematics drawn and designed for the PDU Tester.

4.3.1 Hardware Schematics

Using a schematic design practice that flows from left to down-right, Figure 16 shows how the DAQ's AI and digital nodes are grounded to the Neutral terminals, in addition to how it is connected to the MOXA USB-HUB. The DAQ's DIO ports are connected to a Relay Drive Board which is connected to each of the relays, identified by their -KX naming scheme, neutral inputs, named as A2. A positive voltage of 24VDC is fed into their A1 port. These relays have 8 ports for I/O. A1 (positive) and A2 (neutral) are used to switch the relays on and off between their NO and NC states (port 11 connects to 12 or 14, port 21 connects to 22 or 24).

Signals T0 and T1 are trigger signals that activate different states of functionality within the PDU's PLC. T0 is used for even numbered PLC ports and T1 for odd numbered PLC ports. These signals are taken from the PLC and looped back from the Tester into the PDU. With the switching mechanism of the relays the specific states of the PLC can be triggered, giving tester accuracy and control over the testing process. The PLC will output a specific hex code based on what state it is in. Reading this hex code will be how the Tester will determine the PLC's functionality as it will show if it has the correct configuration or connections. An error on either or both cases will output the wrong hex code.

The I7 port in the PLC is triggered by 24VDC instead of T0 or T1, so the third relay has an output signal of 24VDC. The output of the relays is connected to a 37-pin connector on the tester's back panel which connects to the PDU's PLC via a cable between the PDU and Tester.

5VDC is drawn from the DAQ's power supply port into a distribution block.

The schematic also includes connections between relays and LEDs on the front panel. However, these have not been included in the finished product yet and may be included in the future.

The connection methods of Figure 17 are repeated in Figures 18, 19 and 20.

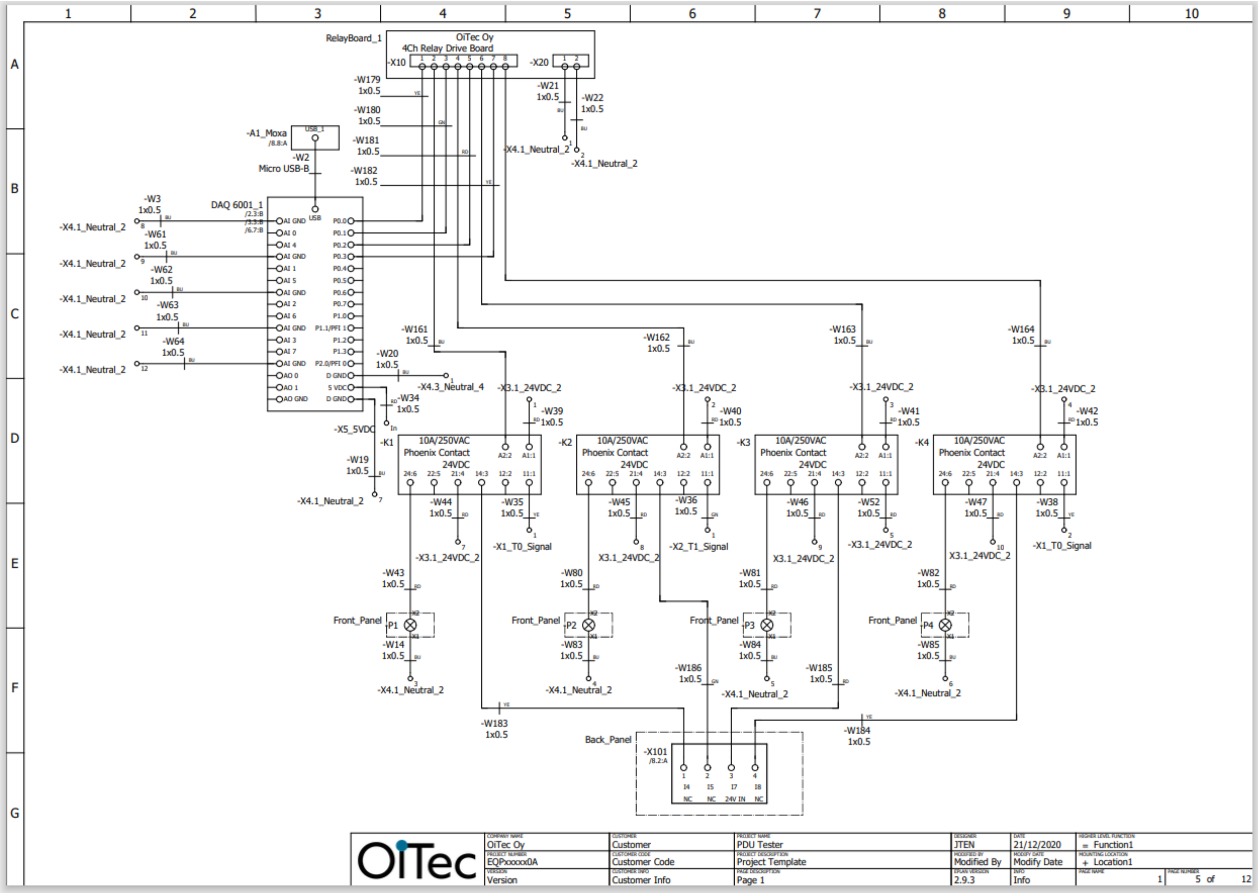


Figure 17. PDU Tester Hardware Schematic, Page 5.

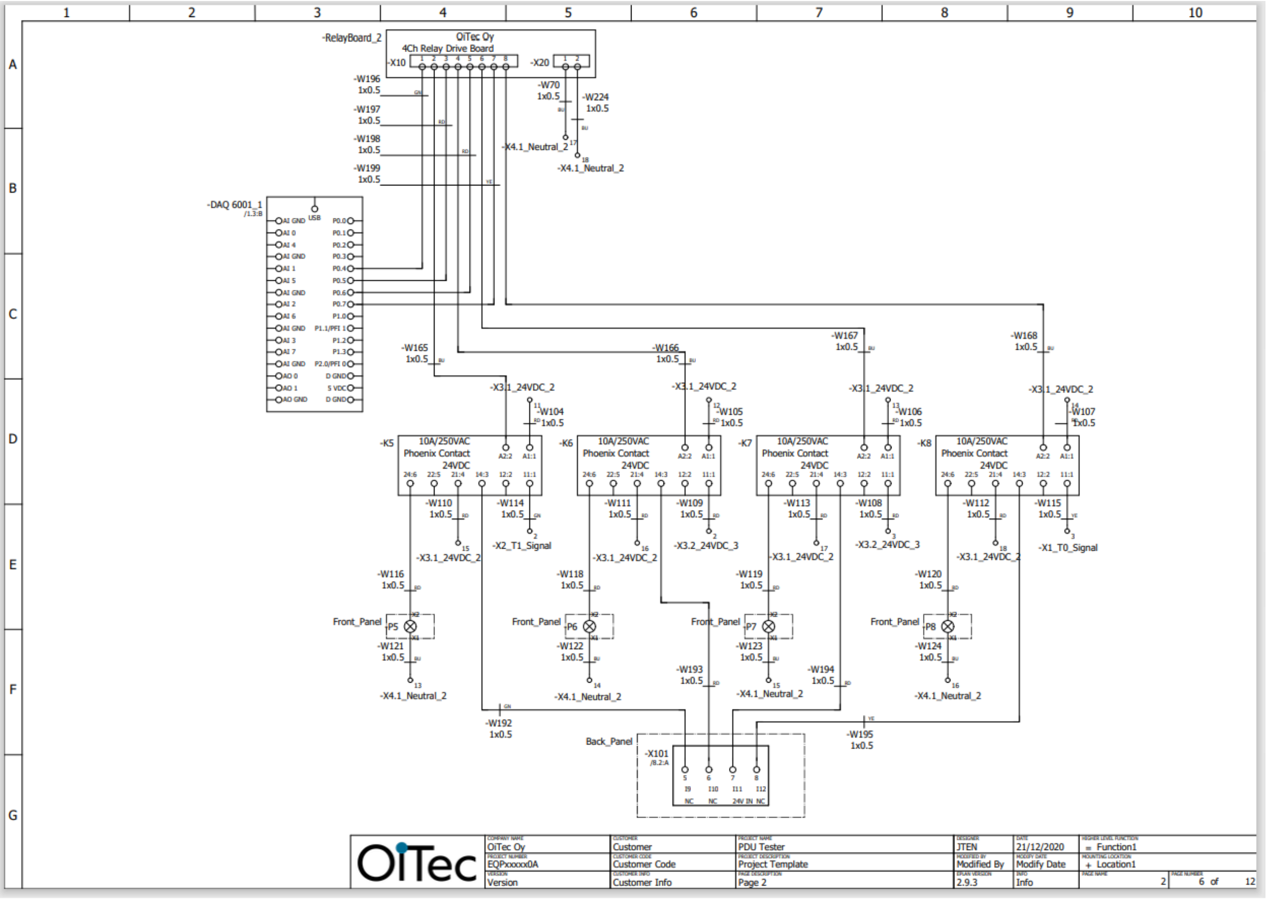


Figure 18. PDU Tester Hardware Schematic, Page 6.

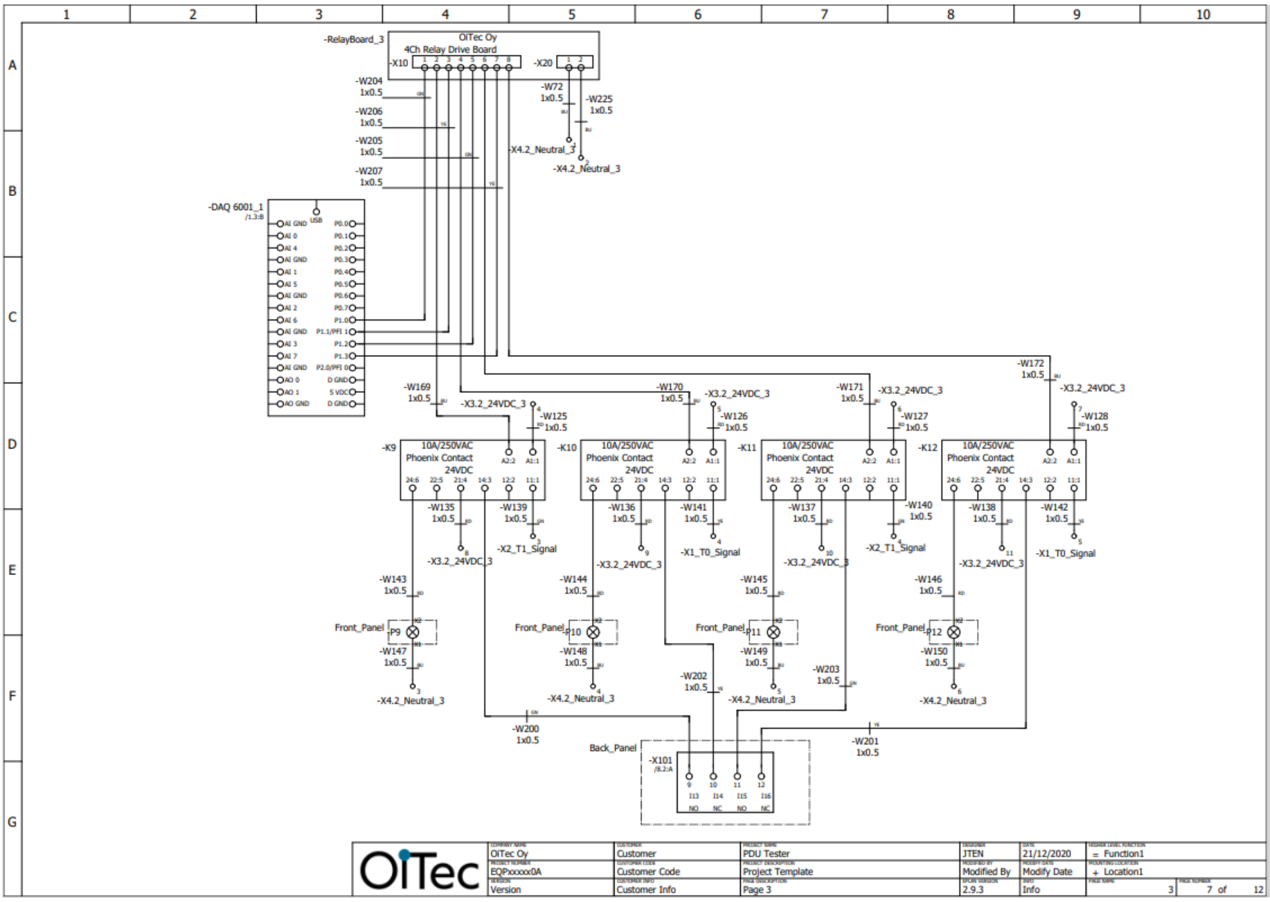


Figure 19. PDU Tester Hardware Schematic, Page 7.

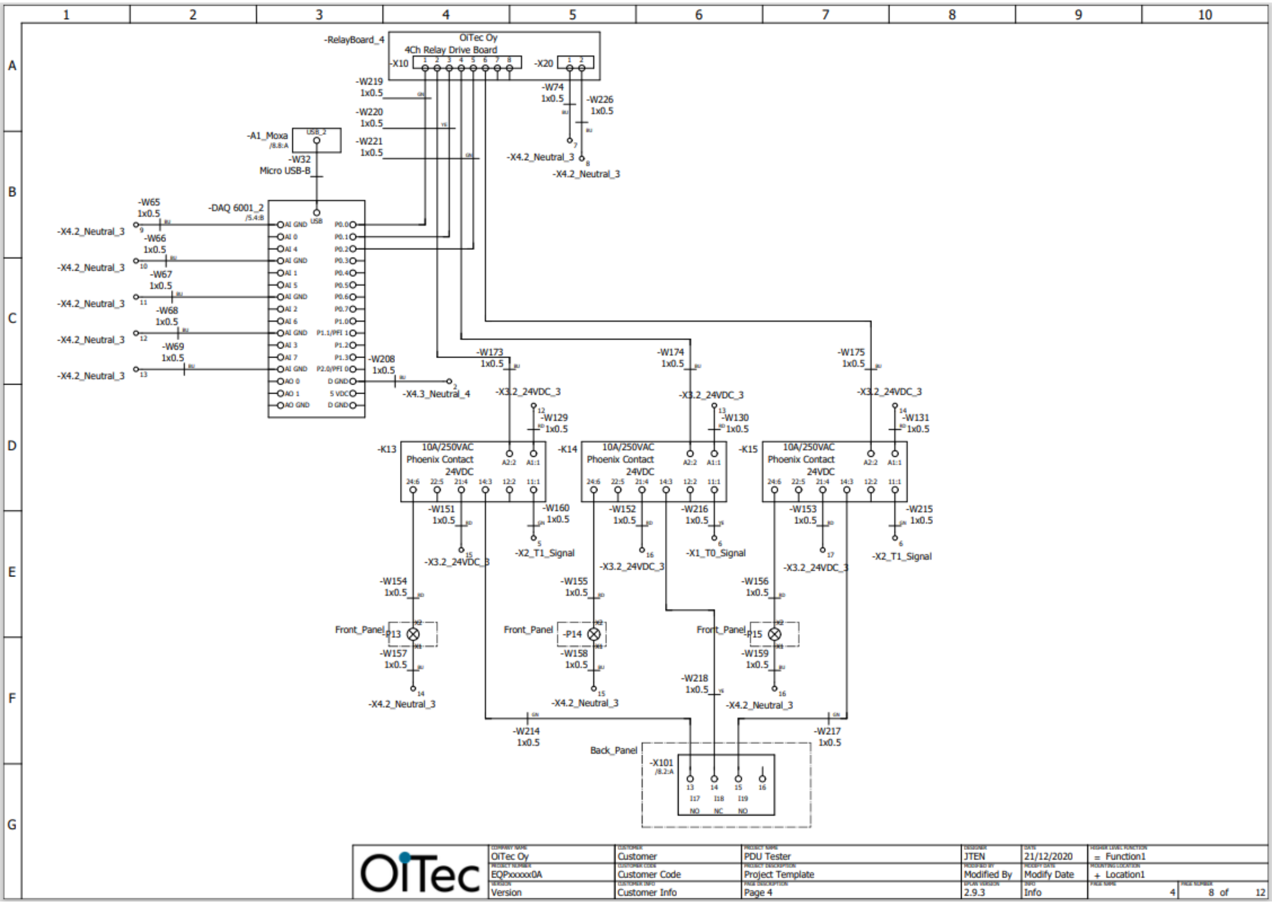


Figure 20. PDU Tester Hardware Schematic, Page 8.

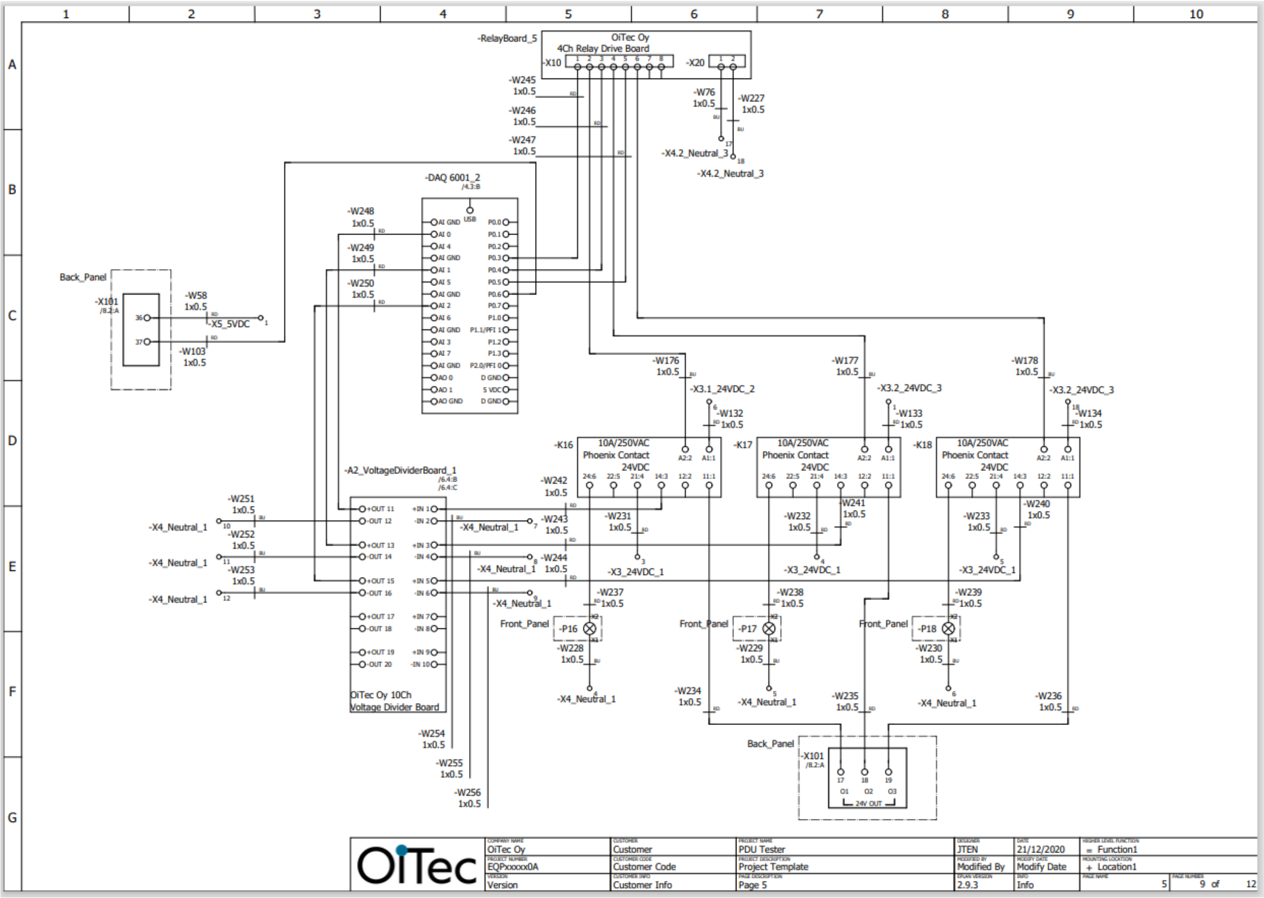


Figure 21. PDU Tester Hardware Schematic, Page 9.

In Figure 21 the tester will read three 24VDC signals outputted by the PLC. For the DAQ to read these signals the relay outputs must first be filtered through a Voltage Divider Board to reduce the DC voltage to a level that does not cause harm to the DAQ.

Pins 36 and 37 should be connected as a loop within the PDU, so testing them will be done by feeding 5VDC into either pin and reading a digital signal from the other. Pin 36 was chosen for the Tester and the reading will be done from pin 37 with the DAQ.

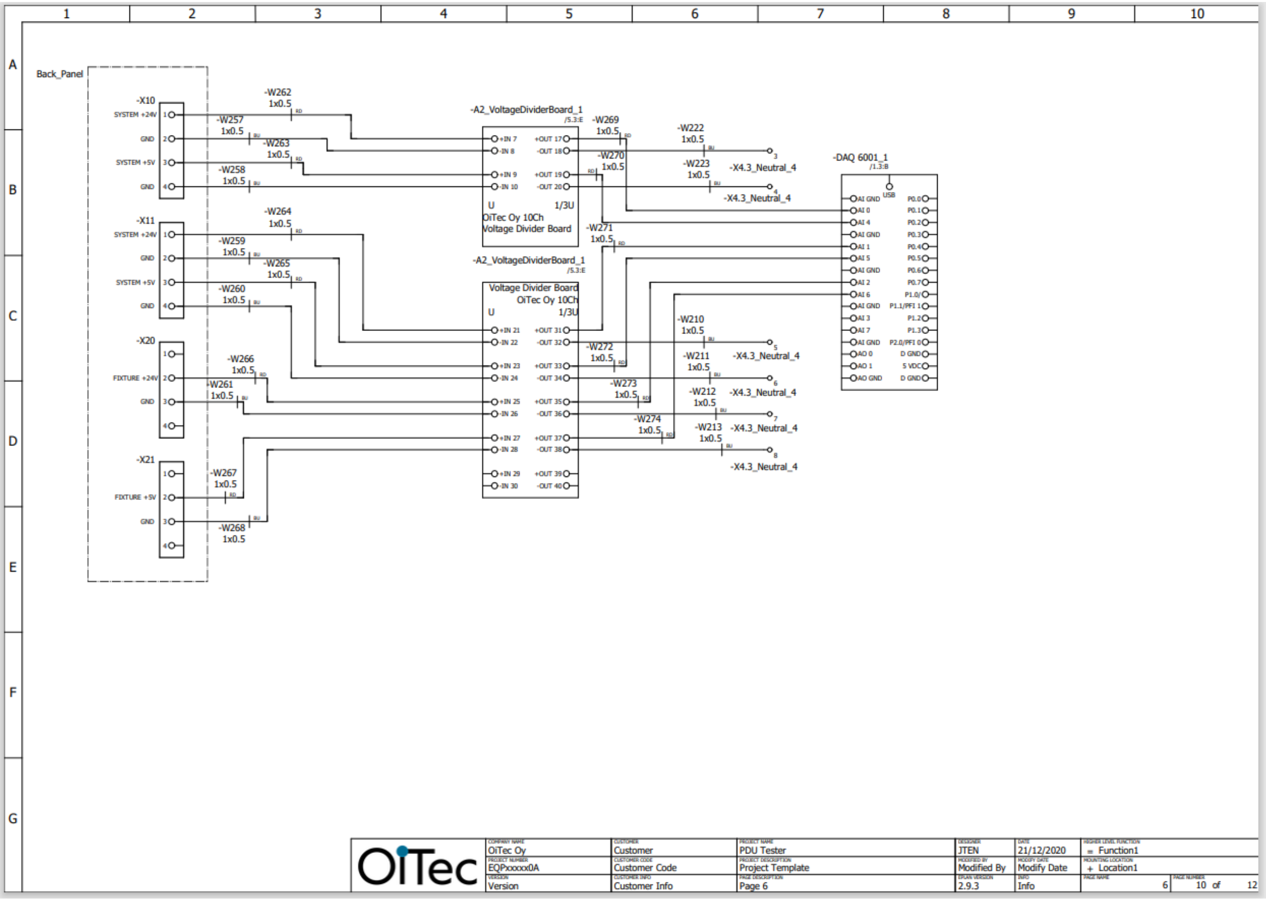


Figure 22. PDU Tester Hardware Schematic, Page 10.

In Figure 22 all the signals coming from the PDU that the Tester DAQ will read are 24VDC signals. For this purpose, they also need to be filtered through a Voltage Divider Board before the signal can enter the DAQ. Since this part of the Tester is measuring the PDU's system voltages and no longer measuring the PLC, there is no need for additional relays to manipulate the PLC's states.

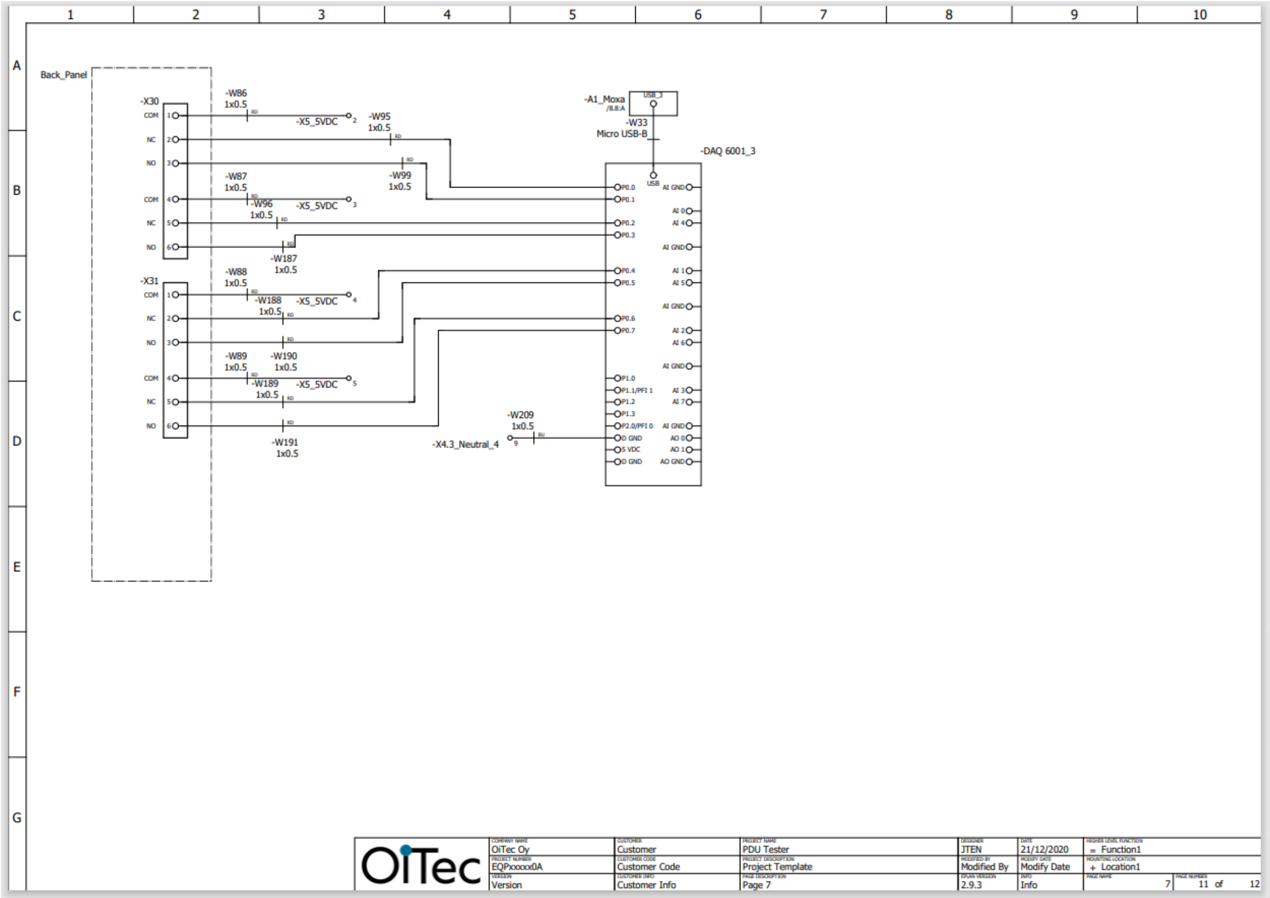


Figure 23. PDU Tester Hardware Schematic, Page 11.

In Figure 23 the Tester will measure the NC and NO states of two internal relays of the PDU. Either relay currently serves no purpose in the PDU. They were added in case PDU functionality needed to be expanded upon in the future. A 5VDC signal is fed to the COM port which will loop back into the DAQ's DIO ports via the NC or NO ports, depending on if the relays are switched on or not.

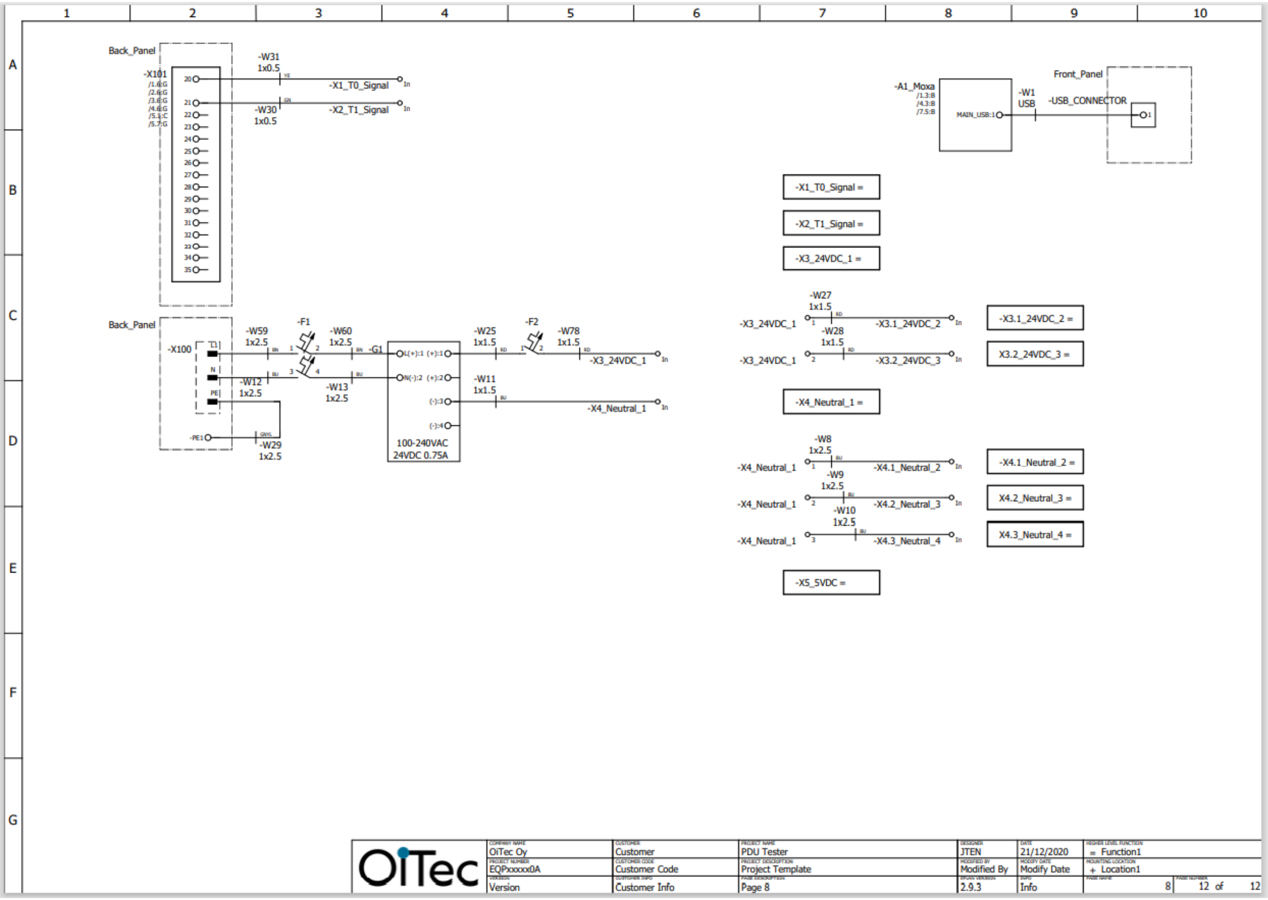


Figure 24. PDU Tester Hardware Schematic, Page 12.

Figure 24 shows how the T0 and T1 signals from the PDU PLC are connected to their input ports in their respective distribution blocks.

Power is drawn from outlets into the Tester via a two pole socket that connects to a power supply unit which converts the AC into DC. The power supply unit's input is protected by a two pole circuit breaker and the output with a one pole circuit breaker. The power is drawn from the supplies positive output into a distribution block designated for 24VDC, which is shared among other 24VDC distribution blocks as there will be many devices that need to be supplied individually with power. The negative output from the supply unit is connected to neutral distribution block terminals and will be used as the reference for ground among the Tester devices.

Finally, the USB-HUB's main port is connected to the front panel.

5 Testing Process

This chapter will cover all the critical points which are to be tested in the PDU as well as go through the process of performing the tests within the software created for this purpose.

5.1 What to test in the Power Distribution Unit?

The PDU's PLC handles all the safety logic and general functionality for the PDU device. For this reason, it is the focus of Tester. Feeding different trigger pulses to the PLC inputs to switch the logic states on and off will be the main method of how the Tester will determine the correct functionality of the PLC, as triggering the proper logic inputs should make the PDU's ModBus output a register value which corresponds with the PLC's logic state.

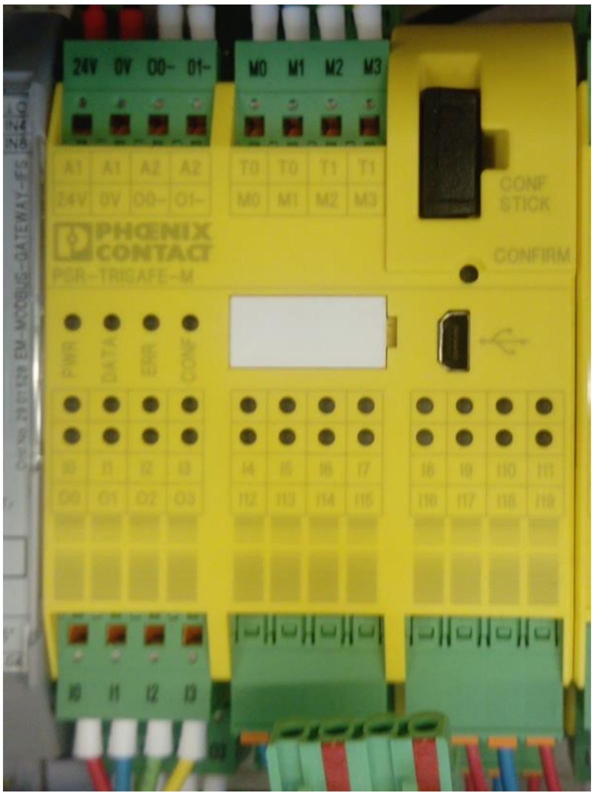


Figure 25. PDU's Phoenix Contact PSA-TRISAFE-M PLC.

By default, the PLC state will be at 01101, which means the value it should output is 13 in decimal. On the PLC this can be observed as I0, I2 and I3 being active, which are LEDs on the left side of the PLC in Figure 25. To trigger I4 the TestStand sequence created for this Tester will switch on the relay connected to I4 via the USB-6001 DAQ, setting the PLC state to 11101, which is a decimal 29. The Tester will cycle through all the PLC inputs that are in use. What this test will show is that the cable wiring is not only correct but that the PLC is able to interpret the proper and specified logic state. Incorrect cabling would lead to unexpected logic states being switched on and off within the PLC, which would harm the PDU's safety functionality.

5.2 Performing the Tests

The PLC has inputs ranging from I0 to I19. It is a 16bit logic controller and each input can be thought of as a bit. Inputs I0 to I15 belong to the same binary batch and I16 to I19 being its own binary batch. Because of this it is easy to calculate the register that the PLC is supposed to output. The TestStand sequence will switch the relay that corresponds to its PLC input on and read the register number the ModBus is outputting. It will then compare the number based on the binary state that the PLC should be in with what it currently is in. If the numbers match then the test is a Pass, otherwise it will Fail. The sequence will automatically and systematically switch through each input until the test is done. The process and results for all PLC inputs that correspond to the trigger pulse T0 can be seen in Figure 26.

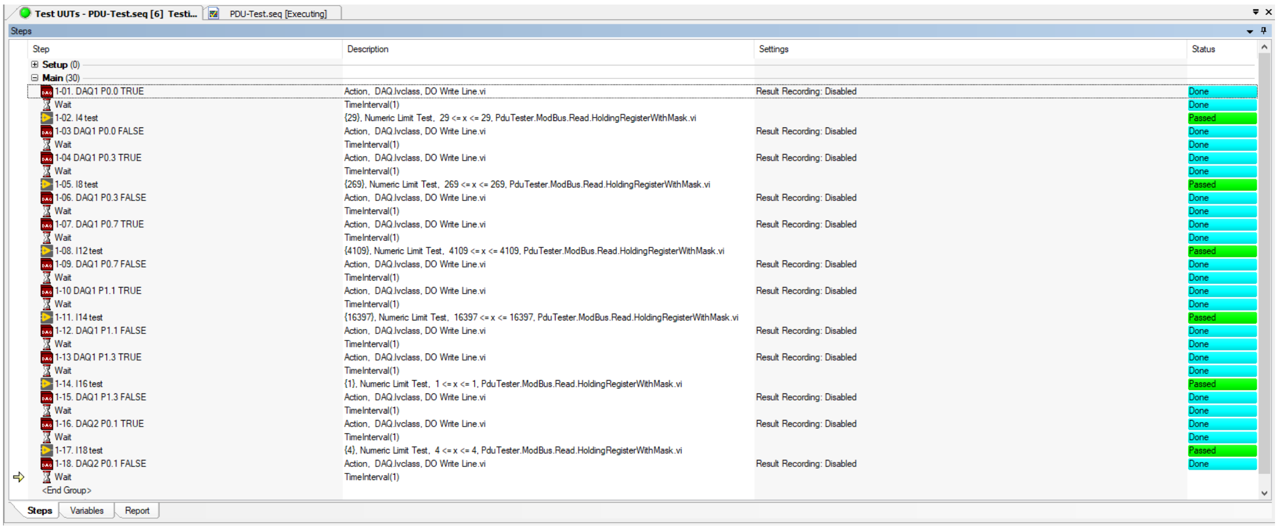


Figure 26. The TestStand test sequence being ran.

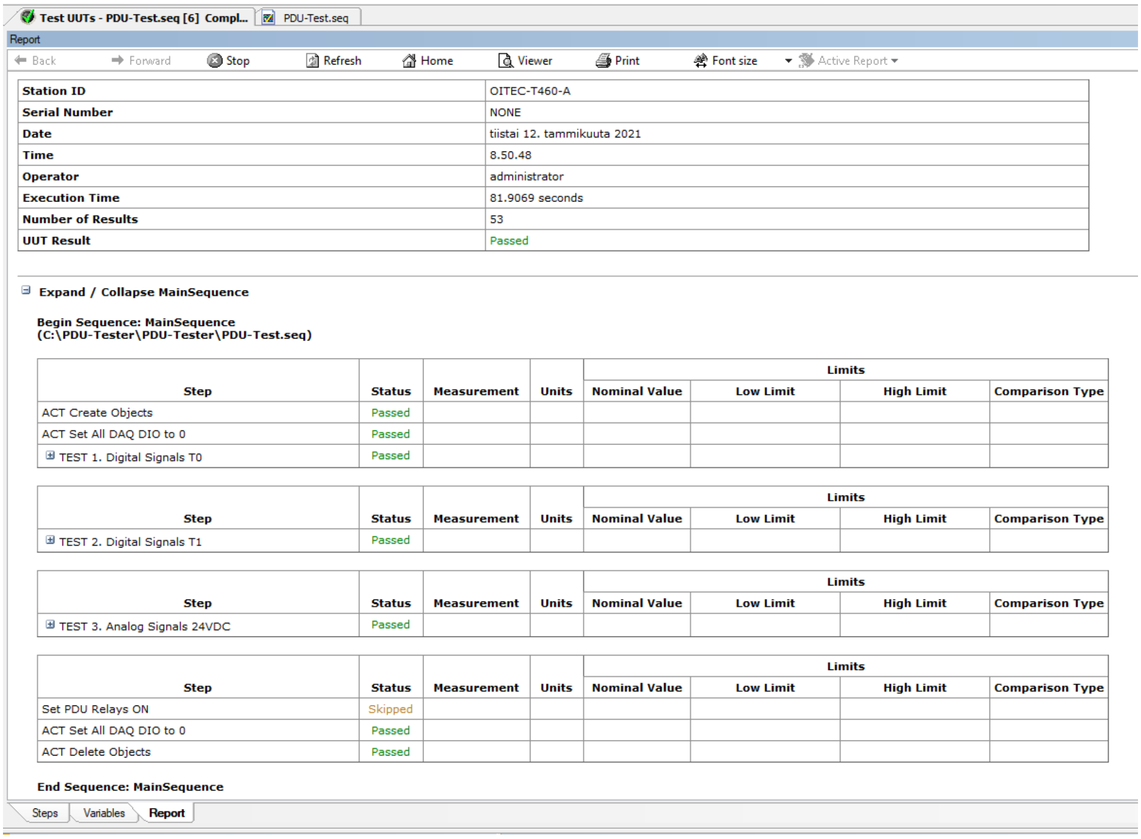
As the calculated values align with what is measured on the Modbus’s end, the test is a success, and these PLC inputs were wired as intended.

6 Test Results

This chapter will look at the measured results of the finished testing process as well as the future of the PDU Tester.

6.1 Results

Figure 27 reveals the full report for the PDU Tester test sequence.


Test UUTs - PDU-Test.seq [6] Compl... | PDU-Test.seq

Report

Back | Forward | Stop | Refresh | Home | Viewer | Print | Font size | Active Report

Station ID	OITEC-T460-A
Serial Number	NONE
Date	tiistai 12. tammikuuta 2021
Time	8.50.48
Operator	administrator
Execution Time	81.9069 seconds
Number of Results	53
UUT Result	Passed

Expand / Collapse MainSequence

Begin Sequence: MainSequence
(C:\PDU-Tester\PDU-Tester\PDU-Test.seq)

Step	Status	Measurement	Units	Limits			
				Nominal Value	Low Limit	High Limit	Comparison Type
ACT Create Objects	Passed						
ACT Set All DAQ DIO to 0	Passed						
TEST 1. Digital Signals T0	Passed						

Step	Status	Measurement	Units	Limits			
				Nominal Value	Low Limit	High Limit	Comparison Type
TEST 2. Digital Signals T1	Passed						

Step	Status	Measurement	Units	Limits			
				Nominal Value	Low Limit	High Limit	Comparison Type
TEST 3. Analog Signals 24VDC	Passed						

Step	Status	Measurement	Units	Limits			
				Nominal Value	Low Limit	High Limit	Comparison Type
Set PDU Relays ON	Skipped						
ACT Set All DAQ DIO to 0	Passed						
ACT Delete Objects	Passed						

End Sequence: MainSequence

Steps | Variables | Report

Figure 27. The TestStand final report.

As was mentioned earlier, Set PDU Relays ON step was skipped because it is not covered for this thesis and will be left for a future update. All the relevant steps have successfully passed.

Begin Sequence: TEST 1. Generate Digital Output T0
(C:\PDU-Tester\PDU-Tester\PDU-Test.seq)

				Limits			
Step	**Status**	**Measurement**	**Units**	**Nominal Value**	**Low Limit**	**High Limit**	**Comparison Type**
Wait	Done						
1-02. I4 test	Passed	29			29	29	GELE(>= <=)
Wait	Done						
Wait	Done						
1-05. I8 test	Passed	269			269	269	GELE(>= <=)
Wait	Done						
Wait	Done						
1-08. I12 test	Passed	4109			4109	4109	GELE(>= <=)
Wait	Done						
Wait	Done						
1-11. I14 test	Passed	16397			16397	16397	GELE(>= <=)
Wait	Done						
Wait	Done						
1-14. I16 test	Passed	1			1	1	GELE(>= <=)
Wait	Done						
Wait	Done						
1-17. I18 test	Passed	4			4	4	GELE(>= <=)
Wait	Done						

End Sequence: TEST 1. Generate Digital Output T0

Figure 28. The TestStand report on T0 signal tests.

Figures 28, 29 and 30 reveal a more in-depth look at the sequences with their measurement limits, values, and result (Status). Within each sequence step the proper values are found from the ModBus output register. There are no tests for I0, I1, I2, I3 or I6 as the PLC is reliant on their logic states just to be turned on or off. They can be considered as default logic states and testing them would be redundant, as without them functioning none of the other tests would be possible anyway.

Begin Sequence: TEST 2. Generate Digital Output T1
(C:\PDU-Tester\PDU-Tester\PDU-Test.seq)

				Limits			
Step	**Status**	**Measurement**	**Units**	**Nominal Value**	**Low Limit**	**High Limit**	**Comparison Type**
Wait	Done						
2-02. I5 test	Passed	45			45	45	GELE(>= <=)
Wait	Done						
Wait	Done						
2-05. I9 test	Passed	525			525	525	GELE(>= <=)
Wait	Done						
Wait	Done						
2-08. I13 test	Passed	8205			8205	8205	GELE(>= <=)
Wait	Done						
Wait	Done						
2-11. I15 test	Passed	32781			32781	32781	GELE(>= <=)
Wait	Done						
Wait	Done						
2-14. I17 test	Passed	2			2	2	GELE(>= <=)
Wait	Done						
Wait	Done						
2-17. I19 test	Passed	8			8	8	GELE(>= <=)
Wait	Done						

End Sequence: TEST 2. Generate Digital Output T1

Figure 29. The TestStand report on T1 signal tests.

Begin Sequence: TEST 3. Generate Analog Output 24VDC
(C:\PDU-Tester\PDU-Tester\PDU-Test.seq)

				Limits			
Step	**Status**	**Measurement**	**Units**	**Nominal Value**	**Low Limit**	**High Limit**	**Comparison Type**
Wait	Done						
3-02. I7 test	Passed	141			141	141	GELE(>= <=)
Wait	Done						
Wait	Done						
3-05. I10 test	Passed	1037			1037	1037	GELE(>= <=)
Wait	Done						
Wait	Done						
3-08. I11 test	Passed	2061			2061	2061	GELE(>= <=)
Wait	Done						

End Sequence: TEST 3. Generate Analog Output 24VDC

Figure 30. The TestStand report on 24VDC signal tests.

6.2 Future Work

The PDU Tester prototype is done and functioning. It can be used to test OiTec's PDU's PLC functionality. There are still several other additions and improvements left that can be added and changed. The schematics within this thesis include additional components such as a Voltage Divider Board, which is not present yet in the Tester, and are needed for tests to read higher voltages that are coming from the PDU. There are also plans to include a resistor board to measure currents and voltages within the PDU.

In addition, there is also the likely possibility that new functionality and software will need to be added or updated should the PDU have its features changed, which is likely to happen.

7 Conclusions

The thesis was done for the purpose of creating a device for OiTec Oy to streamline the testing process of their PDU products. Increasing speed of production via speedier testing processes that also reduce the chances of making human errors was one of the goals of this project that has been met.

While the prototype device is successfully done (see Appendix 1), it is still an ongoing project and will never be truly finished so long as OiTec Oy continues with its line of PDU products (see Appendix 2). It is a device that will always need to have its hardware and software updated whenever the PDU receives a new version that will see larger scale production. The Tester is very modular by design, so making changes for it should not prove to be a difficult or too lengthy of a task.

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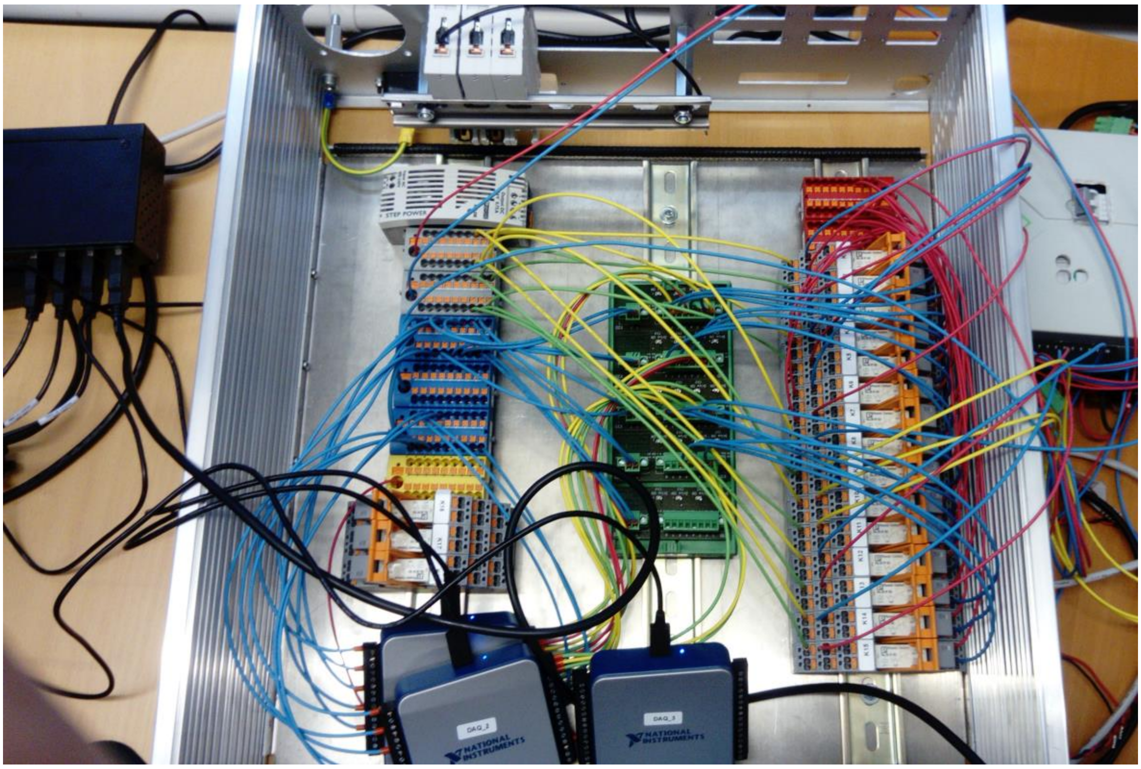
PDU Tester prototype



OiTec Oy PDU