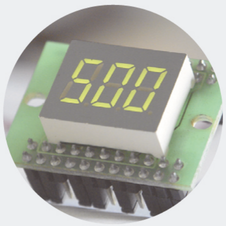
INSTITUTO SUPERIOR DE ENGENHARIA DO PORTO

MESTRADO EM ENGENHARIA ELECTROTÉCNICA - SISTEMAS ELÉCTRICOS DE ENERGIA






Conexão Modbus TCP / IP de turbina eólica para monitoramento em tempo real de uma micrográfica de demonstração

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POLITÉCNICO
DO PORTO

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Microgrid demonstration platform: Modbus TCP/IP connection for real-time monitoring of a wind turbine

(Plataforma de demonstração de microredes: Ligação modbus TCP/IP para monitorização em tempo real de uma turbina eólica)

Instituto Superior de Engenharia do Porto

Faculty of Electrical Engineering

Master in Electrical Engineering – Power Systems

Erasmus Project

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Abstract

Non-renewable energy resources in the guise of fossil fuels are the basic source for industry, energetics, transport and households. Amid the alarming reports on the subject of depleting resources of fossil fuels, a lot of countries promote the use of renewable energy sources. However, plenty of countries still maintain their traditional ways of producing energy. For instance, those countries use coal, which is very harmful to the environment because it destroys the ozonosphere or causes respiratory failure to people. Because of that, many organization perpetually struggle, encumbering enormous fines for companies or countries in general. The costs of installation can be quite high at first but in the course of time, these investments bring dividends. Using renewable energy sources, such as wind power, hydropower, solar energy, the geothermal energy, and biomass, is very attractive, especially for big companies.

The difference in price between the conventional and unconventional way to generate energy might be minimal but multiplied by thousands this small difference becomes a big amount that companies could save. Therefore, it is important for entrepreneurs to get up-to-date information about work parameters, particular generative departments, identify places where can be excessive energy consumption, gathering data, reporting and further analyzing results, and for energy management and visualization of the whole system. Thank to the wireless connection between regulatory PC and remote units, which is the TCP/IP network, it is feasible to obtain plenty of measurements in outlying and very often unavailable places for people.

The software used on this project was *Saia PG 5 Controls Suite*, created to program controllers of the Saia Burgess Controls company. It uses logic that is universal and does not depend on controllers of other companies. Furthermore, the *PG5* contains a whole set of tools, which was sufficient to create the SCADA system without the need to use any other softwares.

Keywords: wind turbine, energy monitoring, Modbus TCP/IP, Saia PG5 Controls Suite, SCADA

Contents

List of figures

List of tables

Abbreviations

- E-energy
- F-frequency
- GECAD-Research Group on Intelligent Engineering and Computing for Advanced Innovation
- GW-gigawatt
- Hz- Herz
- IP-internet protocol
- MW-megawatt
- P-real power
- PLC-Programmable Logic Controller
- rpm-revolutions per minute
- s-second
- SBC-Saia Burgess Controls
- SCADA-Supervisory Control And Data Acquisition
- t-time
- TCP-transmission Control Protocol
- U-voltage
- UK-United Kingdom
- USA-United State of America
- USD-United State dollar
- V-volt
- W-watt
- Ω-omega
- TN, TT, I- the protocolT-references basic types of electrical system
- PDU-Protocol Data Unit
- ADU-Application Data Unit
- MB-MODBUS

- MBAP- MODBUS Application Protocol
- ISEP- Instituto Politecnico do Porto
- GECAD-Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development
- P-active power
- VAC- electrical voltage in an alternating current circuit

1. Introduction

In the first chapter described motivation of the project. It shown the core of the producing electrical energy and advantages of that, as well as, statistic around the world. Further described task of monitoring electrical energy and characterized a smart grid.

1.1 Motivation

First, to point why wind energy is extremely important, is by looking into an energy production figures. Figure 1.1 shows new affiliations of wind farm until 2014 around the world.

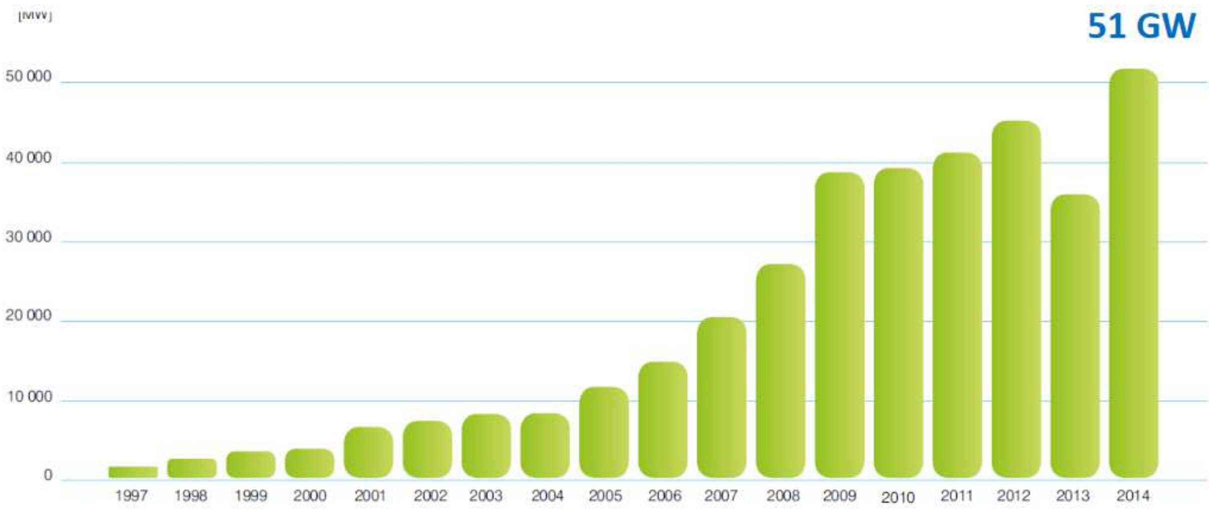


Figure 1.1 New affiliations of wind farm until 2014 around the world[1]

Clearly, since 1997 until 2014 in general new affiliations is seen the upward tendency, which explains that producing energy using wind power, year by year, has become more popular and economic. In 2015, the growth in produced energy by wind was almost the same as half of rising global produced electricity, thereby carbon dioxide emissions remained stable. [2] This was due to industrial restructuring, which improved energy efficiency and the substantial growth of renewable-led by wind.

After reached E=50 GW mark of producing electricity energy for the first time in a singular year, using wind turbines brought another record-breaking year. The following year, in 2015 the amount of produced energy went up by 22% reaching around E=63 GW. Regarding global energy produced in only one year, there were around E=370 GW in 2014 and E=433 GW in 2015, which resulted in 17% increase in only 365 days. This places wind turbine utilisation as the most efficient method to produce energy than any other technologies.[3] In 2015, according to the IEA, China led the way with a record where E=30.8 GW of new installed capacity, breaking the previous record it had set in 2014 for installations in a single year. Until 2016 China had more than E=145 GW of wind power installed, more than in all of the European Union. Two years earlier, it was the first country ever to invest more than 100 billion USD in renewable energy in a single year. Results above indicate how important topic is gathering electrical energy from wind turbine, therefore it is needed to improve researches in order to do it as effective as it is possible. The motivation of the erasmus project was to apply the wind turbine emulator automated and controlled by a SCADA system via Modbus TCP/IP protocol. The remote PC via TCP/IP network would have to control the PLC, which impacts on work of the engine. The rotor of the engine is connected with the rotor of the generator, by common drive shaft. Mechanical energy of the engine's rotor would have been transformed by generator into electrical energy. Apart from control the device the operator would have also possibility to receive data from it.

Advantage of this project was fact, that SCADA systems are very eager used in companies and plants. In the interest of its transparency and intuitive control of the process SCADA systems are very friendly tools for users. To create the SCADA it was not need to pay for the software. Both the software, shared by producer, and TCP/IP standard were totally free.

These days, life without electricity is practically impossible. For example, illuming streets, heating houses, listening to favourite music or even writing this report on the computer wouldn't be possible without electricity energy. However, to produce energy other types of energy are needed. These renewable such as wind turbine or non-renewable like as coal. Despite these renewable are more and more used, those conventional are still on the agenda.

According to International Energy Agency *Coal Industry Advisory Board CIAB*[33] coal fuels 42% of global electricity production. No matter from which energy source electricity is produced, companies try to reduce its usage. As a result, they monitor their electrical energy expenditure.

Monitoring the quality and quantity of electrical energy is not the only object of attention for the small group of researchers. It became a daily practice in power grid enterprises, at manufacturers, at big recipients and sometimes at individual recipients. Electrical energy became a commodity, and just as in the case of other commodities, it's quality is graded. Receivers paying for specified parameters of provided energy, feel a natural need to check these parameters. In many cases, a decline of the electrical energy quality level, may lead to a disruption in the performed processes and a disturbance in the working devices, sometimes even damaging them. To accuse specific energy suppliers it is necessary to have registered parameters of electrical energy quality. Just then, it is possible to prove that the fault lies on supplier side. Power supply enterprises willing to guarantee the appropriate quality of energy, are interested in monitoring parameters of sent energy. The most important are: energy consumption, power factor, change of voltage, frequency and current parameters. Developing technology and the constantly decreasing prices on electronics, caused that these systems can also be used in households. [34] Various studies have shown a reduction in home energy use of 4-15% through the use of home energy display.

According to[35] *Wikipedia* "smart grid" is an electrical grid which includes a variety of operational and energy measures including smart meters, smart appliances, renewable energy resources, and energy efficiency resources. Electronic power conditioning and control of the production and distribution of electricity are important aspects of the smart grid. In the project from the aforementioned characteristics of power grid, only receiving data is included. In more advanced systems it would be a also possibility to compare expected and measured value. Owning these data and analysing it, the user of the energy monitor systems can describe the targets which have to be wrought to reduce costs.

All motives described above show the role that monitoring and conserving energy play. Nowadays, not only big companies but also singular consumers should think about latching onto monitoring energy topics and manage their own way of consuming energy.

1.2 Objectives of the work

The main purpose of Erasmus project was to create SCADA system of wind turbine emulator. The process of control emulator was supposed to provided by an operator through remote PC. In plants, where machines are often carried, it is not comfortable to use metal wires. Additionally each meter of them is extra cost. Thus reasons above, connection between remote PC and wind turbine emulator had to be wireless. The best to this task was to use TCP/IP protocol, which is openly published, which means that everybody can use it. However, to connect PC with main PLC there is need to configure the *Saia PG5 Control Suite.* In order to that it is needed to place IP address of RIO module in destined place. The main PLC is connected with RIO extra module, which includes additional modules of I/O. Precise characterization of main PLC, RIO station, as well as, Modbus TCP/IP is chapter two. In response on messages from the operator, RIO station would set suitable voltage output signals. The signals are sent to engine controller. The change of voltage value [30] induced in the magnetic circuit of the engine a rotating flux relative to the stator, which rotates the rotor through Eddy currents and the Laplace forces. The electrical engine in coupled with power generator by common drive shaft. Spinning rotor of electrical engine is the source of the mechanical energy. Power generator turn this kind energy into electrical and conduct to power grid.

One of the task SCADA, which acronym is Supervisory Control And Data Acquisition is to register received data. The most requested data in the project was produced electrical energy(in watts). User would have possibility to overview the value of energy in real-time, receive chart of produced energy related on time, as well as, save results in excel file. The rest of received in real-time data are voltage between one line and neutral wire, sum of currency of three lines and output voltage of the PLC RIO station.

In Saia *PG5 Control Suite* and precisely in FUPLA editor, it was possible to create logical part of the control process. The graphical language used in FUPLA editor was very easy for beginners. When some errors occurred, it was easy to identify the source of problem. The next tool included in *Saia PG5 Control Suite* was *WebEditor8*. It enabled to create a visualization. More information about *Saia PG5 Control Suite* may one find in chapter two.

In visualization operator could change the wind speed. With changing of wind speed also other parameters are changing, as e.g. production of electrical energy. Operator was supposed to create the chart, shown relationship between the wind speed and production of energy, for defined values of wind speed. Apart from the chart would be possible to send results to excel file.

1.3 Report organisation

The report contains five chapters. In the first chapter the introduction is included, where basic information is described and the motivation behind it. The following includes characterization of employed devices, that were necessary to realise the project. Chapter three has the characterization of the done work, the next chapter- number four, it is the summary and includes lessons learned. The last, fifth, has the bibliography.

2. Applied devices and network

In the chapter described devices used in the project, as well as, the Modbus protocol with extension to the Modbus TCP/IP. Below they are shown general information, specifications, the structure of the frames both Modbus and Modbus TCP/IP, as well as, description of the signals sent between Client and Server. In the end of the chapter described first practical solution of the occurred problem.

2.1 Saia PG 5 Controls Suite

The Saia PG5® Controls Suite is software created by the swiss company to control the PLCs from the same company. The software contains tool set, which is required to carry out and operate automation solutions with instrumentation, control, and, automation (ICA) devices of the company. In the software included programming and engineering tools, ready-made libraries and logic as well as regulation and automation modules. The environment is ready to install on the most popular operation system Windows for PCs.

The *Saia PG5 Controls Suite* contains:

- Project Manager (manage congeneric installations of PLCs connected by network)
- Network Configurator (the task of network configurator is to edit settings of devices included in project and networks used to communicate between them)
- Device Configurator (serve to establish hardware parameters of the PLC)
- Symbol Editor (manage symbols, which were shown in the project)

- Programming methods (the user of software has wide choice of environments to program : FUPLA- function block diagram, S-Edit-instruction list IL, Graftec-sequential function chart)
- Libs [5](libraries which include all the prime functions of the automation technology)
- WebEditor (editor used to create visualisation of SCADA system)

FUPLA editor:

FUPLA editor is Saia Burgess Control company own function block diagram editor.

In figure 1.2 shown exemplary program, created in FUPLA editor.

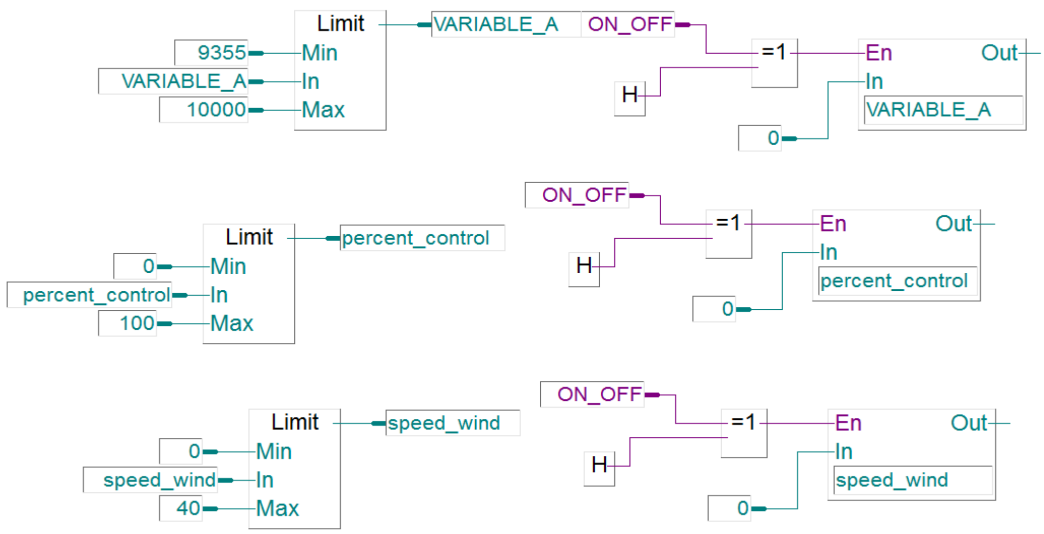


Figure 1.2 Example of FUPLA programme

Although, in FUPLA it is applied graphical language, it varies from other graphical programming interfaces:

- In FUPLA file can be included many blocks, which are needed to construct program. This means that only one file is enough to create the whole function
- To each program block is assigned individual symbol name. Thank to that there is no possible to occur collision during compilation

- There is possibility to extend program into following pages. Window of pages enables to in easy and quickly way to move between pages
- Apart from inputs and outputs, graphical function blocks have also possibility to configure parameters as well as modify states of block in online mode

2.2 Applied PLCs

The main PLC in the project was PCD3.M5560, however it was extended with additional module PCD3.T665 Smart RIO. PCD3.M5560 could not be used because it was set to far from the emulator. All signals, controlling the work of the engine are send from RIO station.

2.2.1 PCD3.M5560

One of the used PLC in the project was *Saia Burgess Controls PCD3.M5560* with RIO module extension.

Figure 1.3 Front panel of Saia PCD3.M5560 [9]

Specification

- [10]Up to 1,023 inputs/outputs

- Can be expanded locally with RIO PCD3.T66x or PCD3.T76x
- Up to 13 communication interfaces
- USB and Ethernet interface onboard
- 2 Ethernet interfaces (PCD3.M6860 only)
- Fast program processing (0.1µs for bit operations)
- Large onboard memory for programs (2 MByte) and data (128 MByte file system)
- Memory with SD the can be expanded to 4 GByte
- Automation Server for the integration into Web/IT system

2.2.2 PCD3.T665 Smart RIO

Smart RIOs can be used either as simple remote I/O stations or as intelligent and distributed Smart Automation Stations capable of executing *PG5* user programs.

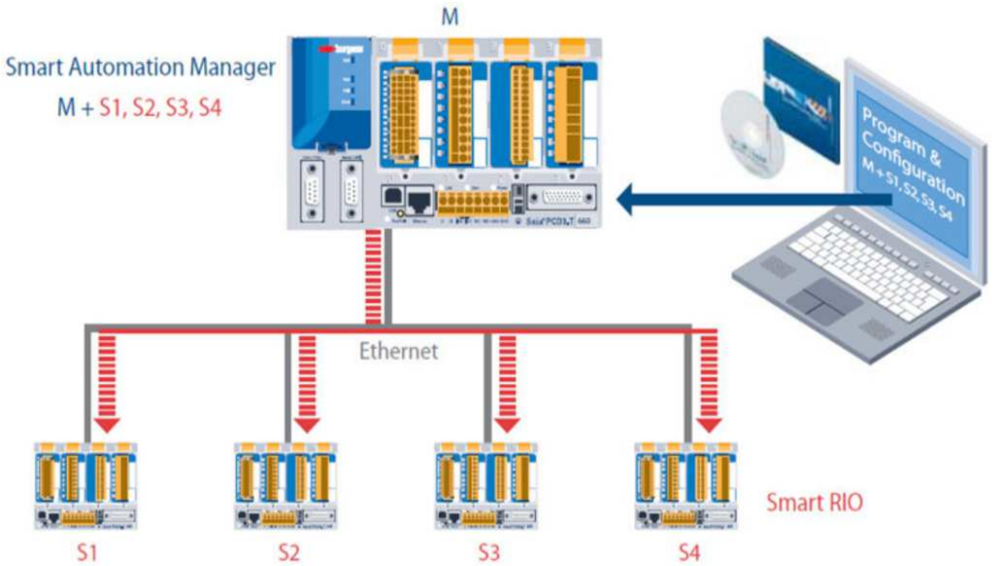


Figure 1.4 The way of communication between PC, main PLC and its extensions [11]

Specification [12]

- Number of slots on I/O modules: 4 (expansive to 16)
- Number of I/O : 64 in basic unit (expansive to 256)

- Supported I/O modules: Saia PCD3.Exxx, PCD3.Axxx, PCD3.Bxxx, PCD3.Wxxx
- The biggest number of stations RIO: 128
- Communication protocol: Ether-S-IO
- 32 kB user the memory
- 512 kB flash memory with files systems
- Embedded communication interfaces USB and Ethernet TCP/IP
- Supply Voltage: 24 V DC
- Work temperature: 0-50 ºC

2.3 Janitza UMG 96 RM

Another step in the project was to use *Janitza UMG 96 RM* power analyser and display received data using *TCP/IP* standard. Figure 1.5 shows the external look of the device.

Figure 1.5 Power analyser *Janitza UMG 96 RM* [13]

The *Janitza UMG 96 RM* can be used for voltage measurement in *TN*, *TT* and *IT* systems. Voltage measurement in the *Janitza UMG 96RM* is designed for the *300 V* overvoltage category CATIII (4 kV rated pulse voltage). Figure 1.6 shows the way of voltage measurement and figure 1.7 illustrates of current measurement.

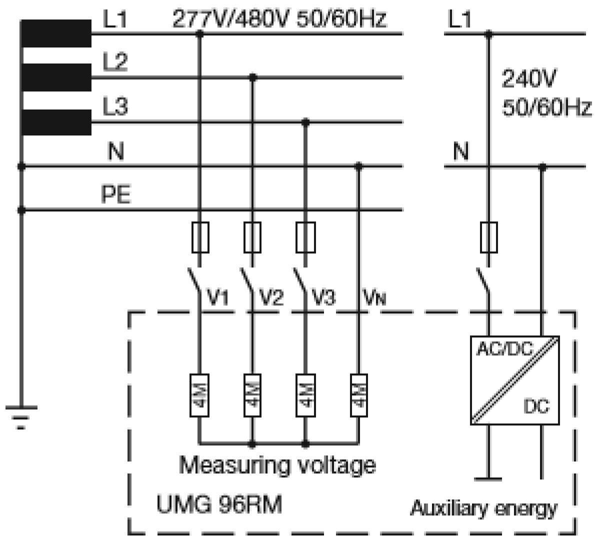


Figure 1.6 Connection diagram to measure voltage [14]

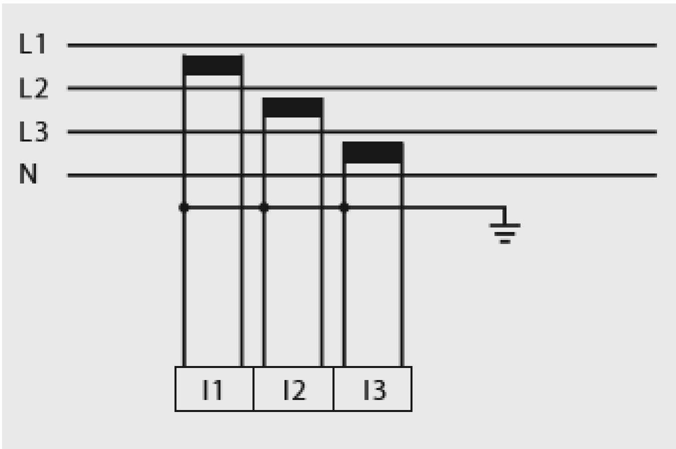


Figure 1.7 Connection diagram to measure current [15]

2.4 Modbus protocol

2.4.1 Basic information

Modbus communication protocol was invented in 1979 by *Modicon* company; now it belongs to *Schneider Electric*; to use with its PLC.[16] Simple and robust, it has since become a *de facto* standard communication protocol, and it is now a commonly available means of connecting industrial electronic devices.

The most important aspects why Modbus is used, are:

- developed to be used in automatics
- the protocol is open and costless
- orders need confirmation, there is signaling of errors
- it is standard, accepted by most of the companies
- it is easy to implement and maintain

Modbus protocol enables communication between many devices (248), connected to the same network. It is very often used to connect prime PC (Master) with remote units (Slave) in SCADA system.

2.4.2 Structure of the frame

The main structure of Modbus protocol contains simple PDU and can be extended to ADU.[17] The structure of the Modbus protocol frame is shown in figure 1.8.

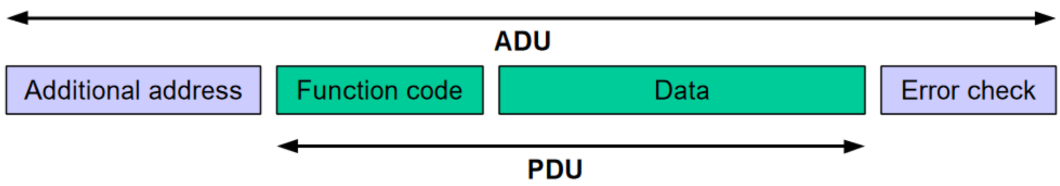


Figure 1.8 General Modbus protocol frame [17]

To fulfill part of Modbus data unit, named *Function code* is needed to use just one byte. When the *Client* sends a message to the *Server*, the *Function code* field "tells" the *Server* which action is being performed. Substituting the value "0" in the *Function code* field is not correct.

Regarding the field named *Data*, it contains additional information, which the

Server uses to take the action characterized by the function code included in the field. This can involve discrete and register addresses, [18]the quantity of items to be handled and the count of actual data bytes in the field. This field may have zero length in certain kinds of requests, in case like that, the *Server* does not require any additional information.

The *Function code* by itself specifies the action. If there is no error in response from the *Server* device to the *Client*, then the response concludes the requested data. If there is some error detected the field contains an *Exception code*, which can be used to arrange the next step to be done.

The example, shown below in figure, FIGURE *Client* can read two states *ON* or *OFF* of a group discrete inputs or outputs. The *Client* has also a possibility to read or write the data contents of registers.

When *Client* sends *Data Request* message to the *Server*, as a retort, the *Server* uses the *Function code* field to indicate the *Client*, either a normal response or with detected errors. For a normal response, which is error-free, the *Server* simply echoes the request . When some kind of error is detected, the *Server* sends the communication, called an *Exception code*, which reports about the detected error.

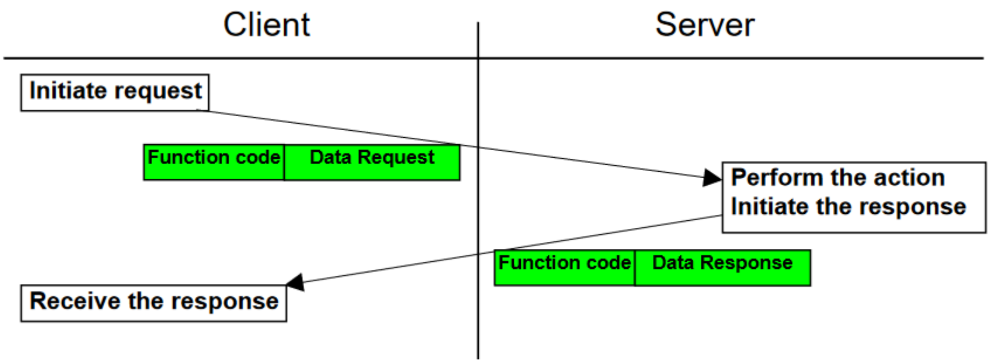


Figure 1.9 Modbus transaction (error free) [19]

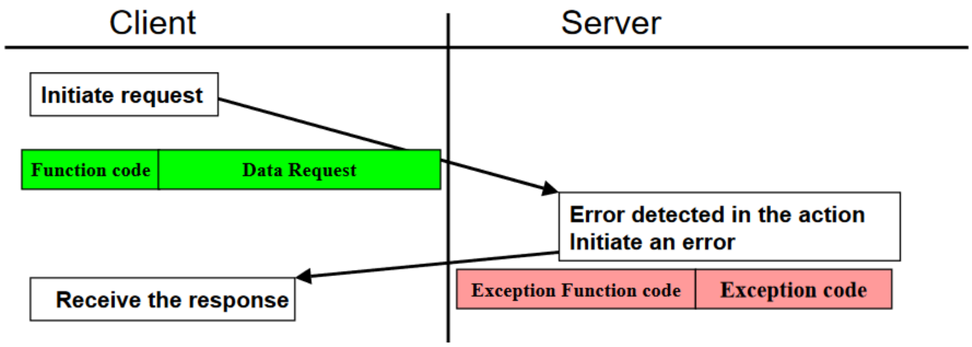


Figure 1.10 Modbus transaction (exception response) [20]

2.4.3 MODBUS TCP/IP

2.4.4 General information

Modbus protocol allows mutual data transmission and cycling own resources between devices included in one *TCP/IP* network. Communication between the *Client* and the *Server* is based on four type of messages:

- *Modbus Request*,this message is sent by the *Client* to the *Server* to initiate a transaction
- *Modbus Confirmation* is the response message send to the *Client* from the *Server*
- *Modbus Indication*, this request message is received by the *Server*
- *Modbus Response* is the message, which is the response thereby sent by the *Server*

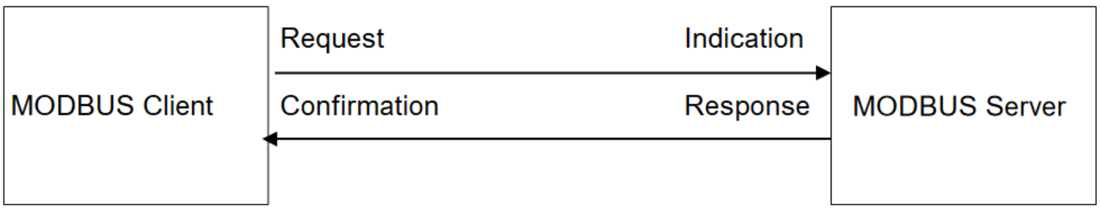


Figure 1.11 Client-Server Model of communication [21]

In *Modbus*, the *Client* and the *Server Model* messages are sent:

- Between applications of two individual devices
- Between application of device and another device
- Between devices and applications of *HMI* or *SCADA*
- Between a *PC* and a device program working online

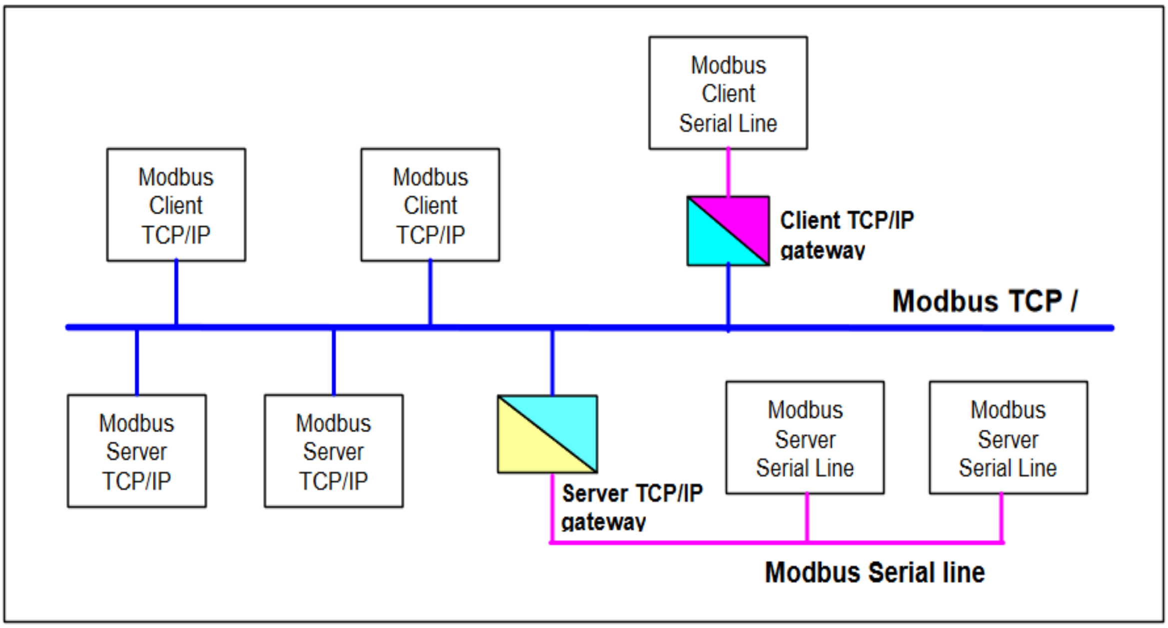


Figure 1.12 Structure of communication in *Modbus TCP/IP* [22]

Simplicity and reliability of *Modbus TCP/IP* renders that it became the standard used in a broad sense automatics. Nowadays, it is one of the most used communication protocols in industrial electronic devices despite the quite long time since its birth.

2.4.5 Frame structure

The main structure of *Modbus TCP/IP* protocol is shown below in figure 1.13.

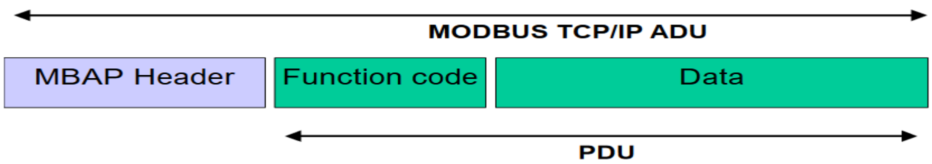


Figure 1.13 *Modbus TCP/IP* frame [23]

Frame of *Modbus TCP/IP* protocol contains the address of the device, where the order is sent. Only devices with *IP* addresses react for order; however, other devices connected to the same network can receive the same order.

Each frame contains control sum to make sure that the frame isn't damaged. The easiest orders let to change the content of the register, change or read bit inputs or outputs but also read of the content of the registers. Each device intercommunicating by *Modbus* protocol receives unique a address. In *Ethernet* networks both *Master* and *Slave* devices can send the order but mostly does it only *Master*.

The field named MBAP Header on the figure above, is seven bytes long. It contains the following fields:

•*Transaction Identifier* (2 bytes)- this identifier field is used for pair transaction between *Clients* and *Server*, when many messages became sent in succession in one *TCP* connection by Client, when it doesn't wait for prior answer from the *Master*

•*Protocol Identifier* (2 bytes)– this field always equals zero for *Modbus* statements. It is reserved to future extension

•*Length* (2 bytes)- the field includes strength of following fields: *Unit Identifier, Function code* and *Data*

•*Unit Identifier* (1 byte)– the field named *Unit Identifier* is used in order to identify remote *Servers* not *TCP/IP* networks. In a typical *Modbus TCP/IP* application server *Unit Identifier* is set on 00 or FF, which are ignored by the *Server* and is repeated again in the response message.

2.5 Control the bulb

2.5.1 Introduction

The first step to understand how the model of PLC- PCD1.M2120 from the *Saia Burgess Controls* company works and to know what is its structure, was by creating the SCADA system to control virtual bulb via PC as well as via manual switch. Figure 1.14. shows a pictorial diagram of the way to control the bulb.

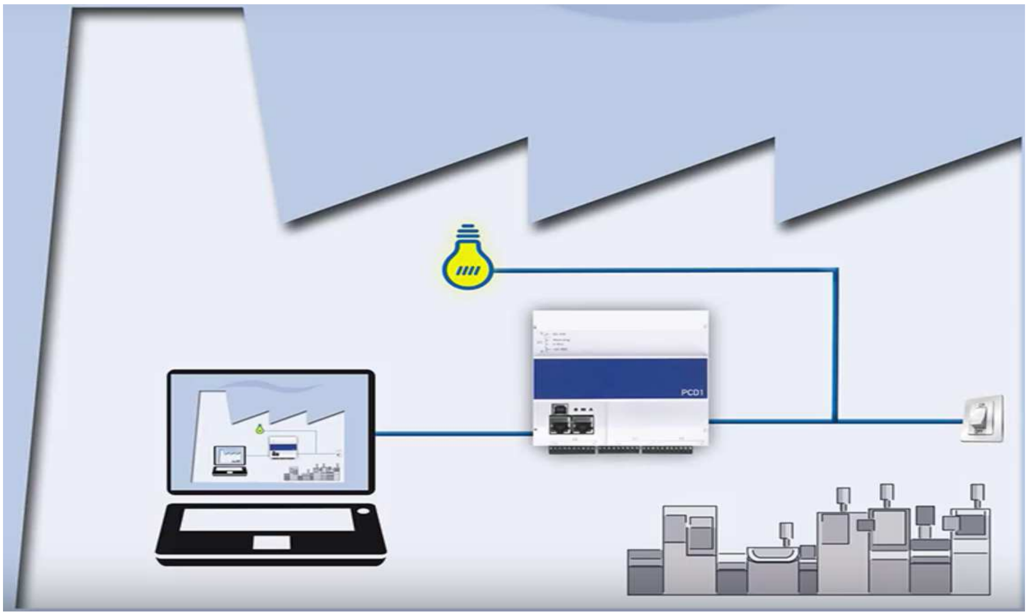


Figure 1.14 The way the bulb works [24]

Other models of PLCs from *Saia Burgess Controls* company, indeed vary in a number of I/O, embedded memory, kind of interface, etc; however, the way it works on this PLC model is exactly the same as others.

2.5.2 Hardware configuration of the PLC

To be able to use the PLC, the first step, it was needed to power it in a proper way and afterwards to connect the PLC with manual button. Figure 1.15. shows how to supply the PLC with two extra modules: PCD2.W525 and the second from family PCD2.Exxx.

It was not necessary to use extra modules. The thing to do, was to just connect wires from individual power generator to *X3* module of PLC, which is responsible for supplying electrical energy to the PLC. Positive pole of power generator was connected to PIN 32 of PLC, which symbolizes *plus* and negative pole of power generator was connected to PIN 34 of PLC, which is *minus*. The wires used for connecting the devices should have a suitable gauge and genre of the core to provide electricity in a proper way. Therefore, 1,5 mm^2 copper wires were used. Mismatched wires could be damaged by an excessively voltage. The power provided by the power generator was equal to *U=24 V*.

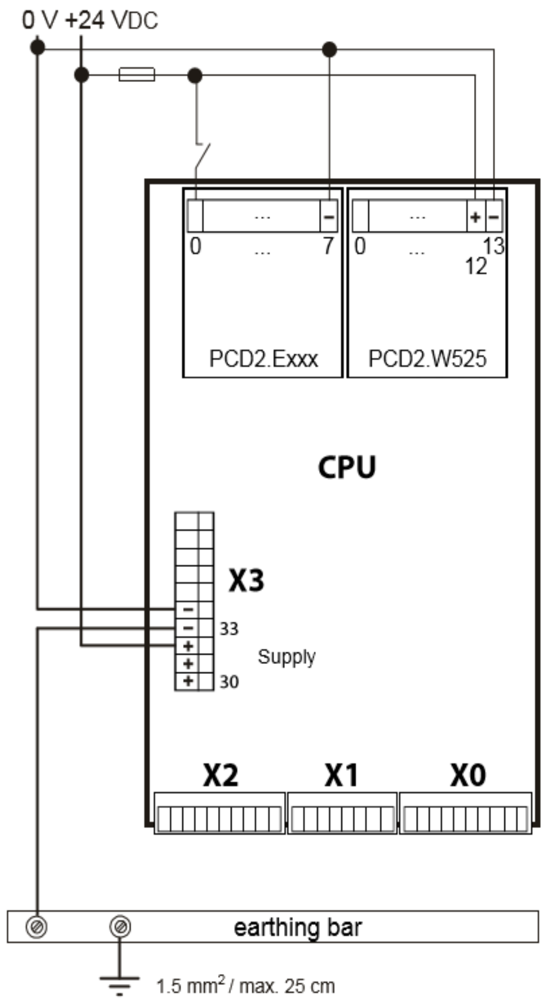


Figure 1.15 Power supply of PCD.M2110R1 [25]

However, to be able to send signals outside it was also needed to supply the module *X0* of PLC, which contains digital outputs. The *plus* of *X3* module was paired with the *plus* of *X0* module and analogously the *minus* of *X3* module was wired with *the minus* of *X0*. The places of *plus* and *minus* of *X0* module, are the first and second pins from right site, which are not visible in figure 1.15. After powering the PLC and its proper modules, the next step to perform was connecting the manual button to the PLC. Shown below there are the anode and the cathode of *X0* module and also the way of colligation the PLC with the switch- figure 1.16.

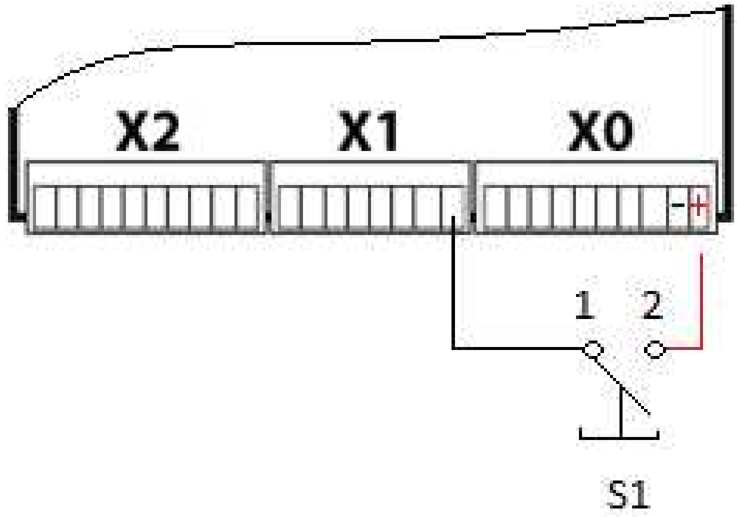


Figure 1.16 Colligation the PLC with manual switch

The mechanical switch has two states. The first one is shown in figure 1.16. Then the switch has zero state- electric circuit is open. The second one would be when the end of the switch is in position number two, which complies with the situation when the button is pressed. Then the electric circuit is closed. Voltage equals *U=24 V,* is sending to digital inputs of module *X0*.

2.5.3 FUPLA programming

To code controls of *Saia Burgess Controls* company, there was the need to release a special software of the swiss company named *Saia PG5 Controls Suite*. Detailed description of this environment is included in chapter 1.4. The software truthfully contains a lot of tools but for this purpose, the most important were *FUPLA editor* and *WebEditor8*. Finished Function Block Diagram, created to control the bulb is illustrated in figure 1.17.

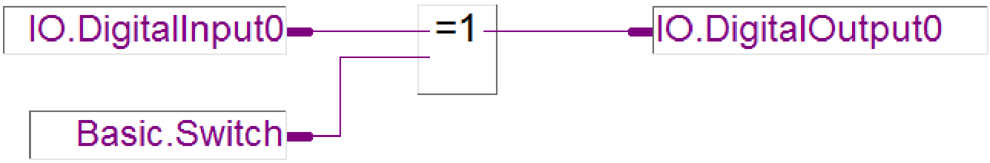


Figure 1.17 Function Block Diagram to control the bulb

The establishment to control the bulb was: it is possible to switch the state of lighting by both buttons, manual and virtual but the state of one of them impacts the next move of the second. To do that XOR (Exclusive OR) logical gate was used. The technique of XOR gate working is shown below in table 1.1. When the number of true inputs is odd the digital logic gates "gives a *true"*.

Table 1.1 The technique of working XOR gate

INPUTS		OUTPUT
A	B	A XOR B
0	0	0
0	1	1
1	0	1
1	1	0

Pressing virtual button *Light* causes set *logical 1* in input *IO.DigitalInput0,*which through the gate, provides signal further to *IO.DigitalOutput0,*causing lighting the bulb. When the mechanical switch is on then the bulb stop lighting, but pressing again either switch or virtual button causes lighting again. Figure 1.18 indicates how it works.

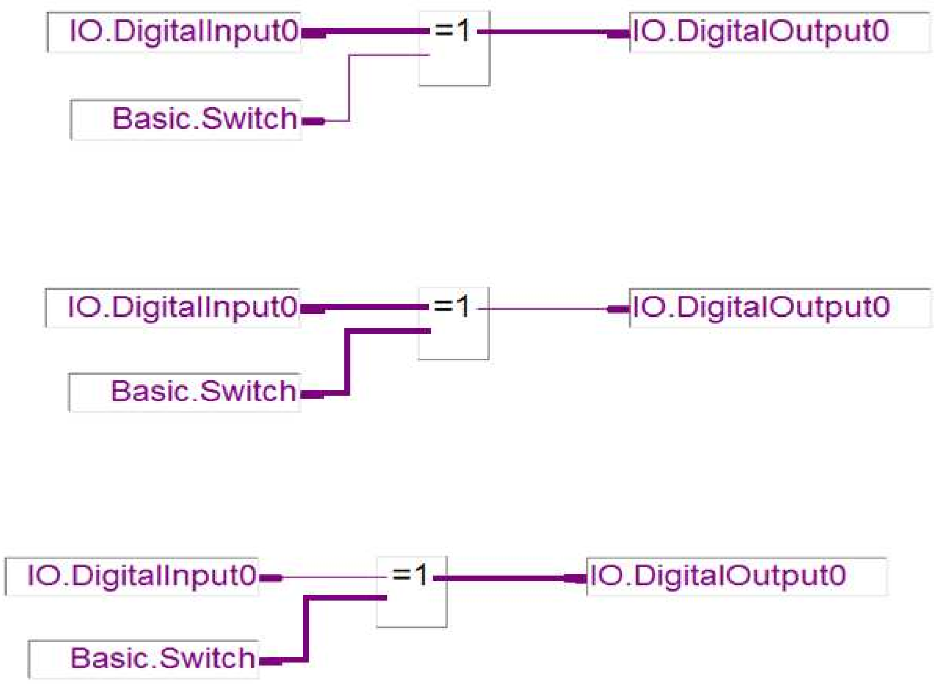


Figure 1.18 Operation mode to control the bulb

To have a visualisation on the web page, the *WebEditor8* programme was used. Figure 1.19 below shows an illustration of the webpage designed in *WebEditor 8*.

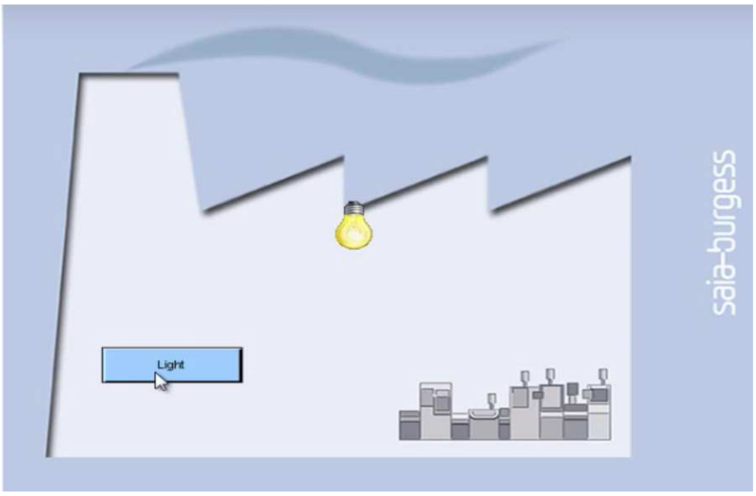


Figure 1.19 The state of lighting in response to set signals [24]

3.Wind emulation platform

In the chapter three described practical part of the work. In chapter 3.2 it is delineated electrical grid, which provided power supply to wind turbine emulator. Then it was characterized the structure of wind turbine emulator and general scheme of devices used during the project. Afterwards they were represented the way out of the task and occurred problem during performing it.

3.1 Control the power analyser

3.1.1 Electrical grid configuration

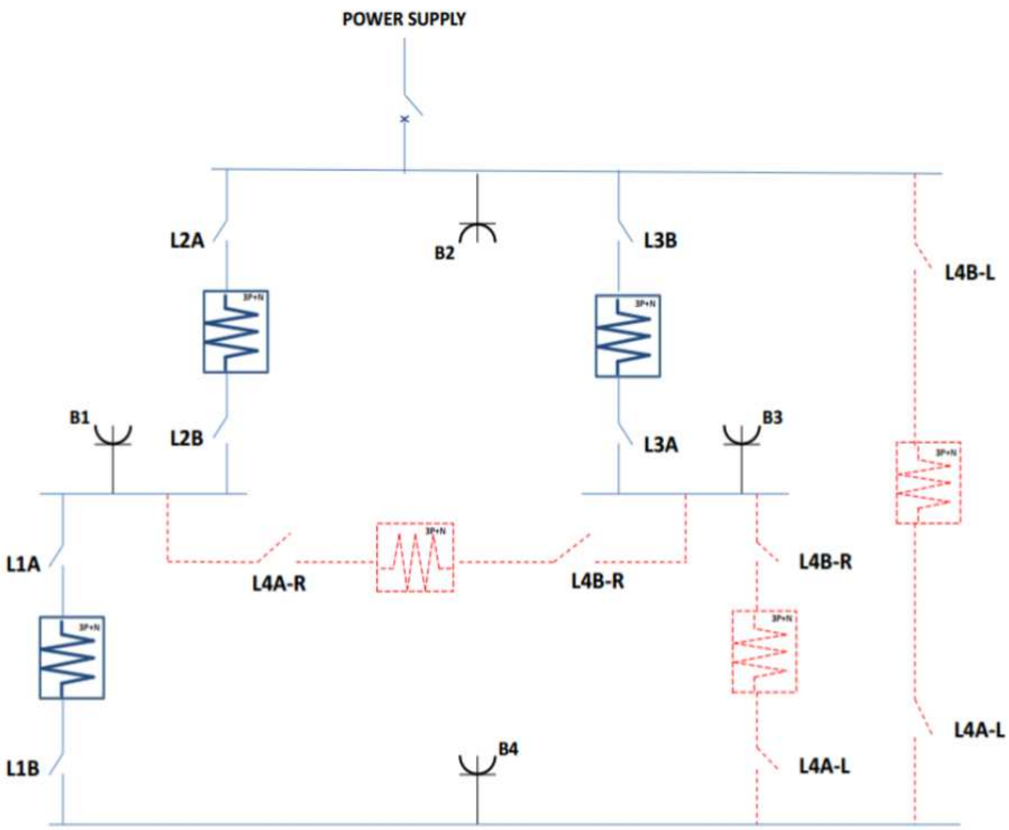
The electrical grid used in the project is placed in GECAD organisation at ISEP in Porto. According to [26]GECAD is Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development, is a research unit settled in the Institute of Engineering - Polytechnic of Porto (ISEP/IPP) having as mission the promotion and development of scientific research in the Knowledge and Decision Sciences domains, having Information Technologies as support. It involves 2 main areas: Intelligent Systems and Power Energy Systems. GECAD is known worldwide in its areas of research, leading some research domains.

Thank to the power analysers set in the electrical grid it was possible to measure the voltage. Figure 1.20 illustrates the used electrical grid.

Legend

Blue and red symbols of resistors in the grid above represent the lines with their resistance. Four output buses ,where the load can be joined, symbolize *B1, B2, B3,* and *B4*. Marked on blue colour lines *L1A, L1B, L2A,L2B, L3A,L3B* and marked on red colour dots *L4A-R, L4B-R, L4B-R, L4A-L, L4B-L* and L4A-L are power analysers. The power grid can be configured to different settings to obtain other values of current. The power analysers with *L4A, L4B* prefixes are deployed behind the switches. Due to this, it is possible to change the structure of the power grid.

The default configuration of the grid is characterized by the blue color, however, the configuration can be changed to different settings which are symbolized by a red colour. Then grid can be mounted in 4 ways. First, establish that none of the wires are connected- this situation represent the blue lines. The second situation would be when the wires, represented by the red line between *B1* and *B3* outputs buses are connected. The third, would be when the red line between *B3* and *B4* outputs buses is joined. The last situation is when the line connected buses *B2* and *B4* is enclosed.



1.20 Electrical grid used in GECAD [27]

3.1.2 *Janitza UMG 96 RM* in FUPLA

The program to read data from *Janitza UMG 96 RM* comprise of 3 blocks: *Init Client TCP, Def Unit Client and Read Float*- figure 1.21.

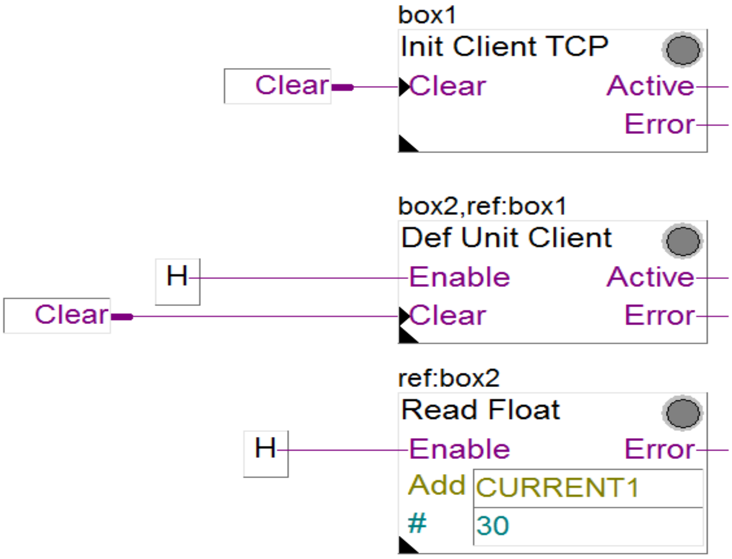


Figure 1.21 FUPLA programme to read values

The first block allows to define a Modbus *Client* for TCP connection. The second one defines a remote unit in a *Client* program and handles the communication with this unit. To do that it is necessary to put the IP address of the remote unit f.e. 192.168.2.231. The third block specifies a read request for floating point values. Below is pointed the remote base address, f.e. 19026, which responds to read sum of power all three lines- figure 1.22.

Modbus Address	Address Above display	Format	RD/WR	Unit	Note
19000	808	float	RD	V	Voltage L1-N
19002	810	float	RD	V	Voltage L2-N
19004	812	float	RD	V	Voltage L3-N
19006	814	float	RD	V	Voltage L1-L2
19008	816	float	RD	V	Voltage L2-L3
19010	818	float	RD	V	Voltage L3-L1
19012	860	float	RD	A	Current, L1
19014	862	float	RD	A	Current, L2
19016	864	float	RD	A	Current, L3
19018	866	float	RD	A	Vector sum; IN=I1+I2+I3
19020	868	float	RD	W	Real power L1
19022	870	float	RD	W	Real power L2
19024	872	float	RD	W	Real power L3
19026	874	float	RD	W	Sum; Psum3=P1+P2+P3
19028	884	float	RD	VA	Apparent power S L1
19030	886	float	RD	VA	Apparent power S L2

Figure 1.22 Defined value to read sum of power of three lines [28]

Format points float values. In order to correctly read the value sequence of the blocks, they have to be proper, which means the *Read Float* block has to reference to *Def Unit Client* block, which references to *Init Client TCP* block.

3.2 Control the wind turbine

The most difficult job in the project was creating the real-time monitoring of a demonstration microgrid based on the simulator of a wind turbine via *Modbus TCP/IP* standard connection.

3.2.1 The wind turbine simulator

To conduct tests in the laboratory of GECAD a wind turbine simulator, connected to electrical grid, was used. Figure 1.23 shows superficies of the wind turbine simulator.

Figure 1.23 Front panel of the wind turbine simulator [29]

Description

EOLYP is a metrological bench destined to study synchronous work of the wind turbine in an electrical energy production aspect excluding the mechanical aspects. Because of the noise and the course of air, which is not suitable to the laboratory environment, the rotor blade was changed by an electric drive with variable speed of the rotor.

The principle of operation

Rotor blade for which operator set the velocity, propel generator from 0 to 1800 rpm. Two sensors set on drive shaft, return information about rotational speed and torque to console displaying the information. The generator is coupled with the public three-phase network by the metrological table, pointing:

- Active power forwarded to the network *P*
- Voltage between lines *U*
- Intensity *I*
- Power Factor *cosφ*

The wattmeter with zero in the middle points of the generator is dependently on the velocity of drive charges or produces energy, marking below-synchronous or above-synchronous work.

The construction of simulator

- 1 frame on casters, dimensions 1200x750mm, height: 1820 mm
- 1 asynchronous motor 1,5 kVA
- 1 generator
- 1 DC tachogenerator/1 torque sensor
- 1 command console
- 1 electrical cabinet
- 1 network coupling unit

Generator features

- Generator 3x400 VAC asynchronous motor
- Active power injected into the network: 0 to 1,2 kVA
- Imax=5A
- Generator efficiency: 78 %
- Speed variation: 0 to 1800 rpm

Electric cupboard

- The inside:
    - 30 mA off switch and thermal and magneto-thermal off switch
    - 2,2 kVA speed regulator with control unit on the console
- Capacitor battery

Control panel

- 1 emergency off switch
- 1 insulating circuit breaker
- 1 START/STOP button
- 4 switchers to attaching capacitors correcting *cosφ*
- 2 lights indicators of thermal failure in engine and generator

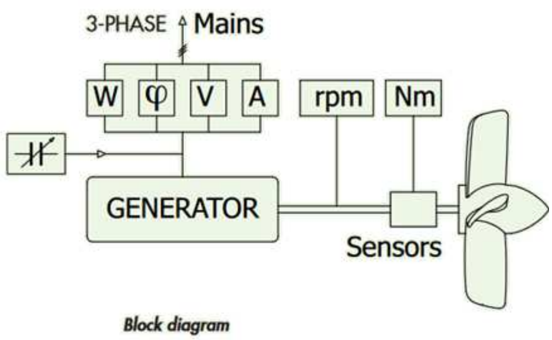


Figure 1.24 Block diagram of a wind turbine [31]

3.2.2 Work of the simulator

The regulatory computer is connected with the PLC in the common *TCP/IP* network. Then the PLC is connected to the electric engine, through the engine controller. To power the asynchronous engine there was used voltage from a grid. To control the work of the engine, voltage signals are sent out of the PLC. In the figure 1.25 illustrated scheme of connected devices to organise the process.

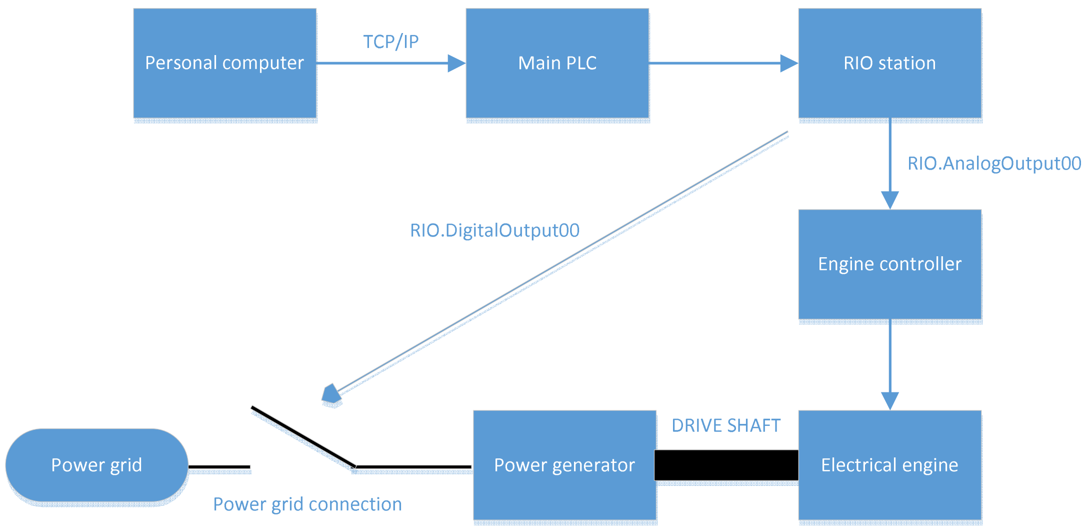


Figure 1.25 Scheme of devices used in the wind turbine simulation process

The change of voltage value [30] induced in the magnetic circuit of the engine a rotating flux relative to the stator, which rotates the rotor through Eddy currents and the Laplace forces. When no load is joined to an engine, the rotational speed of the rotor is almost the same to the rotational speed of the flux. When some load is attached, the load torque causes that the rotational speed of the rotor to become smaller. How smaller it is, is related to the rotating flux.

3.2.3 SCADA of wind turbine

According to predictions it would be possible to control the electric engine collaborating with the generator to produce energy. A customer could control the work of

PLC sending the analogous signals to control the motor and the digital signals to connect and disconnect the output of the generator to the power grid.

The PLC used for this purpose was *PCD3.M5560* from *Saia Burgess Controls* company collaborating with module *PCD3.T665 Smart RIO*. Style of action is exactly the same as the *PCD1.M2120R1*.

The frequency in the power grid in Portuguese houses, as most of the worldwide countries, represents *f=50 Hz*. The generator at least has to reach the same frequency to convey the energy to the grid. As an experiment to achieve that value of the frequency, in the analogue output of PLC, should be set to *U=9.355 V*. Just then, the rotor of the electrical motor spins with rotational speed, which equals around *ω=1500 rpm*. When the frequency equals around *f=50.5Hz,* the asynchronous machine changes the way of working, from motor mode to generator mode. If it gets above this value the energy is being produced.

Starting from value *f=50 Hz*, it is possible to grow the rotational speed of the rotor until the frequency attains value *f=53,10 Hz*. This value of frequency marks the maximum point of the simulator's work. There is no possibility to achieve a higher value. Table 1.2 shown below, illustrates results measured in the generator mode.

The customer can manipulate the rotational speed of the rotor through the control of the digital voltage output of the PLC. The voltage output was expressed by a general value of the work of simulator in percents, where *U=9.355 V* is 0 % and *U=10.000 V* is *100%*. Apart from setting value in volts more intuitively is to set it in percents. An operator does not have to know what is the lowest value they need to set to initialize the process of producing energy. Also, they do not need to calculate the value expressed in volts to achieve a determined level of the wind turbine work f.e. *50%*.

Besides that, for the operator it is also possible to control the work of the device by using the buttons. Pressing the buttons causes an increase or decrease the percent value about 20 %. No matter how many times the buttons would be pressed there is no chance to overstep them both, bottom value *U=9.355 V* and the top *U=10 V*. Simultaneously, after using the buttons, the value implemented in percent and the state of the bar graph, representing this value, changes. Additionally, there is no possibility to put any value without a turn on a wind turbine simulator. Even after setting some values, the webpage of SCADA returns to zero, which is the default state of each edit box: *put value* (in percent) and *wind* speed.

Table 1.2.Measured results with increasing frequency

F (Hz)	P (W)	U (V)	I (A)	N (rpm)	Gu (Nm)
50	300	400	2.5	1497	0,56
50.5	0	400	2.7	1505	0.00
51	-100	400	2.7	1509	-2.32
51.5	-220	400	2.8	1515	-3.51
52	-400	400	2.9	1522	-4.50
52.5	-550	400	3.0	1528	-5.45
53	-650	400	3.1	1534	-6.28

In real wind turbines, the changeable force, which causes the production of energy, is the kinetic energy of the moving wind. Therefore, apart from the value of the work expressed in percents, the work was also expressed in wind speed. For each value in volts was appropriate value in km/h. For values of voltage smaller than $U=9.355\ V$ established that there is no influence of wind. Table 1.3 shows the results.

Table 1.3 Values of analog outputs with corresponding values of wind speed

U[V]	V[km/h]
9.355	0
9.420	10
9.460	20
9.500	22
9.560	25
9.660	30
9.780	35
10.000	40

When an operator put the value in percent then they receive data, such as digital *output voltage, produced energy, the sum of the current of three lines, and voltage between line L1 and neutral wire*.

The flowchart

To ease the problem, encountered during developing the FUPLA program the pseudo-flowchart was employed. Part of it is illustrated below. This part exemplifies applied security system, where there is no possibility to connect the generator to the power grid in a time shorter than t=6s, as well as, to not turn off the whole simulator without precedent disconnecting the power grid from the device.

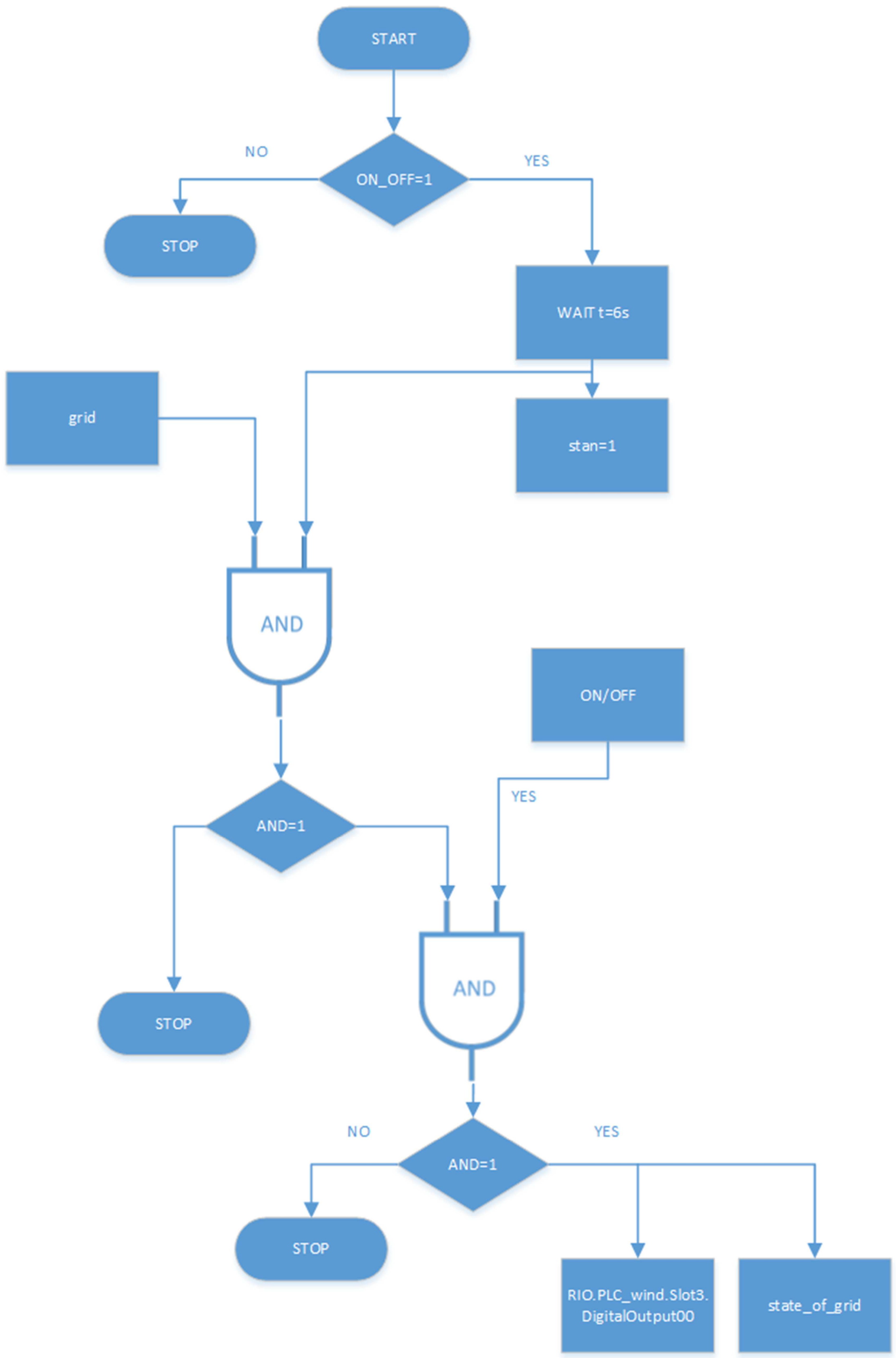


Figure 1.26 The flowchart of security system, included in the problem solution a)

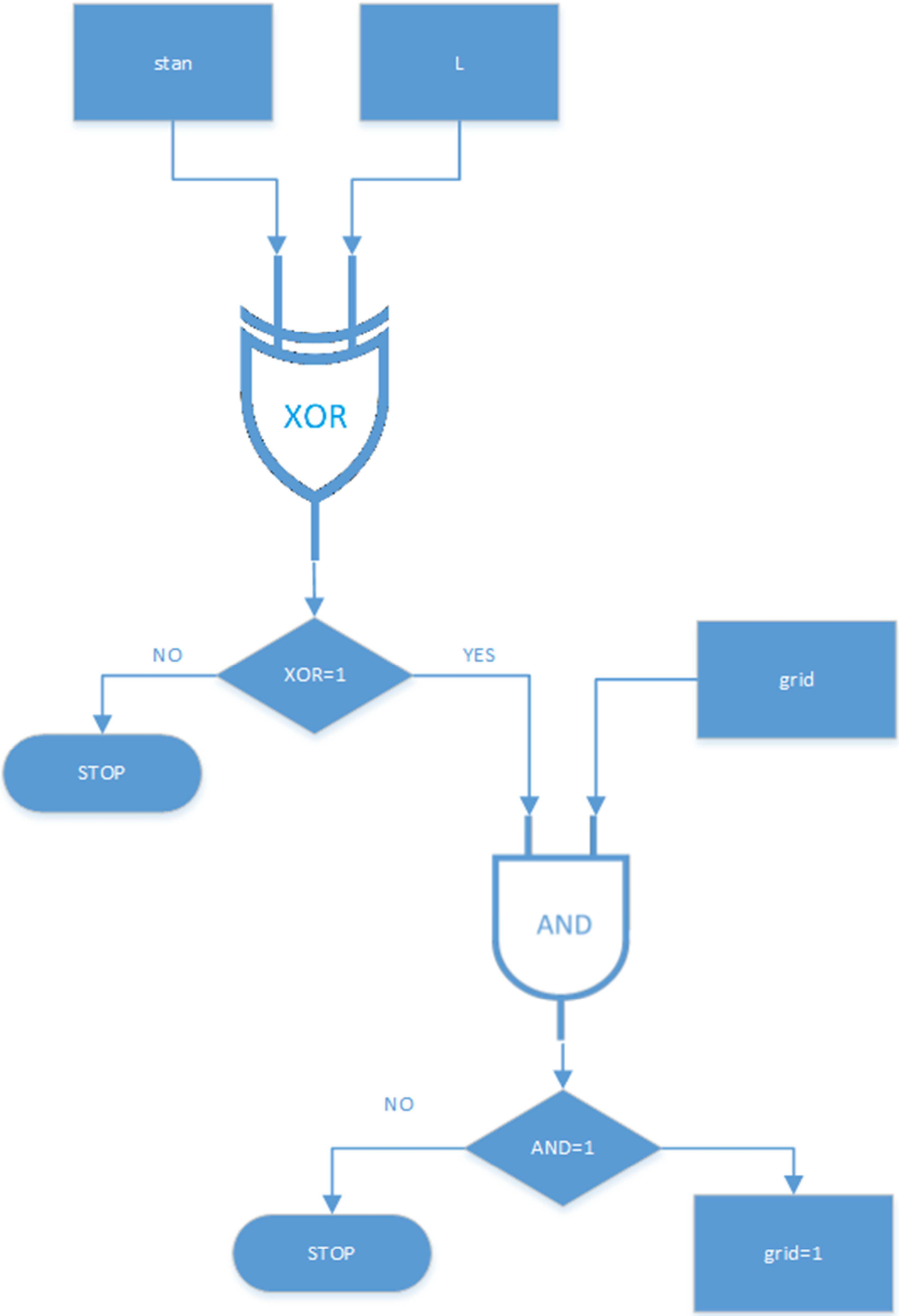


Figure 1.26 The flowchart of security system, included in the problem solution b)

The view of webpage is illustrated in figure 1.27.

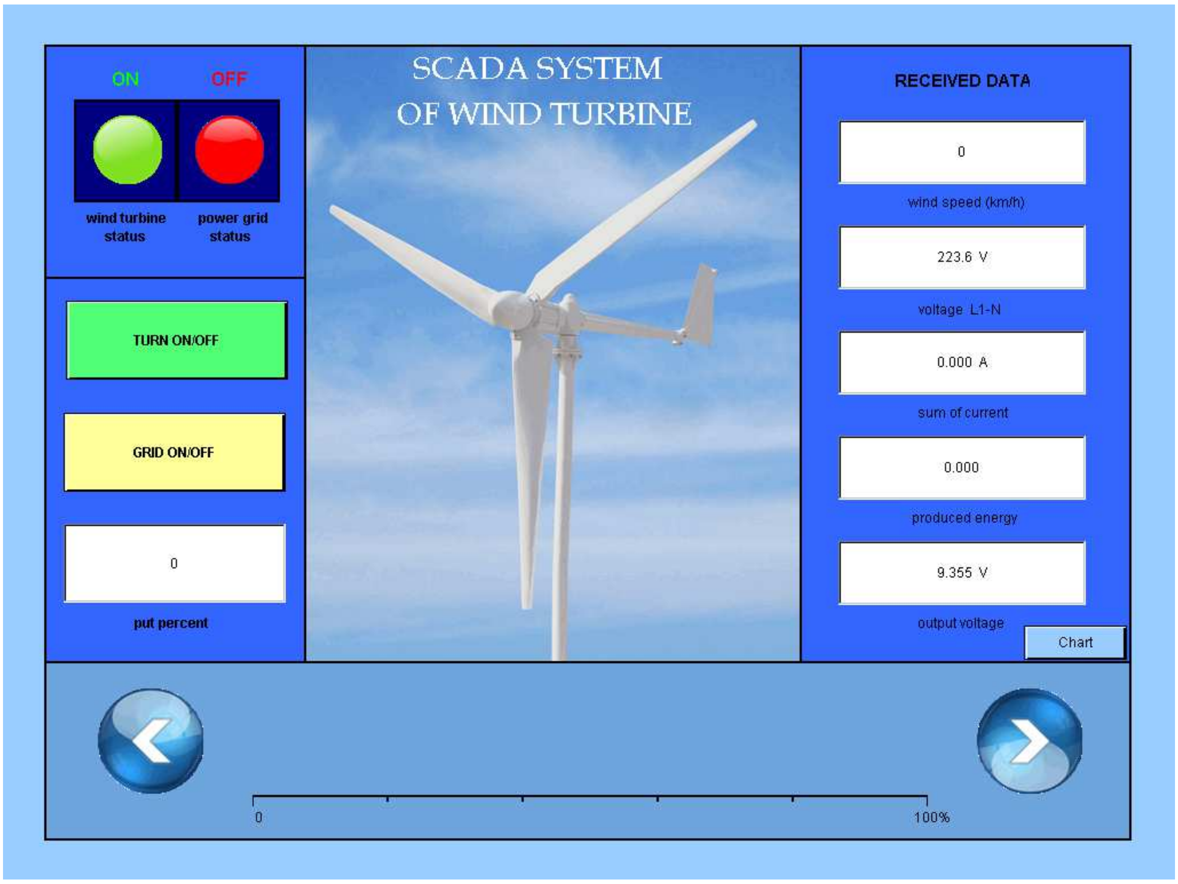


Figure 1.27 SCADA system of wind turbine

The whole SCADA is segmented into five parts; in the first part, there are lights indicating the present status: *wind turbine status* and *power grid status*. Once the wind turbine or grid is on then the lights change their colour from red to green. And inversely, when they are turned off, the lights change colour to red.

The second part is responsible for changing the settings, *TURN ON/OFF* button, like stated in the name it switches the wind turbine on or off. When the input *TURN ON/OFF* is high and there is no value in percents implemented, then the frequency equals *f=50 Hz*. To achieve this value the motor requires the time to be *t=6s*. For the meantime it is impossible to connect the dynamo to the grid, pressing the *GRID ON/OFF* button does nothing. Only after six seconds, one may connect it by pressing *GRID ON/OFF* button. The whole wind turbine simulator can be turned off only when the grid is turned off beforehand, otherwise, it is possible to damage the device. To avoid this situation it applied a security system that does not let it to turn off the whole device without disconnecting the power grid. First, the grid is disjointed, later the whole simulator is turned off. In the third part named RECEIVED DATA, it displayed suitable data. To receive and read sent data, the power analyser, *Janitza UMG 96 RM,* was used. The received data was: *output voltage , the produced the energy, the sum of the currents of three lines, and the voltage between line L1 and neutral wire*[37].

The fourth part of the window is responsible for displaying topical values on the bar graph and buttons to change the value of the voltage. The whole bar graph was divided into 5 pieces, each 20%. It applied this value of the pieces because only then it succeeded to divide the bar graph into equal parts.

In the last part in the middle of the webpage window it showed an illustration of a wind turbine with three rotor blades.

3.3.4 Encountered problem

In the beginning of the project it was assumed that there could be a possibility to change the speed of the rotor by changing both percent value of digital output and wind speed. After many tries to solve this task, it was noticed that it is impossible to accomplish. When the percent value would be set then it should be displayed with an estimated value of the wind speed. Through this way of thinking there would be always a mistake when estimating the value. Implementing into the *put percent* edit box value f.e. *value[%]=7%*, which is *U=9.4 V* in the output, suits approximately the speed of the wind equals *V=10 km/h*. However, for *V=10km/h,* that represents *U=9.42 V*, gives a value in percent that equals 10%. And again, the value expressed in percents, points the value in volts, which in a row points the value in km/h. Then the whole situation repeats again- the loop was noticed . Figure 1.28 shows that.

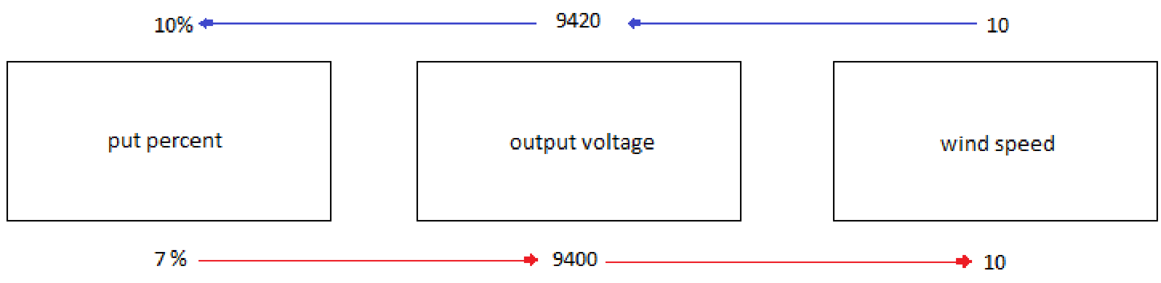


Figure 1.28 The mistake perpetrated with initial assumptions

4. Case studies

This chapter is continuation of chapter 3.3 and it describes case studies of wind turbine. Below are illustrated results.

Figure 1.29:

- Profile of produced energy related on wind speed

On the webpage was possibility to change the wind speed and monitor produced energy in the process. The wind speed was changed in values[km/h]: 0,10,20,22,25,30,35,40,35,30,25,22,20,10,0. The chart is showed below.

D**escription**

In the red colour illustrated speed of wind. The blue ones symbolizes produced energy. The legend of colour is the same for all attached charts. In first second of the process the generator was not connected to the grid- the value of produced energy is equal zero. After t=1s,it is shown sudden growth of the value of produced energy to more than E= 600W. With growth of the wind speed there is growth of produced energy. The biggest value of produced energy is for wind speed v=40km/h and equals around E=1100W. After reaching this point, the value of wind speed falls down and the same happens with produced energy. After time equals around t=8s the generator is disconnected to power grid. Then there is no produced energy.

Figure 1.30:

- Illustrates the profile of production energy related from value of wind v=20 km/h

Decription

Before t=1s, power generator is connected to the power grid. The produced energy is equal around E=750 W. Further the value of speed increases v=20km/h. The produced energy for whole process equals from E=600 W to around E=900 W. In the same intervals are illustrated sudden growth of produced energy. At these times it was noticed loss of current.

Figure 1.31:

- The chart is analogous to previous chart but the value of wind speed this time equals v=40 km/h

Description

The description of the chart is analogous as for previous chart. The difference is however in values. The value of wind speed equals v=40 km/h and then there is the biggest value of produced energy, around E=1200W.

Figure 1.32:

- Process of control the wind speed was between value of frequency f=50 Hz and f=53.10 Hz. For the second value production of energy was the biggest. The chart below illustrates the profile

Descripton

The characterization of this profile is the same as for wind speed v=20 km/h and v=40 km/h. This time produced energy equals around E=1300W for almost whole process.

Description of all charts

Based on charts above it one may conclude that with the increase of the wind speed the quantity of produced energy(in watts) grows. When the time of hold simulation is longer, then the results are more accurate. The biggest value of produced energy was noticed when frequency f=53.10 Hz. Then the value equals around E=1300 W. In the beginning was estimated that for f=50 Hz the wind speed equals zero. When the wind speed equals zero, the produced energy should be equal zero, however on charts it can be seen some values. It explains that it was some inaccuracy in estimating value for wind speed when it equals zero.

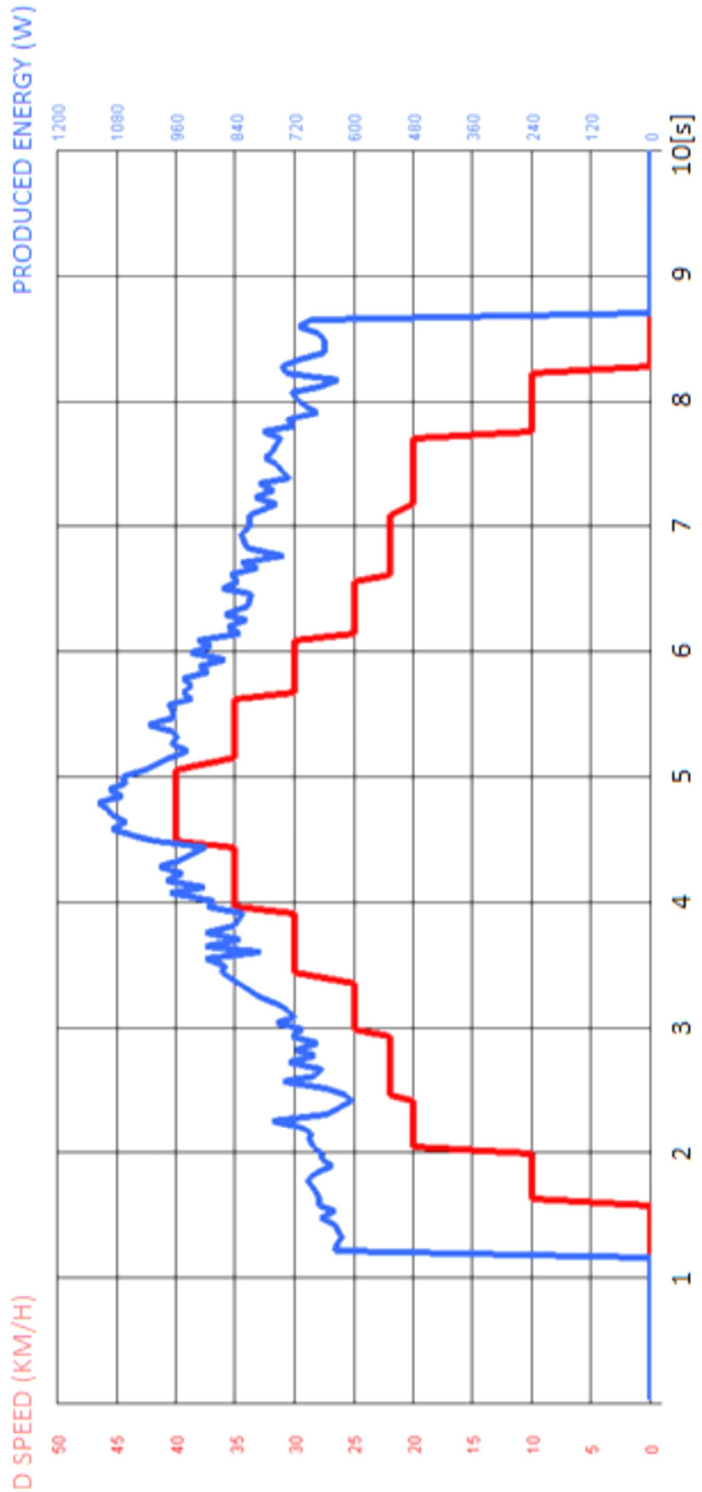


Figure 1.29 The profile of the production electrical energy related on the wind speed

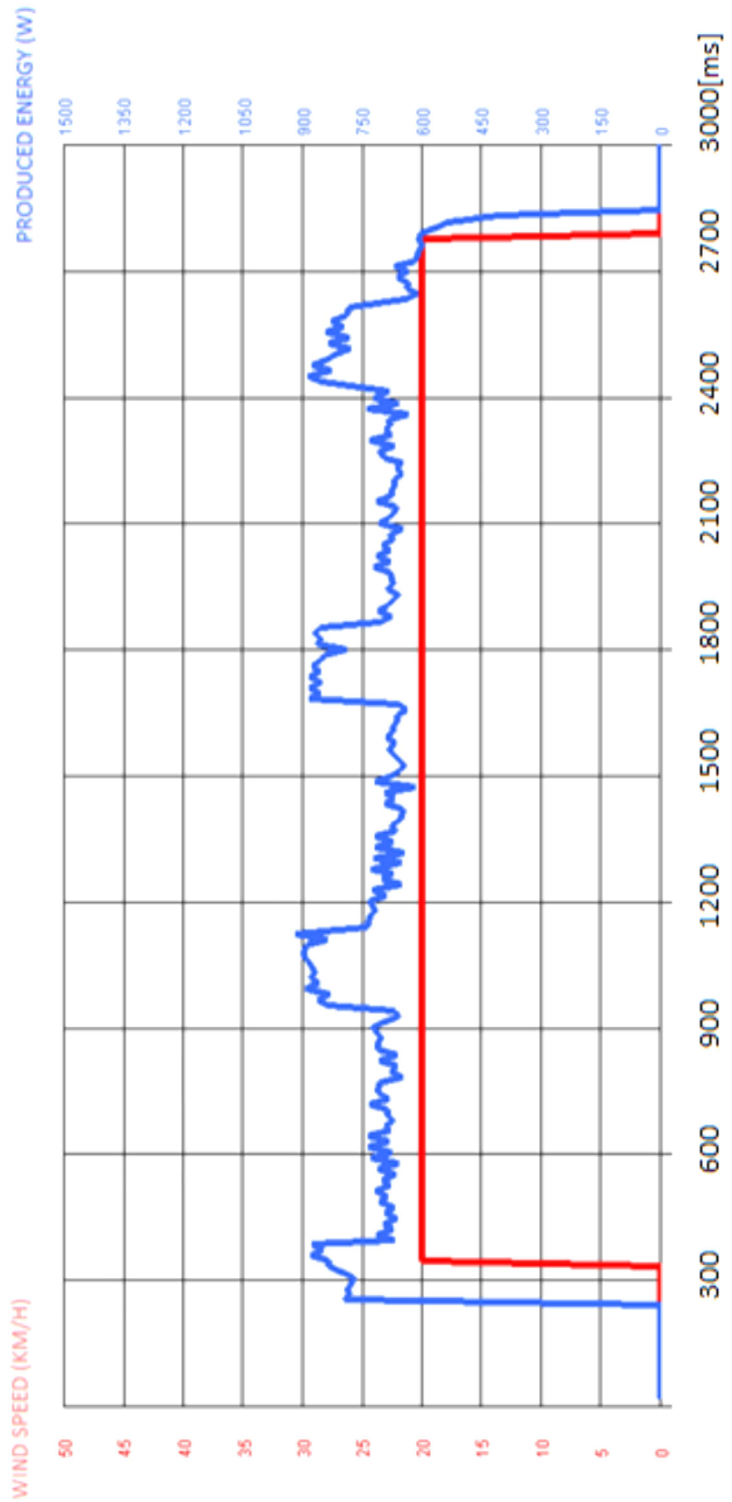


Figure 1.30 The profile of the production electrical energy related on wind speed equals v=20km/h

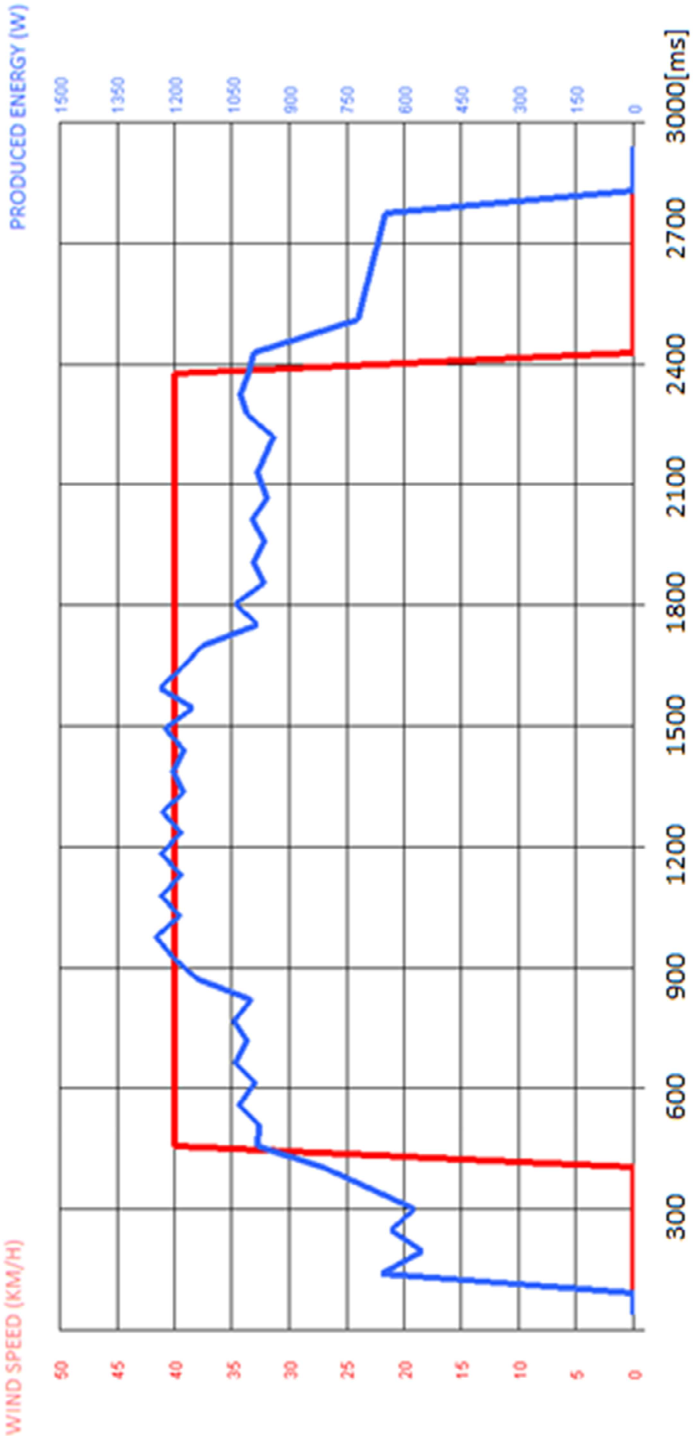

PRODUCED ENERGY (W)
WIND SPEED (KM/H)
3000[ms]
300
600
900
1200
1500
1800
2100
2400
2700

Figure 1.31 The profile of the production electrical energy related on wind speed v=40 km/h

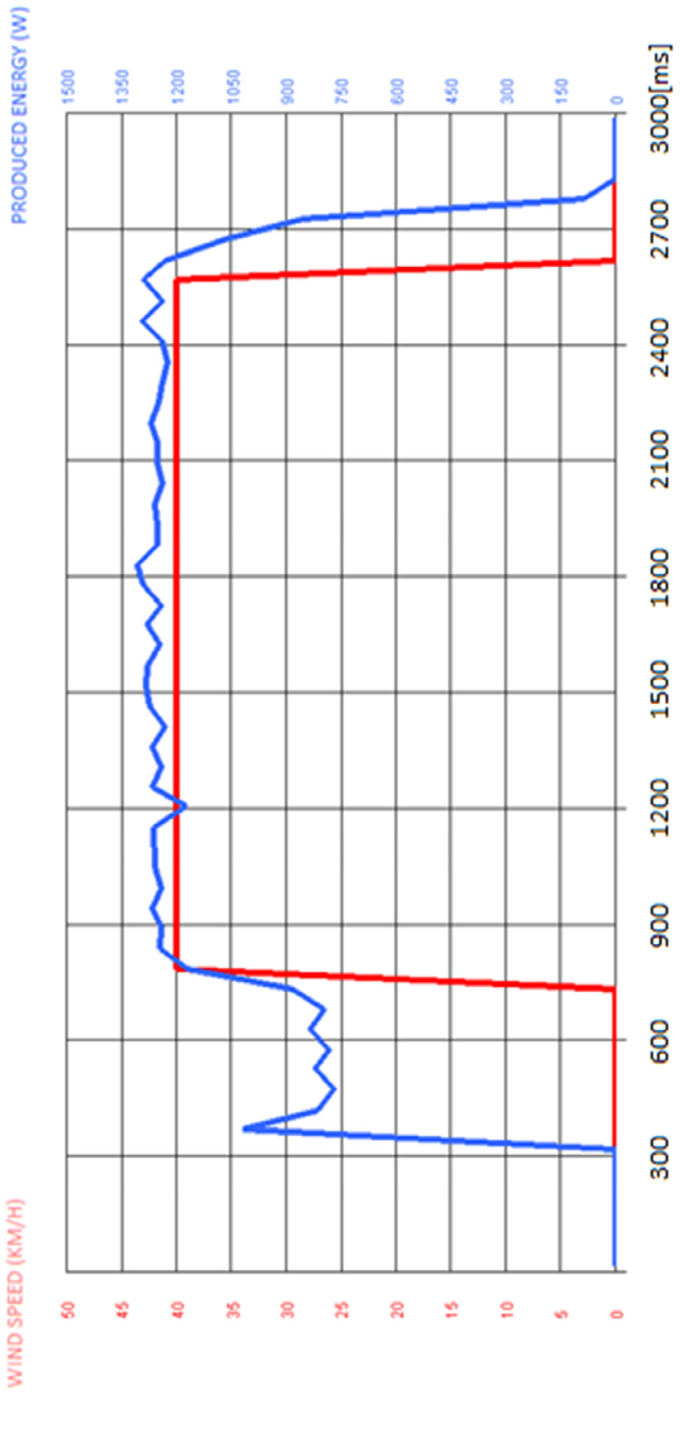

PRODUCED ENERGY (W)
WIND SPEED (KM/H)
3000[ms]
2700
2400
2100
1800
1500
1200
900
600
300

Figure 1.32 The profile of the production electrical energy related on frequency f=53.10 Hz

5. Conclusions

In the report it includes a description of real-time monitoring wind turbine simulator in Modbus TCP/IP connection. The software used in the project was *Saia PG5 Controls Suite.* The main PLC, which controls the work of the RIO stations was PCD3.M5560, with an extension of RIO module, which was PCD3.T665 Smart RIO. The monitoring of electrical energy parameters was done by JANITZA UMG 96RM EL power analysers.

The main goal of the *Erasmus Project* was to learn how to use the SCADA system. It can be said that the software used, *Saia PG5 Controls Suite,* was a really good environment because all editors and configurators were integrated into one program. Most of the problems occurred not during programming or using *WebEditor8* to create a visualization but with during the configuration of both. Sometimes it was needed to use a translator because the description of *Saia PG5 Controls Suit* and helpdesk included technical language. Nevertheless, *Saia PG5 Controls Suit* is a very good tool to design a SCADA system. Using the graphical programming was intuitive, fast and easy to understand.

An initial assumption of controlling the wind turbine was to control the wind turbine by changing the value in percent or to control the wind speed. However, it turned out impossible to do, therefore it was decided that controlling the power using percent values would control the wind turbine and there would be displayed an adequate value of the wind speed.

Within the webpage view there is a light visualisation of the wind turbine status and the connection to a power grid; however, there is a chance that mechanical troubles can occur, e.g. when there is no power supply connected to the electrical engine. After pressing the ON/OFF button, on the webpage, to turn it on, the light changes into a green colour, which means that the electrical engine is on but effectively the engine can be off. The same situation happens with the connection to the power grid. To avoid the situation above, one should send signals to PLC informing about the real status of the whole device. The disadvantage of the *Saia PG5 Controls Suit* software was that it worked obscurely from time to time - to eliminate compilation error it was needed to delete some block used in FUPLA editor and put it back again.

In the motivation chapter, it is described that producing energy from the wind turbine is practically free from defects but life shows there are some. The blades of the wind turbines cause noise with various frequencies, which impacts unfavorably on people and animals. Impeding radio waves and magnetic fields of radars is also caused by the wind turbines. A further disadvantage is that they are dangerous for birds, especially shifting ones. Every year a number of birds crash with wind turbines blades. Against all appearances, they are very expensive in exploitation and what users say is that they get spoiled very often. And certainly, apart from windy days, there are also days that are not windy. Then wind turbines don’t work and don’t produce energy.

This report can serve for some companies to solve similar problems or to implement the same systems. GECAD organisation can also use it to measure the production of electrical energy by simulating and using it to desirable purposes.

In the end of this report I would like to personally thank my mentors who helped me when some problems occurred. First of all, I would like to thank Professor Zita Vale, who was my ordinator in my erasmus project. Thank you professor for this valuable project, which I think taught me a lot. Learning SCADA systems was one of my goals to learn as an engineering student. Also, I would like to thank PhD Pedro Faria, who was always my support and cared about my well-being in GECAD organisation. The person, who had substantial impact in the report and always tried to help me with some issues was graduate Omid Abrishambaf. Because of people working in GECAD organisation I have been feeling very welcomed. Moreover, I felt like a real member of GECAD and will be observing further performances and released innovations from them.

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Appendix

In appendix included:

- The complete FUPLA program
- The complete *WebEditor8* visualisation