Wind Mill Technology

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1. Synopsis[1]

"The aim of this project is to build a model which controls the electrical power from a wind mill. When the generator is connected to the grid, the generator shall deliver constant power. The rotor is through a power electronic circuit and a transformer connected to the grid. A power electronic circuit controls the induction generator slip. Power, voltage, current and speed are measured through transducers. A digital signal processor is controlling the system."

"This project is dealing with control, regulation and supervision of electrical power from a wind mill. The electrical power from the wind mill must be constant with use of "slip regulation" The wind mill generator, which is an induction machine with wound-rotor, is electrically connected with at "stiff" electrical power grid. The wind mill generator is mechanical connected with a dynamometer. The dynamometer is the primary mover."

[1]This synopsis is a description of the main task of the project, from "Project: Wind Mill Technology, the University of Southern Denmark, Electrical Power Engineering".

2. Preface[2]

The first known use of the use of wind dates back to 3,000 BC with the first Egyptian sailing ships. In the seventh century in Persia came the first windmill that was used for pumping water or grinding grain. In Europe the windmills also appeared in the seventh century. From these Europeans machines resulted the well known Dutch windmills, which were very sophisticated in a mechanical way. In the United States of America was created the first horizontal shaft mill with multiblade by Daniel Halladay in 1854, this windmill was used to pump water in isolated zones. Because of his slowly movement, this machines weren't created to generate electricity.

In 1890, the Danish Goverment launched a program aimed at developing wind power production, and this program was leaded by the teacher La Cour. Poul La Cour's machine launched in 1892, was the first one conceived, designed and built to generate electricity. He was considered the danish's Edison, and his work established the first steps in manufacturing modern windmills. The aerodynamic theory was not enough developed, so his machines were simple clasic rotors with low performance.

Since the late nineteenth and early twentieth century Joukowski, Sabinin and Drzewieky in Russia; Betz and Prandt in Germany; Constantin and Eiffel in France developed the aerodynamics theory. The design criteria of these investigators were adjusted to the new generations of wind turbines.

At the end of the World War II, and as a result of fossil fuel shortages, European goverments were interested in the use of renewable energy. During that period measurement methodologies were developed in several countries. This period lasted until the mid-sixties, when the world economy recovered. The electrification was extended enough to cover most rural areas, and wind power plants were not competitive with conventional plants. As an example, a Danish company started manufacturing two-and three-bladed wind turbines at that time. It is also known that in the 50's appeared the first alternating current turbines.

In 1973, as a result of the oil crisis occurred because of the Arab-Israeli conflict, began another stage in the area of using wind as an energy source, sharing the stage with photovoltaic solar energy. Back in the eighties wind power receives a boost when environmental issues became first order problems.

As a result of the above mentioned energy crisis of 1973 appeared the first research programs relating to wind energy, both national and supranational.

Since the 1980s they have seen an exponential increase, both in unit power ratings and overall capacity. The theory of modern wind turbines has not been established before the 20th century. Currently wind turbines with three blades and horizontal shaft prevail. The driven electric generators are of the asynchronous or synchronous type, with or without interposed gearbox. Modern systems are designed for variable speed operation which makes power electronic devices play an important part in wind energy conversion. Nowadays, the most common rated of wind turbines is 1-2 MW. But it is also produced wind turbines with a rated power above 2 MW.

Manufacturing has reached the state of a high-tech industry. Countries prominent for the amount of installed wind turbine systems feeding into the grid are in Europe Denmark, Germany and Spain. Outside Europe it is the United States of America and India who stand out with large rates of increase. The market and the degree of contribution to the energy consumption in a country has been strongly influenced by National support schemes, such as guaranteed feed-in tariffs or tax credits.

Kyoto protocol and UN Climate Change Conference 2009 (which replaces Kyoto protocol) also help renewable energies to have a key role in the supply of electricity. In UN Climate Change Conference 2009, the final goal that was intended to a global reduction in CO2 emissions by at least 50 % compared to 1990.

Climate changes, earth's fossil energy resources limited and the strong political opposition against strengthening nuclear power in many parts of the world contributes more and more to the world's ever rising need of renewable energy in the future. And the future in windmill is off-shore wind parks. Without the interference of forests and population centers, the huge white sails of the windmills at sea generate more power. Denmark it was clear as early as 1991, when he inaugurated the first prototype offshore wind farm, known as offshore wind in the jargon of the industry. So I can say that more and more countries will join to this clean way to generate electricity that will help the world to avoid climate change.

[2] my preface is based in the following books and websites:

-Z. Lubosny (2003). "Wind turbine Operation in Electric Power Systems". Springer.
-T. Burton, D. Sharpe, N. Jenkins, E. Bossanyi (2001). "Wind energy handbook". John Willey & Sons, Ltd.
-Manfred Stiebler (2008). "Wind Energy Systems for Electric Power Generation". Springer-Verlag Berlin Heidelberg.
http://es.wikipedia.org/wiki/Conferencia_sobre_el_Cambio_Clim%C3%A1tico_de_la_ONU_2009
http://www.cubasolar.cu/biblioteca/energia/Energia40/HTML/articulo06.htm

3. List of contents

4. Introduction

The requirement of this project is to control, regulate and supervise the electrical power from a wind mill. The electrical power from the wind mill must be constant with use of “slip regulation”.

This semester, I have had two subjects:

- Control Engineering and Signal Processing.
- Power Electronics and Electric Machinery.

In these two subjects, I have specific information about the different parts in which my project is divided. So I have applied it during my study. The project can be solved with knowledge in electric machines, power electronics, control engineering, signal processing, project management and basic knowledge within mathematics, electrical physics, circuit theory, digital and analogue electronics, electronic data processing.

My limitations in this project have been my little knowledge about electronics. The control of the induction machine has been the harder part. When I began the project, it took me a long time to identify all the components and its function into the control system.

After the identification of all the devices, I started testing. my limitations in this area have been the bad performance of the induction machine. The experiments has delayed my work, because of I have made them several times the same tests, to be sure of getting the right values.

I have found some alternatives while doing this project. But, at the end, time ran out faster than I expected. I delayed the planning so I could begin the control system. I have also found much work in the theoretical part about the PWM and the powerboard. To solve my problem, first, I wrote all the theoretical parts without making a lot of measurements. So in a short period of time, I did measurements for the control system, and perhaps I would need longer time to do it.

I have improved the knowledge in electronics systems and learned the new software Labview. So this project has helped me to gain better understanding on working electronic systems mixed with machines.

5. Main report

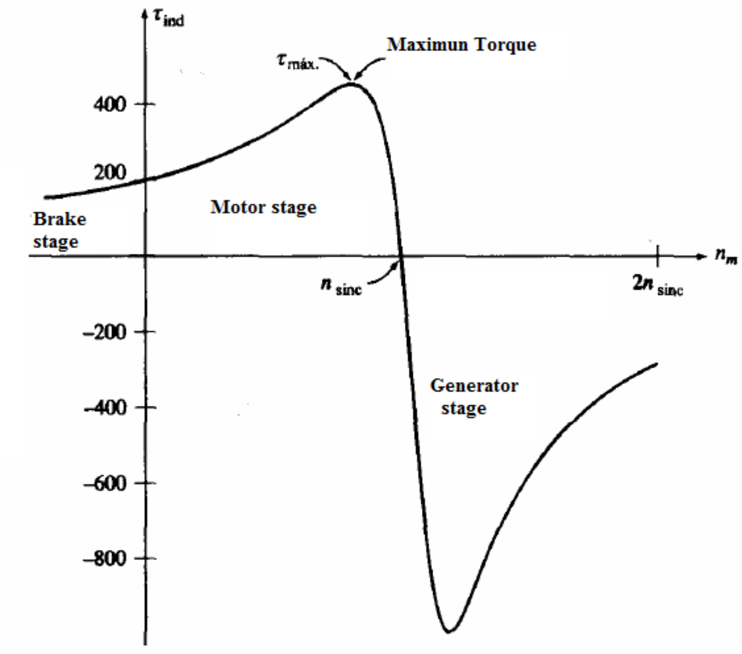
5.1. Generator

The machines used to work as generator in windmills are the asynchronous machine or the synchronous machine. It depends of the country, but the most common machine used in Denmark is the asynchronous.

Asynchronous machine have a lot of advantages vs. synchronous machines. The asynchronous machine, especially in the form of cage induction machine is a robust and low cost generator. They are very flexible machines, and with an electronic controller, the speed of the generator can be allowed to vary with the speed of the wind. Although, they also have disadvantages. Asynchronous generators require relatively complicated electronic controllers. They are usually not started without an energized connection to an electric power grid, unless they are designed to work with a battery bank energy storage system. But the cost and performance of such a system is generally more attractive than the alternative systems using a synchronous generator.

The asynchronous is also known as induction machine. This machine can work in three stages, as a generator, a motor or a brake. In my project I use the induction machine as a generator to transform the mechanical energy from the wind into electrical energy. There are two types of induction machine: the wound-rotor machine and the squirrel-cage machine. In my case, I use the one with slip regulation, because this has been previously set in the project by teachers.

In my project the mechanical energy is produced by a dynamo who works as a motor. The induction machine, to work as a generator, needs to get a higher speed than the synchronous one. This is shown in the curve beside.



Plot 1. Torque-speed curve of an induction machine.

1. Theoretical study.

Asynchronous rotating machines consist of a stator with a preferably three-phase winding, and a rotor carrying either a cage winding or a polyphase coil winding. Rotor voltage is produced in rotor coils by stator, that’s the reason why they are called asynchronous machines.

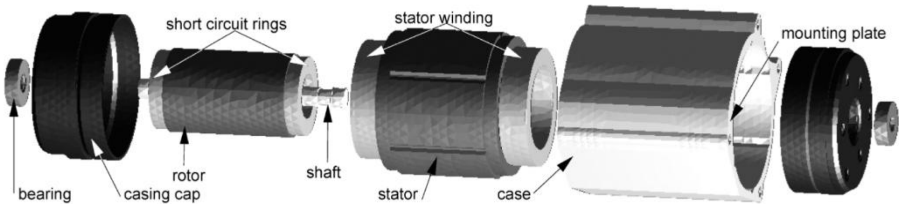


Figure 1. Three-phase induction machine.

The Ring Asynchronous Machine’s rotor has a three phase winding group. Generally the three phase rotor’s winding is star(Y) connected and rotor conductor’s points are connected with rings of rotor shaft. Then rotor wrapping is short circuit by slipping brushes. So the rotor current can be measured from rotor’s brushes and the motor can be controlled and set up its speed adding external resistor.

The machine works in a simple way. The stator is supplied by a three phase current, so a counter clockwise magnetic field (Bs), is induced in the air gap between stator and rotor. This magnetic field rotates with the synchronous speed ns. The machine is working as a generator, the shaft is rotating with a determinate speed (in reality, this movement is provided by the wind), so that, the rotor is also rotating with a higher speed than the synchronous. So the magnetic field and the rotor turning induce a voltage in the rotor coil, which also generates a magnetic field (Br). According to Lenz’s law, the rotor rotates in the direction of the rotating field such that the relative speed between the rotating field and the rotor winding decreases. The difference between the rotor speed n and the synchronous speed ns is called the slip and is defined as

Formula 1

$$s = \frac{n_s - n}{n_s}$$

The equation of the magnetic field’s speed n (sync) is shown below, where p is the poles and f1 is the stator frequency.

Formula 2

$$n\,(sync) = \frac{120\,f_1}{p}$$

Formula 3

$$E_r = (v \times B)l$$

The equation above is the induced voltage E, electromagnetic force (emf), caused by a loop of conductor with a side of length l moving in a direction parallel to the magnetic field, B, at a speed v. The rotor has to be connected with the grid, so it can supply a current with a different frequency (f2). This frequency is calculated as

Formula 4 $$f_2 = f \times s$$

I need to get the equivalent circuit to study an asynchronous machine, so, in laboratory I have been making test to know the performance characteristics of the machine. The machine that I have used is the following one:

Feedback 64-520/ Three Phase Sync/Async Motor/Generator-Slip Ring

Supply 220 V Δ 380V Y

Rated at 415/380 V 300w

3000 r.p.m at 50 Hz Power requirement 380/415 V Three Phase AC

After making the tests that are going to be described later, I get the equivalent circuit of the induction machine. This circuit allows me to make a theoretical study about the machine.

In this circuit it is shown the line and phase voltage and the resistance values and inductance values, all are in ohms (Ω).

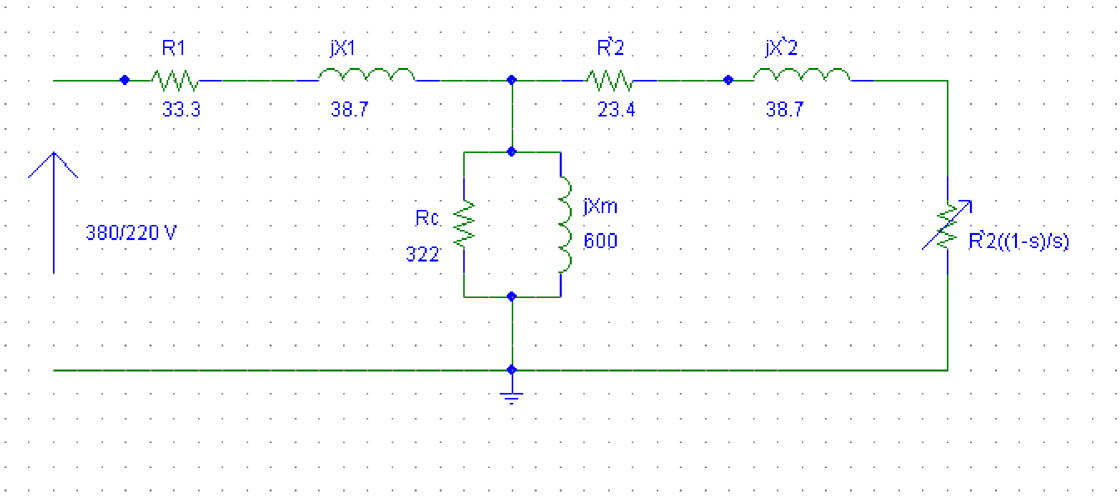


Figure 2. The equivalent circuit of an asynchronous generator.

First, I calculate the equivalent Thevenin voltage and impedance. With this circuit I will predict the performance of the machine. I calculate this circuit with the equations shown below.

Formula 5 $$\overline{Z_1} = R_1 + jX_1$$

Formula 6 $$\overline{Z_2} = R_c // jX_m$$

Formula 7 $$\overline{Z_{th}} = \overline{Z_1} // \overline{Z_2} = (30.2555 + j31.4548)\Omega$$

Formula 8 $$\overline{V_{th}} = \frac{V_{1-p}}{|Z_1 + Z_2|} |\overline{Z_2}| = 187.5864V$$

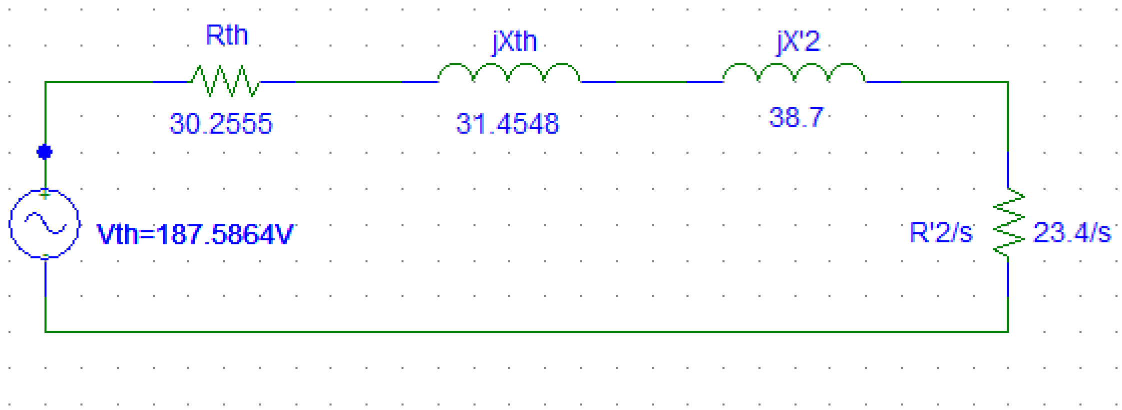


Figure 3. The equivalent Thevenin circuit.

Once I have the Thevenin circuit, I are able to calculate the torque of the machine, a very important characteristic to know how the machine works. This study is also important to compare with the real values that I obtain from the experiments made with the machine.

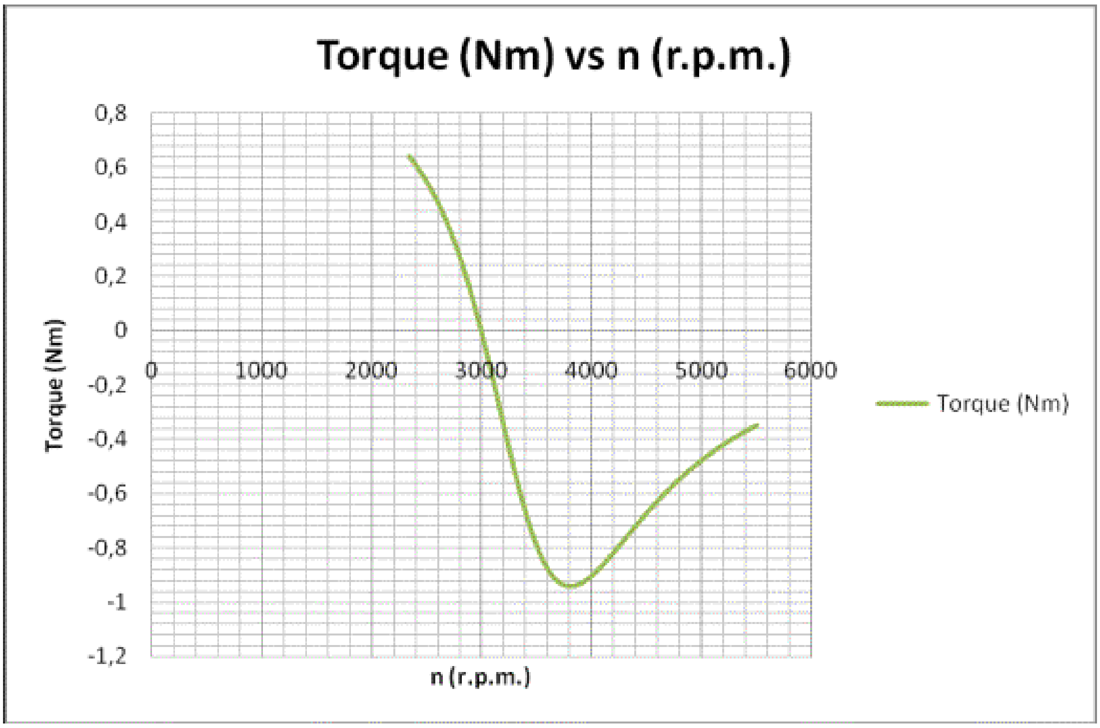
Formula 9 $$P_{mech} = T_{mech}\omega_{mech} = I_2{}^2 \frac{R_2}{s}(1-s)$$

Formula 10 $$\omega_{mech} = \frac{2\pi n}{60} = (1-s)\omega_{syn} = \frac{n_{syn}}{60} 2\pi(1-s)$$

Formula 11 $$\omega_{syn} = \frac{4\pi f_1}{p}$$

Formula 12 $$T_{mech} = \frac{1}{\omega_{syn}} \frac{V_{th}^{2}}{(R_{th}+{R_2}'/s)^2+(X_{th}+{X_2}')^2} \frac{{R_2}'}{s}$$

As I see in the equation above, the torque is inversely related to the slip, what it means that has a relation with the speed of the shaft. In the graph below, I calculate more values of speed than the ones that I get of my experiment, with the machine working as a generator. Thus, I can know if the machine works as I expect to. With the maximum value of speed that has been tested in laboratory, 3481 r.p.m., I get a torque of -0.7691 Nm. The goal of this study is also to know the speed that I need to have in the shaft to generate electricity. This speed goes from 3000 r.p.m to 4000 r.p.m.



Plot 2. Torque-speed profile in theory.

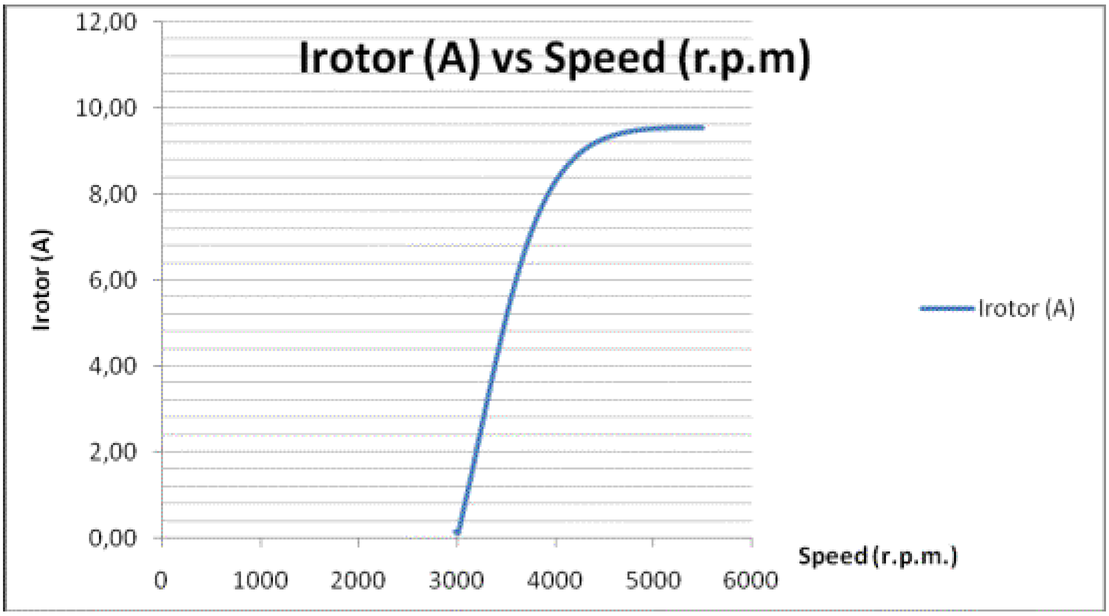
In the graph above, I calculate more values of speed than the ones that I get of my experiment, with the machine working as a generator. Thus, I can know if the machine works as I expect to. With the maximum value of the speed that has been tested in laboratory, 3481 r.p.m., I get a torque of -0.7691 Nm, so compared to the graph, I get similar values in theory and in reality. The goal of this study is also to know the speed that I need to have in the shaft to generate electricity. This speed goes from 3000 r.p.m to 4000 r.p.m.

With the Thevenin Equivalent Circuit I can also calculate the current that flows though the rotor as it follows:

Formula 13
$$I'_2 = \frac{V_{eq}}{\sqrt{(R_{eq} + {R'_2}/{s})^2 + (X_{eq} + X'_2}}$$

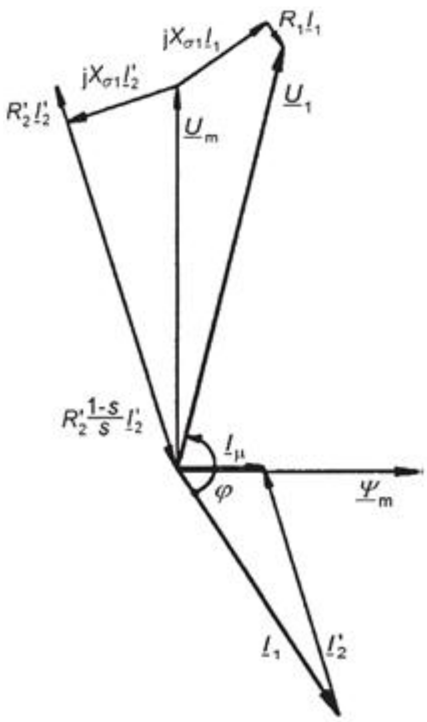
Formula 14
$$I_2 = I'_2 \times a$$

The graph which shows the relation between the current in the rotor and the speed is below.



Plot 2. Torque-speed profile in theory.

The value of the current through the rotor must not be very high, because in my project, the rotor windings are connected to a rectifier bridge and to a filter, and these components are not built to support very high currents. This can be seen in the graph, so I choose to work in a ratio of speed from 3000 r.p.m. to 3500 r.p.m. In windmills the control is done with the current through the rotor because the wind is changeable. In the control I have also to take under consideration that this current has a different frequency than the frequency from the stator. This frequency is related to the slip.



The figure, which is shown beside, is a vector diagram, which indicates generator operation. It is referred to the circuit equations according to Kirchhoff's law. In the generator the slip is negative, the main field voltage Um, appearing at the reactance Xm in the equivalent circuit, is leading the magnetizing current Iμ by a right angle. The diagram shows that the rotor current flows in an opposite direction than the voltage. The negative slip makes the torque negative (as I see in the graph above), that's also why the current flows in an opposite direction than the voltage. I are supplying electricity to the grid.

Figure 4. Vector diagram (Generator operation).

The following theory is related to the efficiency of the machine.

The below picture shows the power flow when the machine works as a generator. The slip in the generator is negative, so that the air gap power (Pag) and mechanical power (Pmech) are also negative. This implies that the power flow across the air gap is from rotor to stator.

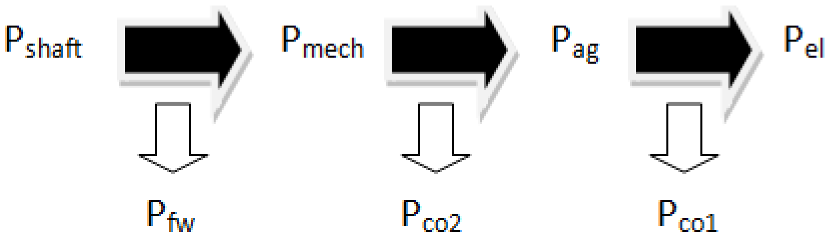


Figure 5. Power flow in the induction generator.

The induction generator is used to produce electrical power, this electrical power is given to the grid from the stator.

Formula 15 $$P_{el} = 3V_1 I_1 cos\theta_1$$

There is a current flowing through the stator, so there are losses. This also includes skin effect, eddy current loss and hysteresis in the magnetic material of the stator core.

Formula 16 $$P_{co1} = 3R_1 I_1{}^2$$

The power that crosses the air gap is the one that is going to be transformed into electrical power, but not all due to the losses in the stator.

Formula 17 $$P_{ag} = P_{el} + P_{co1}$$

There is also losses in the resistance of the rotor. The rotor losses depend on the slip.

Formula 18 $$P_{co2} = 3R'_2 I'_2{}^2 = P_{ag}\, s$$

The mechanical power (Pmech) that I have is not the same as the one that I have in the shaft (Pshaft), due to the friction and windage losses (Pfw), which are dependent on speed.

Formula 19 $$P_{mech} = P_{ag} + P_{co2} = 3R'_2 \left(\frac{1-s}{s}\right) I'_2{}^2$$

Formula 20 $$P_{fw} = P_{co2}\left(\frac{1-s}{s}\right) = P_{ag}(1-s)$$

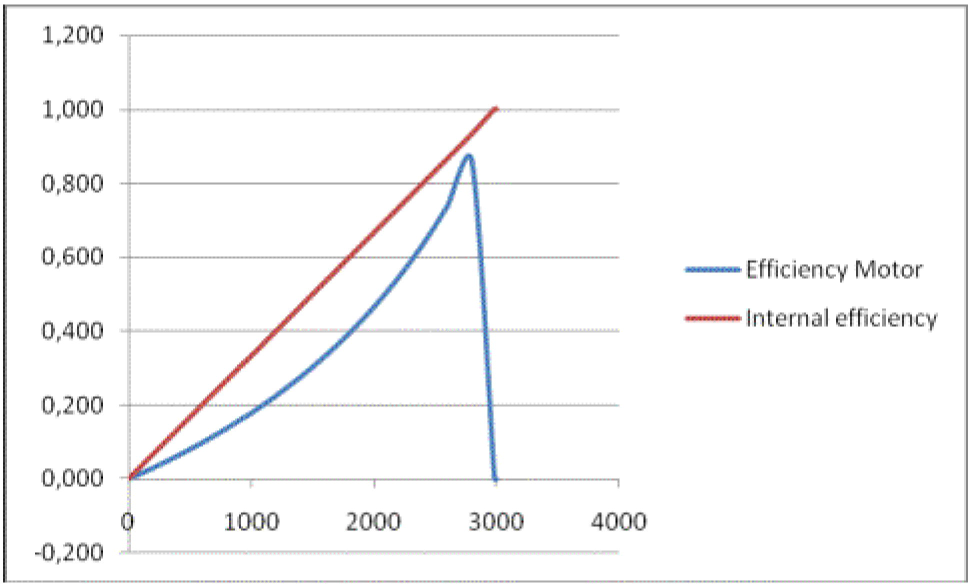
Formula 21 $$P_{shaft} = P_{mech} + P_{fw}$$

The efficiency and the internal efficiency of the induction machine are described as:

Formula 22 $$Eff = \frac{P_{el}}{P_{shaft}}$$

Formula 23 $$Eff_{int} = 1 - s$$

In the asynchronous machine, the slip has very low values. This is a good point, due to this low values mean that I get a high internal efficiency. This concept represents the ratio of the power in the output to the air gap power. The graph below shows the efficiency and the internal efficiency in my theoretical calculations, but only when the machine works as a motor.



Plot 3. Efficiency and internal efficiency in an induction machine.

The real efficiency is not the same as the internal efficiency due to all the losses that the machine has. The theoretical efficiency of the machine, when the machine works as a generator is very difficult to calculate. In reality, the machine is producing electricity through the rotor and in the stator, so this is a special situation, and it does not fit with the theoretical way of calculating power (that has been explained above).

To conclude, I have tried to explain briefly the way that this machine works. All the calculations are based in the equivalent circuit, and those values are got from testing the machine, so maybe, they are not the correct ones (although my theoretical calculations are very similar to the results from experiments). I tried to calculate the efficiency of the generator, but I realized that the machine that I are working with, has a different connection to the grid than the one explained in books. The stator of the machine is connected to the grid, while the rotor is also connected to the grid through all the rectifiers and PWM device. This means that I are producing electricity in both coils of the machine, and this differs from theory. In theory, it is said that electricity is generated and then it flows to the grid from the stator coils. So the mechanical power introduced in the machine would be the electrical power generated plus all the losses power in coils, the friction and windage losses.

2. Practical study.

The tests that have been done in laboratory are described below:

2.1 MEASUREMENT OF STATOR RESISTANCE

Assuming that the windings of the three motor phases are identical, I just get the value of resistance in one of the three windings. To do this, I use a polymeter. What is really important to get is the resistance per phase, so it is independent of the type of connection. The equation to get the resistance is the following one:

Formula 24 $$R_1 = \frac{V_{dc}}{I_{dc}}$$

We do not use that equation, because I measure directly the stator resistance with the polymeter after the machine have been running for a while.

The obtained value is:

$$\boldsymbol{R_1} = 33.3\Omega$$

2.2 BLOCKED ROTOR TEST – SHORT CIRCUIT TEST

Through this test, I determine the values of rotor resistance and reactances. To do this, the rotor must be perfectly fixed, not turning, thus the slip is the unit. Under these conditions, I apply to the machine a balanced three-phase voltage which will increase from zero to the voltage that supplies the nominal stator current. This voltage will be always lower than the nominal one.

The equations used to calculate the parameters are shown below.

Formula 25 $$P_{sc} = m_1 R_{sc} I_{sc}{}^2 = \sqrt{3} V_{sc} I_{sc} cos\varphi_{sc}$$

Formula 26 $$R_{sc} = R_1 + R_2 = \frac{P_{sc}}{m_1 I_{sc}{}^2}$$

Formula 27 $$R'_2 = R_{sc} - R_1$$

Formula 28 $$Z_{sc} = \sqrt{(R_{sc})^2 + (X_{sc})^2} = \frac{V_{sc}}{I_{sc}}$$

Formula 29 $$X_{sc} = X_1 + X_2$$

Formula 30 $X_1 = X'_2 = \frac{X_{sc}}{2}$

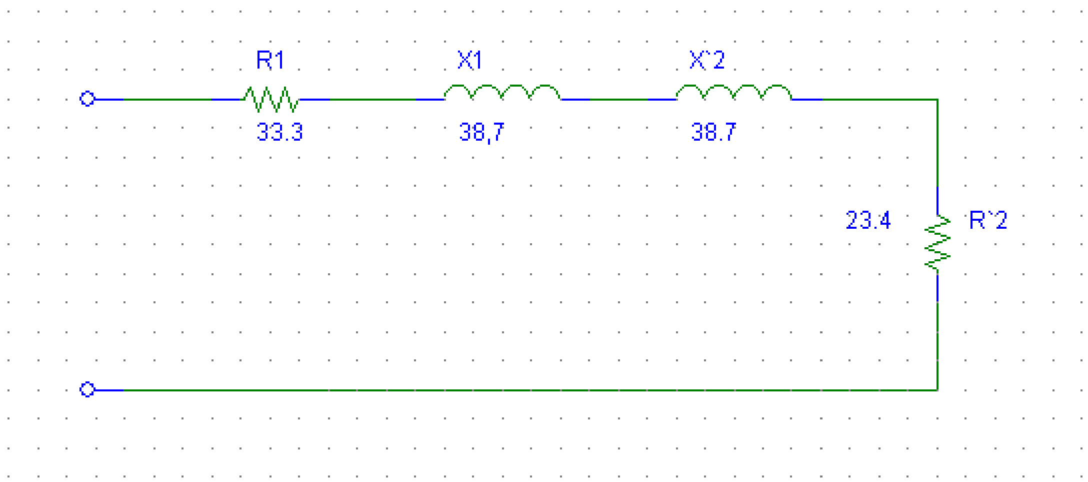


Figure 6. Short circuit of the induction machine.

To make measurements, I have set 300 W (he rated power of the machine) per three phases. This experiment is made with the rated stator current, but this value was not given in the characteristic plate of the machine. I have measured the power, the line voltage and the current flowing through the stator.

$\boldsymbol{V_{SC_L}} = 221V$ $\boldsymbol{I_{SC}} = 1.33\ A$ $\boldsymbol{P_{SC}} = 301\ w$

$$R_{sc} = \frac{301w}{3(1.33)^2} = 56.72\Omega \quad Z_{sc} = \frac{221\ V}{\sqrt{3}(1.33A)} = 95.93\ \Omega \quad X_{sc} = 77.3724\ \Omega$$

$$R'_2 = 23.42\ \ \Omega \qquad X_1 = X'_2 = 38.6862\ \ \Omega$$

With this test I also get the relation between stator and rotor. I measure linear voltage in both sides of the machine, stator and rotor. Previously I have set 380V in the stator. The following equation shows the relation:

Formula 31 $$a = \frac{N_1}{N_2} = \frac{V_1}{V_2}$$

$$a = \frac{378V}{106V} = 3.566$$

With the turns ratio “a” value I can calculate R_2 and X_2 .

$$R_2 = \frac{R'_2}{a^2} = 1.8417\ \Omega \qquad X_2 = \frac{X'_2}{a^2} = 3.0422\ \Omega$$

2.3 NO LOAD TEST

In general, in this test, the engine is fed at the rated voltage and frequency. I measure the power consumption, the current flowing through each phase and the voltage applied to the stator.

In this test, the shaft power output is not measured (there is no load, therefore the rotor circuit is opened and current does not flow through the phase), so that, I measure all the losses power (iron, copper in the stator, and friction). Therefore, the no load test lets me to measure these losses, and from them the parameters in the core machine, using the following equations:

Formula 32 $$P_0 = m_1 R_1 I_0{}^2 + P_{FE}$$

Formula 33 $$cos\varphi_0 = \frac{P_0}{m_1 V_1 I_0}$$

Formula 34 $$P_{FE} = P_0 - m_1 R_1 I_0{}^2 \ = m_1 R_C I_0{}^2$$

Formula 35 $$R_C = \frac{P_{FE}}{m_1 I_0{}^2}$$

Formula 36 $$Z_{eq} = \sqrt{(R_1 + R_C)^2 \ + (X_1 + X_m)^2} = \frac{V_1}{I_1}$$

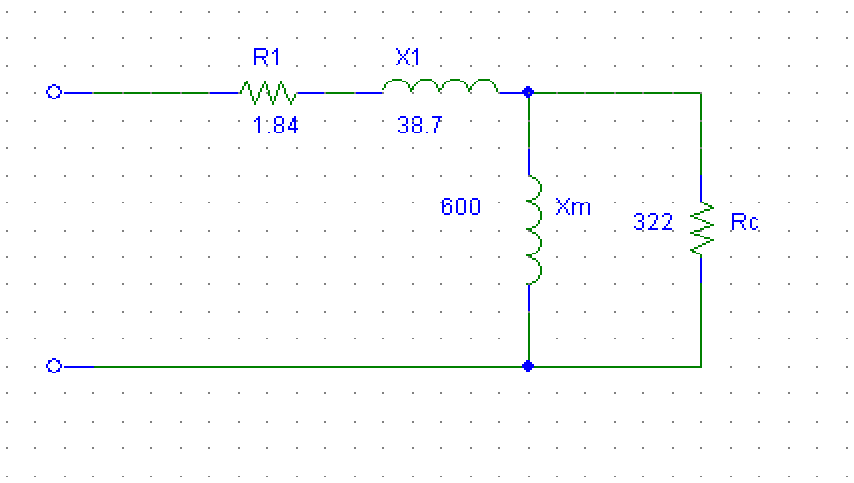


Figure 7. No load circuit.

We have set the rated linear voltage (380 V). Then, I have measured the power per phase, the voltage and the current flowing through the stator.

$$P_0 = 32\ w \qquad V_1 = 380V \qquad I_1 = 0.3A$$

$$P_{FE} = 32w - 33.3\Omega(0.3A)^2 = 29.003w$$

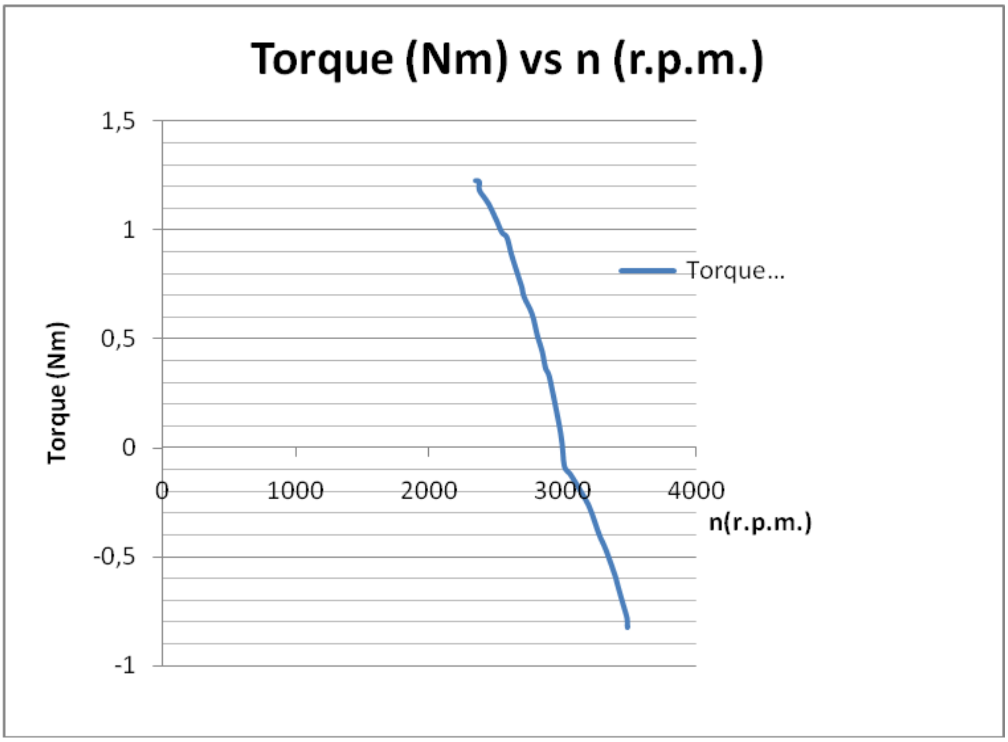
$$R_C = \frac{29.003w}{(0.3A)^2} = 322.2555\Omega \qquad Z_{eq} = \frac{\frac{380V}{\sqrt{3}}}{0.3A} = 731.3103A$$

$$X_m + X_1 = 639.0579\Omega \qquad X_m = 600.3717\Omega$$

2.4 Load test: Determination of T-s curve

To determine the characteristic curve T-s from the machine, I will be testing different values of load, obtaining different values of mechanical torque to each value of speed.

At the beginning of this test, I will start measuring with the machine working as a motor and the dynamometer as a load. When I get to 3000 rpm, I change the connections in the dynamometer and it starts working as a motor and the asynchronous machine as a generator. I modify the speed over the rated value (3000 rpm), so that I are producing power. I obtain different points of the characteristic curve. I measure the voltage, the current, the power, the torque and the speed.



Plot 4. Torque-speed in the real asynchronous machine from the laboratory.

The graph is very similar to the experimental one, as I explained before. I have had a lot of problem doing this test, due to the machine is relatively new. I did the experiment several times. At the beginning, I got very low values of torque, when the speed was close to the maximum speed (our maximum speed is close to 3450 r.p.m.). I expected higher values of torque, to reach -1 Nm, but in the test, it was not possible. Then, with my calculations, I realized that this machine does not approach to -1 Nm.

The chart shows the values that I got from the machine working with feedback.

Test Generator No.	V_1(V)	V_2(V)	V_3(V)	I_1(A)	I_2(A)	I_3(A)	Power factor	Real Power (W)	Torque Nm	Speed rpm
1	371	367	375	0.30	0.32	0.29	-0.192	65	0.064	2984
2	374	368	374	0.30	0.32	0.29	-0.153	51	0.085	3011
3	376	368	375	0.30	0.33	0.30	-0.175	60	0.119	3053
4	376	368	375	0.33	0.36	0.33	-0.260	99	0.172	3106
5	376	369	374	0.40	0.43	0.41	-0.294	134	0.248	3178
6	375	369	375	0.44	0.47	0.46	-0.303	155	0.295	3212
7	376	369	376	0.55	0.58	0.57	-0.311	198	0.401	3272
8	378	370	374	0.61	0.63	0.62	-0.319	222	0.448	3307
9	377	369	376	0.66	0.69	0.68	-0.319	242	0.501	3340
10	376	369	373	0.75	0.77	0.76	-0.326	277	0.589	3390
11	377	371	373	0.79	0.81	0.80	-0.329	295	0.633	3409
12	377	370	374	0.87	0.89	0.88	-0.329	324	0.720	3449
13	376	369	375	0.93	0.94	0.94	-0.329	345	0.785	3479
14	377	370	374	0.96	0.97	0.96	-0.331	357	0.818	3480
15	377	370	374	0.95	0.97	0.96	-0.331	357	0.821	3483
16	377	371	375	0.95	0.97	0.96	-0.333	357	0.826	3481

Chart 1. Values from the feedback program.

To sum up the practical study, the asynchronous machine is working in a right way as a generator, but not as I expected. It has given me a lot of problems with measurements, several times, I have been testing it, following the same standard and each time, I have obtained different values. One of the reasons is that the machine is new, and the brushes did not make good contact with the rings correctly. After running the machine several times, problems were less.

3. Conclusion.

In Denmark, the asynchronous machine is one of the most popular machines used in windmills, because of its simplicity and effectiveness. In this type of machine, I have access to the coil of the rotor. The electronic devices used in control the machine, are connected to the rotor coil. And this machine is perfect for this purpose. The more important value to control is the rotor current, so this machine fits to the requirements in the control.

My theoretical study was based on experiments, so maybe, noticeable mistakes have been done. I used correct formulas taken from recommended books. In the experiments, I follow the standardization in testing asynchronous machines, but measurements depend on the instruments used, and they are unpredictable. And the fact that the machine is a new one, and at the beginning it does not work as I expected, has delayed a lot my work.

5.2. AC/DC converter

AC/DC converters are used in the wind turbine generator systems to connect and purposes. Structure of converter system includes rectifier (AC/DC converter), filter and inverter (DC/AC). It works between power system and asynchronous machine terminal. In my case I are connecting converter to the machine rotor terminal and second side I should connect to converters transformer.

In this chapter I will describe my AC/DC converter.

1. Construction

I have some various structure of rectifier. To build it I can use controllable or uncontrollable elements. First one are for example thyristors or MOS-FETs, second one are diodes. During the AC/DC construction I can use different elements. In my project, the rectifier will be a six-pulse bridge for three-phase input and it will consist of diodes. This part of converter is responsible for transform current of a given voltage, frequency and number of phases into DC current[3].
After rectifier I have two elements: capacitor and coil. Combination of them is intermediate element which is working as low-pass filter. I are using that because after diode-bridge, I still have harmonic in current and I also need filter to get 1% ripple of output voltage. The 1% is because of DC/AC inverter on power board, for correctly work should get signal no bigger than this 1% of ripples.

2. Theoretical calculations

2.1 Focusing on voltage and current in the circuit.

For choosing elements of filter I need to know the values that I are getting from the rotor, how big is DC voltage after bridge and what value of current I have to keep in the output of filter.

I start with the rotor calculations. I set power to P=300 [W] with asynchronous speed n=3270 rpm. That means that the slip, for the range of speed n =3270 r.p.m. and n_s = 3000 r.p.m, is:

$$|s| = \left|\frac{n_s - n}{n_s}\right| = 0.09$$

When I know the slip, I can calculate next values:

[3]Manfred Stiebler, Wind Energy Systems for Electric Power Generation, 2008, ISBN 978-3-540-68765-7

a) Rotor frequency $f_{rot} = f \cdot s$ $f(3270) = 50 * 0.09 = 4.5[Hz]$

b) Voltage at a given speed.

Formula 37 $V_{rotor,n} = V_{rotor} \cdot s_n$ $V_{rotor}(3270) = 0.9 \times 106 = 9.54[V]$

c) Peak voltage at a given speed.

Formula 38 $V_{peak,rotorn} = \frac{V_{rotorn}}{\sqrt{3}} * \sqrt{2}$ $V_{peak,rot}(3270) = 7{,}789[V]$

We can also calculate a DC voltage that I have after the rectifier bridge.

Formula 39 $V_{DC\,n} = V_{rotorn} * \sqrt{2} * \frac{3}{\pi}$ $V_{DC\_3270} = \frac{9{,}54[V]}{\sqrt{3}} \cdot \frac{3\sqrt{2}}{\pi} = 7{,}43[V]$

To calculate the current, I use the equivalent circuit of the rotor. The circuit is present on figure 8.

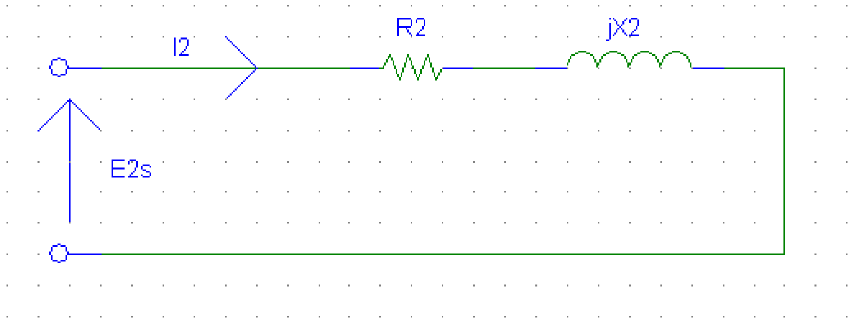


Figure 8. Rotor equivalent circuit (symbol 2nd in the figure is an index and $E_2s = V_{rotor,n}$).

The current that I want to introduce in the input of the bridge, can be calculated using the following formula:

Formula 40 $I_2 = \frac{\frac{V_{rotor,n}}{\sqrt{3}}}{\sqrt{R_2^2 + (jX_2)^2}}$ $I_2 = \frac{\frac{9{,}54}{\sqrt{3}}[V]}{\sqrt{(1{,}88417)^2 + (3{,}0422)^2}[\Omega]} = 1{,}5488[A]$

So the value of the rotor current is I=1.5488 [A]

2.2 Values of filter elements

I have several types of filter and each has three kinds of passive elements – RLC. Circuits containing two store elements, are known as second-order circuits because their responses are described by differential equations that contain second derivatives[4]. In my project I are working with low pass filter RLC as it is shown in the figure bellow:

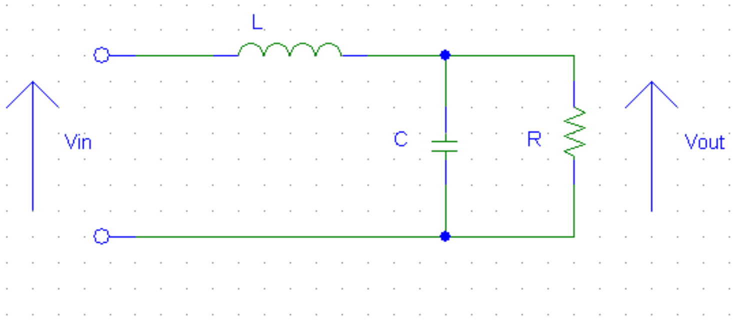


Figure 9. Schematic of low pass filter RLC.

From the ratio of input and output voltage I obtained the following formula:

Formula 41

$$\left|\frac{V_{out}}{V_{in}}\right| = \frac{R}{\sqrt{\left(R - LRC\varpi^2\right)^2 + L^2\varpi^2}}$$

And I made second ordinary transfer function to continue my calculation.

Formula 42

$$H(j\varpi) = \frac{R}{R - LRC\varpi^2 + Lj\varpi}$$

I started with the inductance of the rotor calculation, and it depends on the rotor frequency.

Formula 43 $X_2 = 2\pi f_{rot} L_2 \Rightarrow L_2 = \dfrac{X_2}{2\pi f_{rot}}$ $\quad L_2 = \dfrac{3{,}0422[\Omega]}{2\pi \cdot 4{,}5[Hz]} = 107{,}5958[mH]$

I got a very high value in the inductance. I checked the inductances in the laboratory and the biggest one that I found had the value of L=64 [mH] (with an internal resistance of R=0,5 [Ω]). That is why next calculations and measurements were based on that value.

[4]Manfred Stiebler, Wind Energy Systems for Electric Power Generation, 2008, ISBN 978-3-540-68765-7
[5]Theodore Wildi, Electrical Machines, Drives, and Power Systems, 6th ed., ISBN 0-13-177691-6

2.2.1 Ripples.

The output voltage fluctuates between 1,414 E and 1,225 E where E is effective value of the line voltage. So the peak to peak ripple is only E=0,189E" and the fundamental ripple frequency is six times the line frequency[5]. That means: frequency for DC voltage is 6 times bigger than frequency of rotor.

Formula 44 $f_{DC} = 6 \cdot f_{rot}$ $f_{DC} = 6 \cdot 4{,}5[Hz] = 27[Hz]$

To find the correct values of LRC for 1% signal ripples, I used values of specific gains and the bode diagram for secondary order function.

magnitude H	0,001	**0,01**	**0,1**	0,5	$1/\sqrt{2}$	1	$\sqrt{2}$	2	10	20	100	1000
$20\log_{10}H$ [dB]	-60	**-40**	**-20**	-6	-3	0	3	10	20	26	40	60

Chart 2. Specific gains and their decibel values[6].

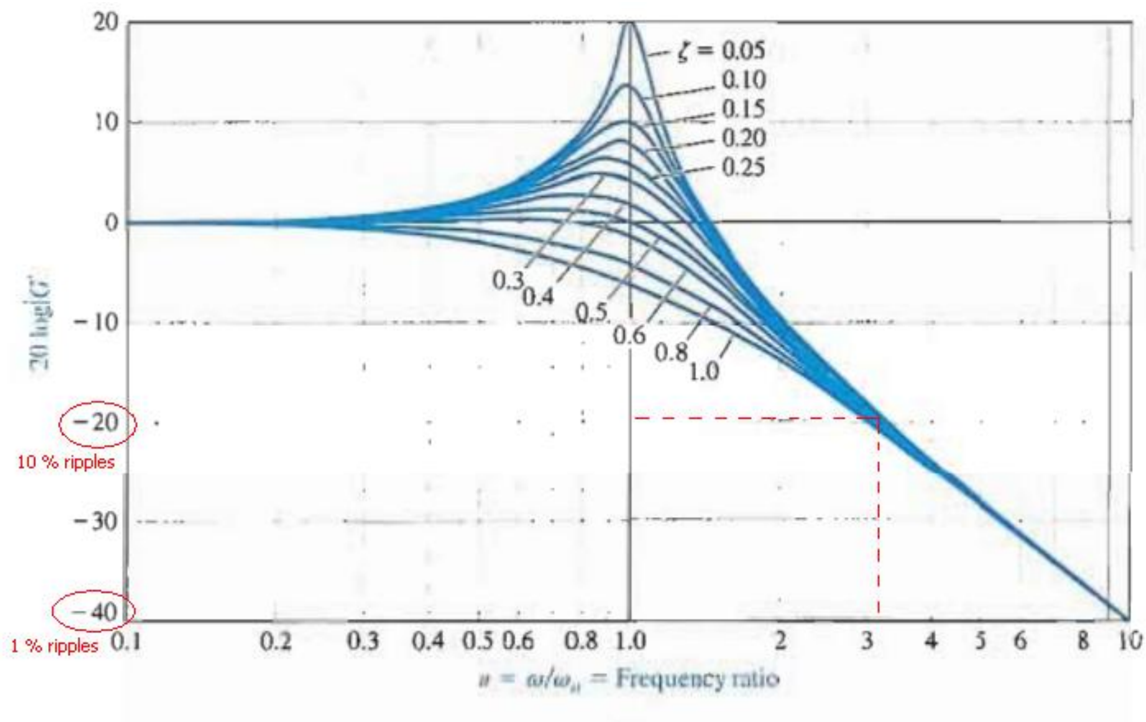


Figure 10. Bode diagram for secondary order function[7].

[6] Charles K. Alexander, Matthew N.O. Sadiku, Fundamentals of Electric Circuits, 2nd ed., ISBN0-07-115126-5
[7] R. C. Dorf, R. H. Bishop, Modern Control Systems, 11th ed., Pearson International, 2008, ISBN 978-0-13-227028-1

The base pulse for DC voltage after diode bridge is like in the below formula:

Formula 45

$$\varpi_0 = \frac{1}{\sqrt{LC}}$$

2.2.1.1 Calculating for 1% of ripples .

As I can see in chart 2 and figure 11, to get 1% ripples I need to go down to – 40 [dB], then the frequency ratio is 10:

Formula 46

$$\varpi(f_{DC}) = 10 \cdot \varpi_0 \quad \text{and} \quad \varpi = 2\pi f$$

$$\varpi_0 = \frac{\varpi}{10} \quad \text{I get} \quad \varpi_0 = 16{,}9646\left[\frac{rad}{s}\right]$$

With the natural frequency calculated ϖ_0 and using the formula 47, I can calculate some combinations of RLC. I chose a constant value of inductance, and I calculated different values of capacitor. I show the values in Chart 3.

Formula 47

$$LC = \frac{1}{\varpi_0^{\ 2}}$$

R comes from the formula 41.

L(mH)	C(F)	R(Ω)
11,000	0,316	0,110
21,000	0,165	0,210
31,000	0,112	0,310
41,000	0,085	0,410
51,000	0,068	0,510
61,000	0,057	0,610
71,000	0,049	0,711
81,000	0,043	0,811
91,000	0,038	0,911
101,000	0,034	1,011

Chart 3. Values of filter components.

Capacitor values are very high and are impossible to get in laboratory, in particular for inductor L=64 [mH]. That is why I decided to increase tolerance for ripple from 1% to 10%.

2.2.1.2 Calculating for 10% of ripples.

One more time using Chart 2 and figure 10, I know that 20dB is related to $3{,}2\omega_0$.

$\varpi(4{,}5[Hz]\cdot 6) = 3{,}2\varpi_0$ ω_0=16,9646 ω=54,28

That give me the next frequency.

$$f = \frac{\varpi}{2\pi}$$ f=8,64[Hz]

For this new value of frequency, I get a value of capacitor. It`s C=5,6 [mF] (for inductance of L=64 [mH]) and R=7Ω.

To check my calculating I used Pspice simulation. Below I present my schematic:

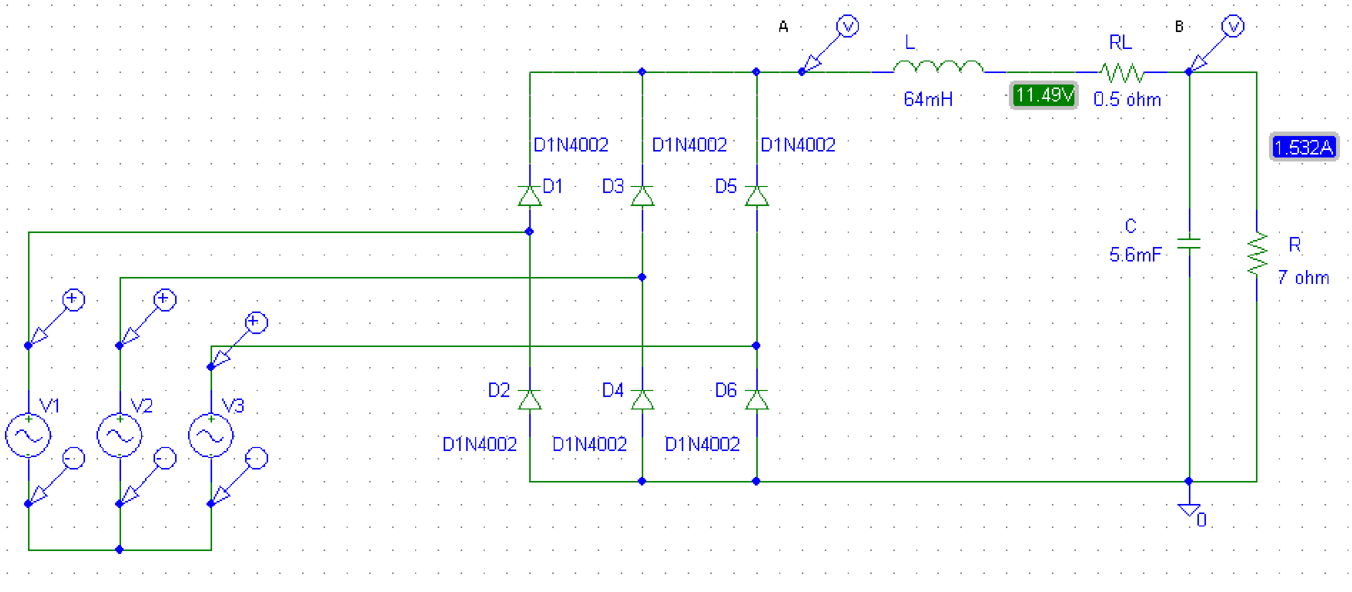
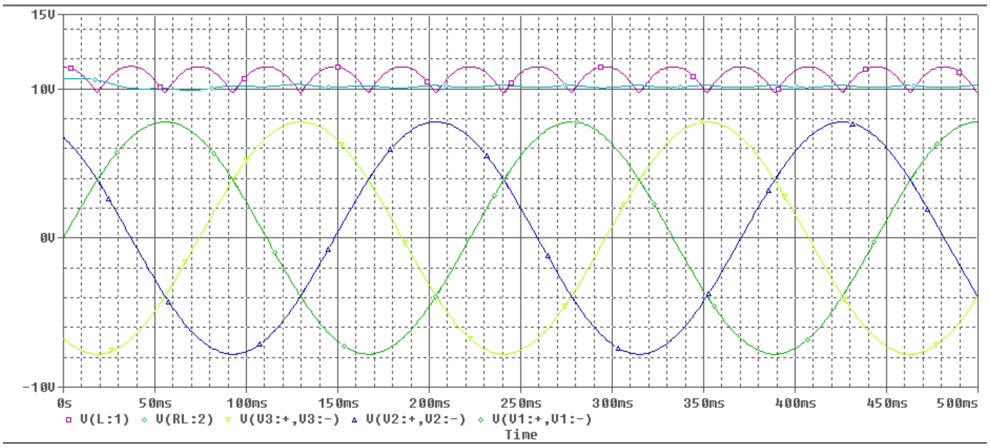


Figure 11. AC/D converter – Pspice model.

<u>Parameters of schematic and simulation:</u>

- Input: VSIN sources, shifted in phase by 120 degree; V_{ampl} = 7,7894 V; f =4,5 Hz; Voff=0.
- Transient analysis: Print Step 0,01s; Final time 0,5s; Step Ceiling 0,001s.
- Voltage Markers: differential on sources, after rectifier (A), after filter (B).

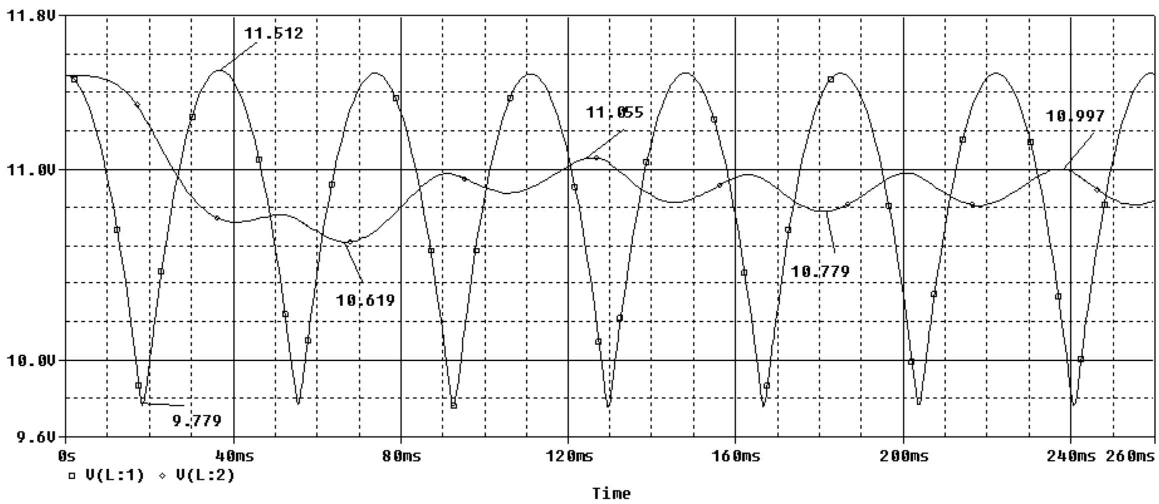
For these parameters, I get the following graphs:



Plot 5. Voltage on the source, after diode-bridge and after filter.

In plot number 5, I can see voltage of three phases from source (light green, dark green, dark blue), rectified voltage after bridge (pink) and almost DC voltage after filter (light blue). That characteristic I would like to get with my built converter.

Let see how voltage ripples look closer:



Plot 6. Voltage after diode bridge and filter.

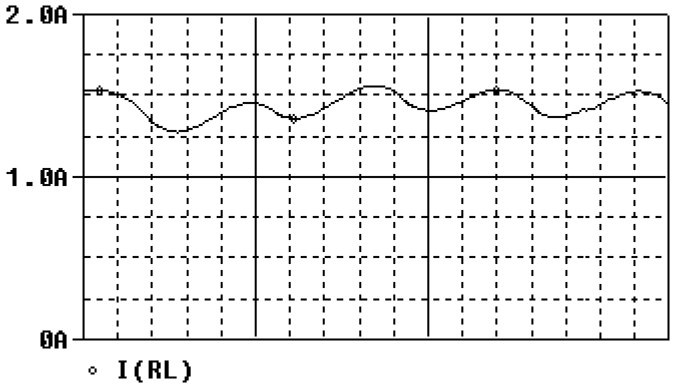
In the plot 6, I have rectified and filtered the signal. The first signal has this maximum value V_{max_b}=11,512 [V] and the minimum value is V_{min_b}=9,779[V], so the difference is ΔV_{bridge}=1,712[V]. Second signal (after filter) has more unstable ripples at the beginning, but after time = 160[ms], the maximum value is V_{max_f}=10,997[V] and the minimum one is V_{min_f}=10,779[V] – it`s ΔV_{filter}=0,218[V]. To answer the matter, I got 10% of ripples, so I linked that two signals:

Formula 48 $$\frac{\Delta V_{filter}}{\Delta V_{bridge}} \cdot 100\% = 12.73\%$$

Results are bigger than 10% but when signal starts from V=11,512[V] and decreases to V=10,618[V], it`s about 50% of rectified signal, so I suppose that after longer time I get 10% of ripples. It doesn`t change the fact that the theoretical calculations are correct.

On PSpice model I can also see that voltage after rectifier is smaller than should be. Calculated is V_{DC}=12,869[V] and on simulation is equal V_{DC} =11,49[V]. I have voltage decreasing in diode-bridge about 1,38 [V] . It`s associated with losses on each diode.

We checked current on the output of filter and it`s on correct level 1,532 [A]



Plot 7. Current on the output of filter.

3. Choose real components and build the converter.

To build my converter I used an already built diode bridge from WTE Power Semiconductors, and the below components:

- Rectifier: type 26MT80;
- Inductor: L=64[mH], R=0,5[Ω];
- Capacitors: electrolity C=2,2[mF] (twice), C=1[mF] and C=220[uF]; for U=35[V];
- Power variable resistor from feedback – 7 [Ω];
- * Radiator: SK 100/50. (We did not use radiator because of the low current and that it can work with the following value of temperature: 150ºC).

I thought about cooling the bridge, to do that, I should use a radiator. From datasheet I know that heat supplied cannot be more than 150 ºC. To calculate the biggest resistance that I can use in the circuit, I pick up suitable radiator to cool the bridge, so I have to know Rt_{jc} thermal resistance case mounting surface – 0,2 K/W (from datasheet), Rt_{cs} thermal resistance junction to case at DC operation per bridge – 1,16 K/W (from datasheet), Rt_{sa} - thermal resistance between the plate during the cooling bridge.

Going step by step, I am doing the following calculations:

Formula 49 $$Rt_{all} = \frac{T_j - T_a}{P}$$

Formula 50 $$Rt_{all} = Rt_{jc} + Rt_{cs} + Rt_{sa}$$

Where:

T_j – maximum permissible temperature on the diode bridge - 150°C (from datasheet).
T_a – surroundings temperature - 20°C.
P – power at output from diode bridge (from datasheet).

To get Rtsa, I calculate the output current of converter. The power is kept constant, the same input and output: $P_1 = P_2$, then:

Formula 51 $$\sqrt{3}V_1I_1 = \sqrt{3}V_2I_{out}$$

Formula 52 $$\sqrt{3}V_1I_1 = \sqrt{3}V_1\frac{3}{\pi}I_{out}$$

Formula 53 $$I_{out} = \frac{I_1\sqrt{3}}{\sqrt{3}\frac{3}{\pi}}$$

Formula 54 $$\frac{T_j - T_a}{P} = Rt_{jc} + Rt_{cs} + Rt_{sa}$$

Formula 55 $$Rt_{sa} \leq \frac{T_j - T_a}{P} - Rt_{jc} - Rt_{cs}$$

The picture shows the filter that I built :

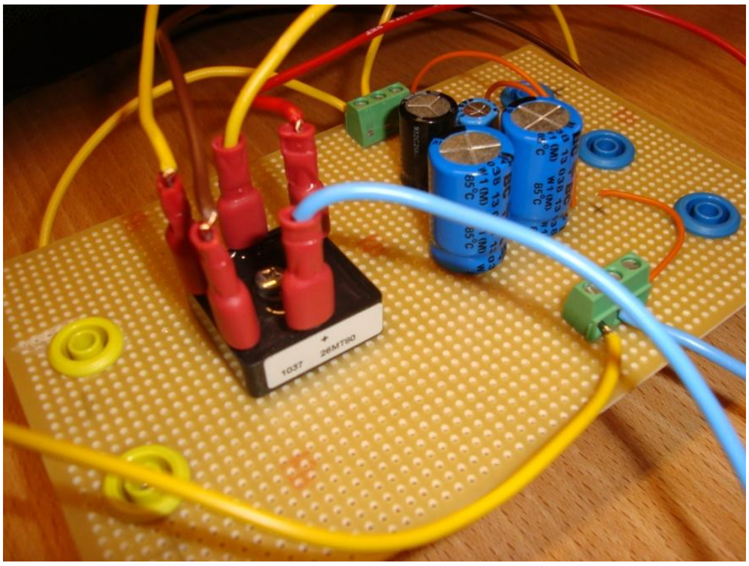
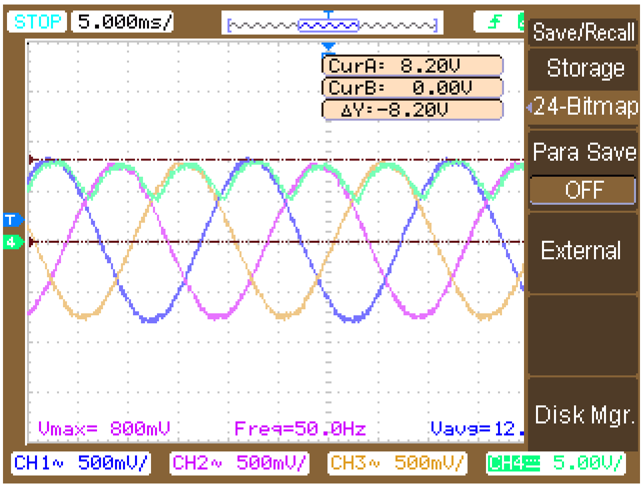


Figure 12. my built converter AC/DC

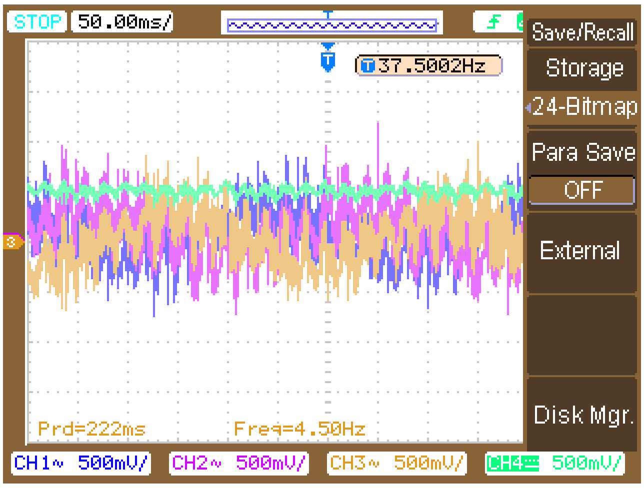
4. Measurements.

After building the converter, I tried to support my theoretical considerations by practical tests. I connect my converter to the induction machine and to the oscilloscope to see the voltage. At first moments, I explored diode-bridge. Characteristics which I get I present bellow, the green signal is the one after the bridge:



Plot 8. Three phases and voltage after rectifier.

We got a clean signal from the three phases voltages and a good results of the rectified signal. Then, I connected elements of filter and I saw bigger noises on all characteristics. I suppose that is because of a big amount of wires. It could be due to, there was not a good connection between soldered components. Actually I had some problems with generator and feedback system. To get characteristics in the plot 9, I should increase the speed of the machine to n=3400[rpm] and then decreasing it to set the following speed n=3270[rpm]. Only using that way I could get the expecting plot.



Plot 9. Three phases and voltage after filter.

Despite disruptions, I get the main goal. The green signal in plot 9 shows the voltage after the filter. The graph shows a lot of noise, but it is quite similar to the theoretical results. So finally, I think that my measurement is quite correct.

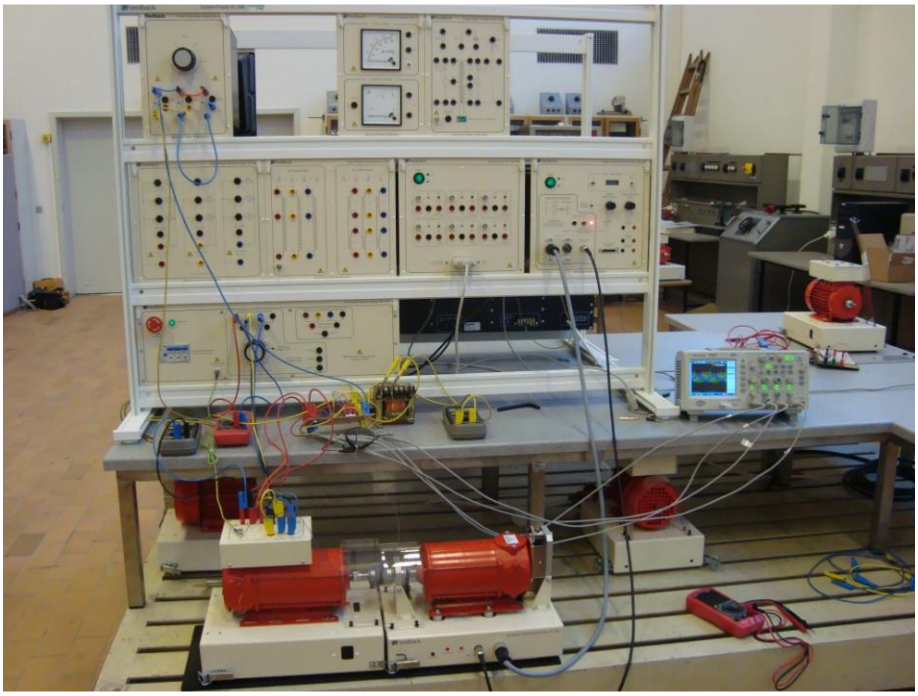


Figure 13. Laboratory measurements.

5. Conclusion.

In that part of my project, I changed AC voltage to DC. I have done it using a 6-pulse diode-bridge and a low-pass filter.

It took me a lot of time and I have done many calculations focusing with the filter and lots of PSpice simulations. In the report, I present one of the ways to get correctly values of filter and the best calculations which have been made for generator parameters. Rectifier and filter, which were connected, are working. Unfortunately I didn`t get 1% of ripples for voltage after filter. That is why I can`t connect converter with power board system.

I have made as much as it possible in the time that I had. I could not focus on details, but finally, I think that is quite good.

5.3. Inverter and Pulse Width Modulating (PWM).

1. PWM inverter,

Inverters are circuits that convert DC voltage to AC voltage in a desired amplitude and frequency. As the output voltage can be set up, this is made with constant frequency or varying the frequency. Several output voltages can be obtained by using DC voltage inputs, with a constant efficiency performance of the inverter. If the input DC voltage is constant and it cannot be set up, some voltage outputs can be gotten by changing the gain of the inverter. And this action is made by pulse with modulation. The gain of the inverter is the ratio between output ac voltage and input dc voltage. On an ideal inverter, the output voltage should be sinusoidal wave form. In a practical inverter, the output voltage is not totally sinusoidal because there are some harmonics.

The bridge circuit of an inverter can be constructed by using transistors, MOSFETs and diodes. In this Project transistors are used like it is shown in the below figure.

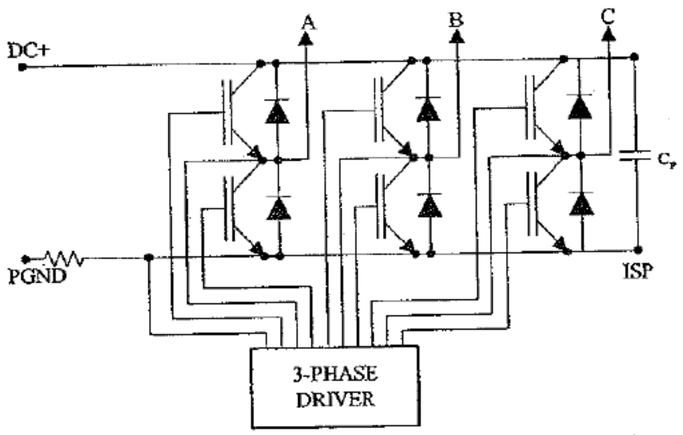


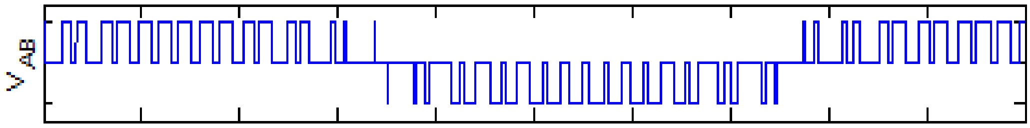
Figure 14. PWM Inverter.

Pulse-width modulation uses a rectangular pulse wave whose pulse width is modulated resulting in the variation of the average value of the waveform.

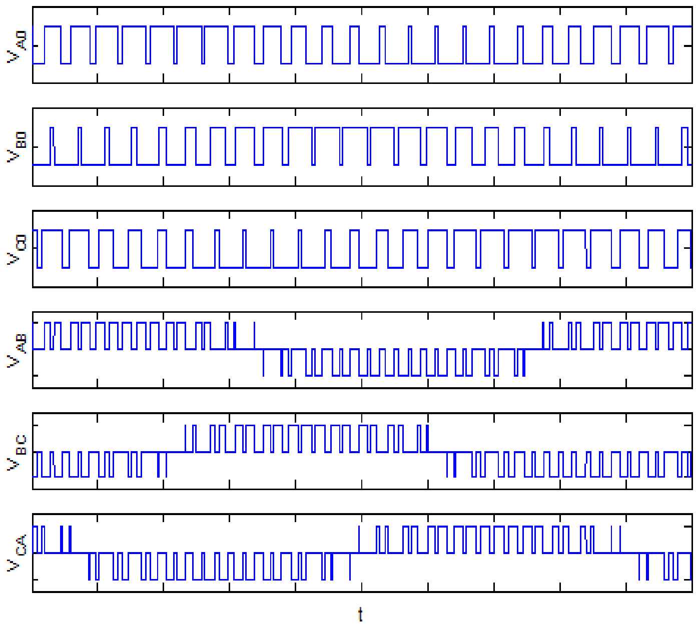
1.1 Operation:

PWM received the 6 pulse signal from microcontroller. In my case, I use Arduino to generate the sinusoidal signal because the powerboard works with digital.

For 1-phase, when the transistor 1 conducts, I have the signal A and when the transistor 2 conducts I have the signal B.



Plot 10: PWM signal for 1 phase



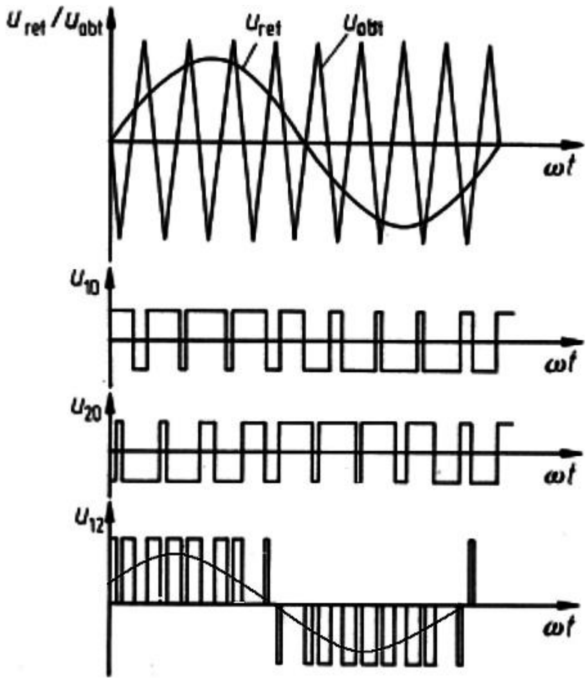
Plot 11. Signals seen in the PWM.

On a three phase bridge circuit of inverter, the polarizations can be obtained by switching the sequence of the transistors. When one of the legs of the two switches (transistors) is opened, the other switch is never opened at the same time. And each switch provides a pulse, which has amplitude π, and on the other pulse is seen with an angle (α).

As this action occurs in each leg, and, therefore in this way, three phase output voltages can be gotten. And the voltages on the each leg (V (A0), V (B0) and V (C0) can be changed between 0 volt and Vdc/2 volt. In my case, I have a different range of voltage, so what is explained is in theory.

The best system to control the asynchronous machines is the change of frequency that inverters use. This change is provided using pulse width modulation (PWM) with a constant input dc voltage. Effective voltage can be gotten, and this voltage can be controlled on this type systems. At the same time, by using this modulation, the harmonics can be reduced.

The inverter that is fed by the filter after the ac/dc converter, has two switches transistors and on the each legs. By using PWM control, this can be controlled by changing the obtained angle (α) and contrasting between sinusoidal signal with the according desired frequency and the triangular switching signal. And this action is applied by using microcontroller, which is connected to computer program. In this Project, to fit that purpose, Arduino Duemilanove ATMEGA328 is used. IN the following figure, it is shown this triangular signal and the modulation of PWM.



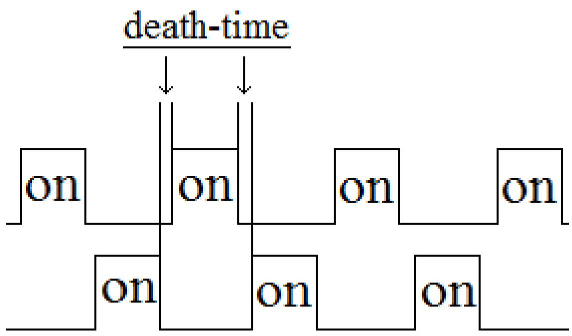
Plot 12. Modulationof PWM.

In my project, the function of the Arduino program is to compare the two analogic signals, to convert them into digital. So that, in the output of the microcontroller, I get the U10 signal (modulation PWM). The modulation of PWM is a synchronous modulation, using sinusoidal reference voltages and a triangular carrier voltage. So, the main goal, it is to compare both signal, the one from the tyristors and my sinusoidal reference signal. The results are depending on whether uref > utri or uref < utri. This is shown in the Figure above, for u10 and u20, resulting in the output line-to-line voltage u12.

The modulation ratio is defined using reference and triangular voltage amplitudes:

Formule 56 $$m = \frac{uref}{utri}$$

In my case, I must also focus on the problem of dead time.



Plot13. Death time.

PWM input signals of the transistors provokes that the transistors T1 and T2 are turned on or off.

The situation in which both transistors are working simultaneously, could not happen, because in that situation, a short-circuit could be provoke. That's the reason why it is not possible to obtain the 100% duty cycle, due to the rise and fall times of applying the transistors. So dead time is necessary to add, in the case that, the second transistor turns to be off.

Formule 57

$$Dead_{time} = \left(1 - \frac{tem}{255}\right) x T_{PWM}$$

Formule 58

$$Dead_{time} = \left(1 - \frac{V_{ADC0}}{5}\right) x T_{PWM}$$

Where:

V_{ADC0} – Voltage on Analog to Digital Converter input
T_{PWM} – PWM signal period

5.4. Control.

5.4.1. LabView.

Objective :

Labview is a software that I use to measure and to calculate control systems.

We have made a program for the regulation of the circuit. I measure the speed and the power of the rotor, next I calculate the value of the current of the rotor to send it to the powerboard, to change the voltage and the current to get a constant power.

<u>1. Measurement</u>

1.1 Power of the rotor

1.1.1 Connection

I use a powermeter to measure the power of the rotor. To connect the powermeter to Labview, I use a GPIB USB cable.

1.1.2 Program

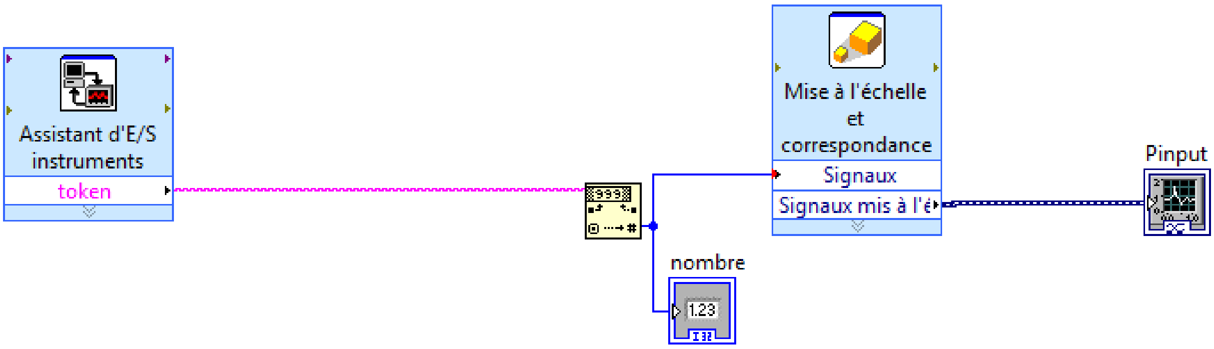


Figure 15. Diagram of power program.

I use I/O Instrument to configure the analogique input and to measure the power.

1.2 Speed of the rotor.

1.2.1 Connection.

We use 2 cables to connect the speed control panel with the NI USB 6008.

1.2.2 Program

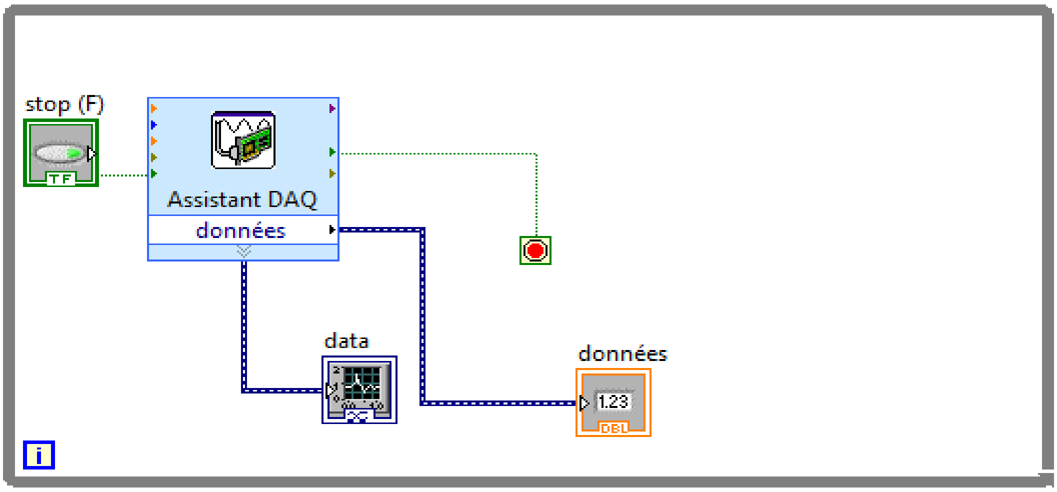


Figure 16. Diagram of speed program.

I use DAQ Assistant to configure the voltage. Next, I choose ai0 for analogique input.

1.2.3 Measurement

The objective of this measurement is to find a coefficient between the speed and the voltage.
I have connected the rotor and the stator of the induction machine in Star.
I have connected the NI USB 6008 from computer to control pannel on "external speed".

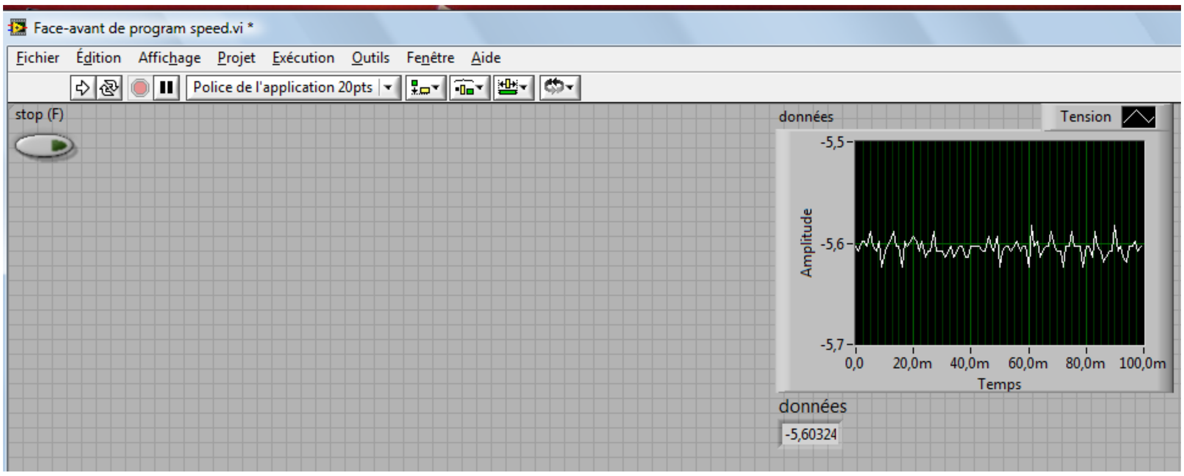


Figure 17. Measurement with speed program.

After measurement I find the coeffient between the speed and the voltage:
For 2900 rpm I have 5.60 V
So I have 5.6V → 2900 rpm
1V → 518 rpm

2. Calculation

Formula 56 $$P_{mec}=T_{mec}.\omega_{mec}=I_2^2.\frac{R_2}{s}$$

Formula 57 $$I_2^2=\frac{T_{mec}.\omega_{mec}.s}{R_2}$$

Formula 58 $$I_2=\sqrt{\frac{s.T_{mec}.\omega_{mec}}{R_2.}}$$

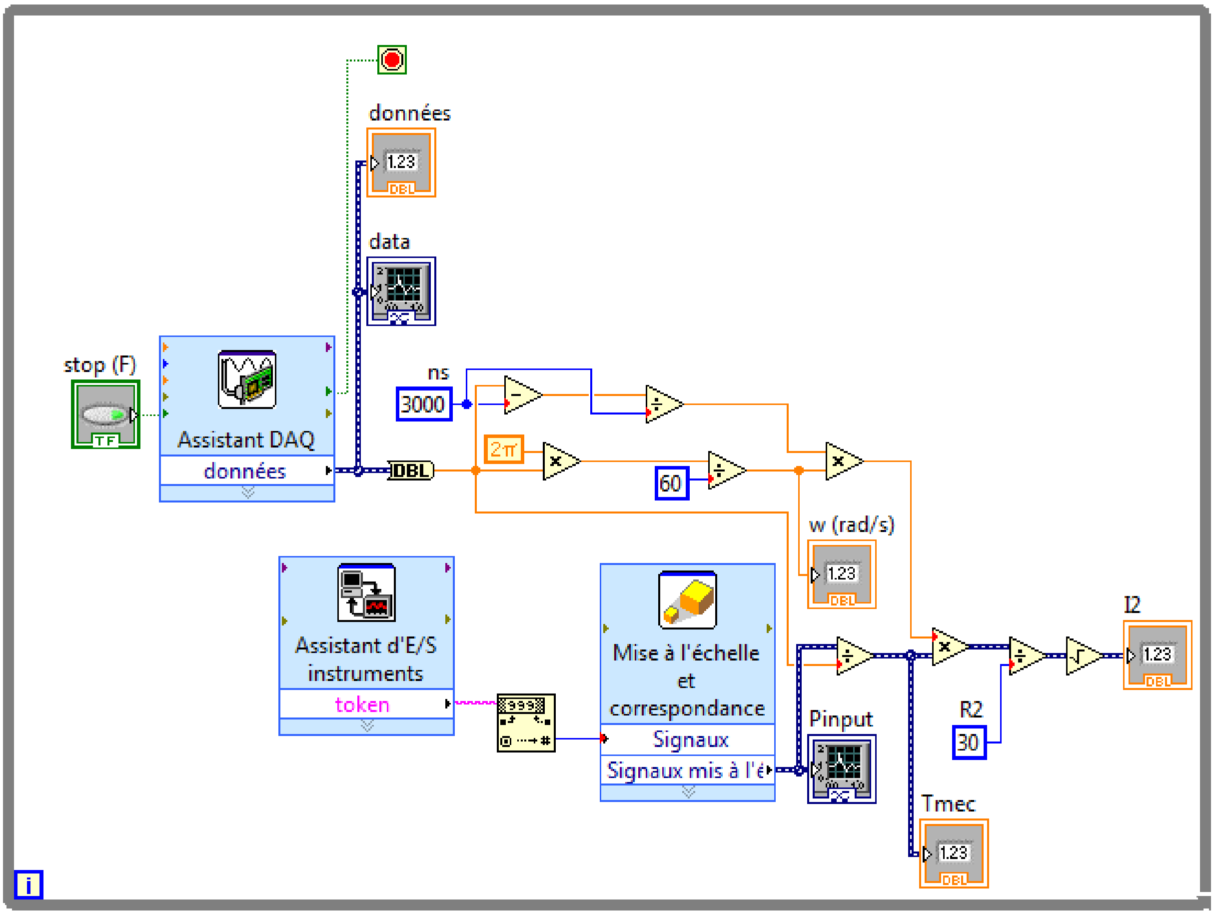


Figure 18. Diagram of calculation of current.

I add both power and speed program in the current program to find the value of the rotor current.

3. Difficulties and solutions.

- Problems.

Working with a new software was difficult.

Understanding why it is useful Labview in the project.

How to acquire the data. I have had some problems configuring and connecting, because there were many types of data (speed, current, voltage, power).

How to program to obtain the acquisition of data?

The speed program worked but I didn't find good results, because I have not obtained a signal constant and I were expected to obtain it.

The power program was not finish because I needed more time to end it.

We didn't know how to send the value of the current rotor in the microcontroller.

- Finding solutions.

To solve my problem, I have asked many questions at the teachers, the other groups and I have studied using Labview tutorial.

- Future perspectives.

We can try to have a good result for the speed program. To finish the power program and to find how to send the value of the current in the arduino software.

Conclusion:

To sum up, the speed program works to measure the speed of the motor because I have obtained the result to hope. However, the power program need some modification to work.

Labview can acquire data, to calculate and to generate a value. To finish the program, I would need more time

5.4.2. Arduino.

Arduino is a software that permits to make a program. This program permits me to regulate the PWM signals. The program was making by the teacher. I should understand how the program controls the PWM.

Objective: The objective of the program is to generate 6 pulses to control the IGBT's (insulated-gate bipolar transistors).

1. Program Description.

The program is called Program for 3-Phase PWM controller and will be implemented and controlled through the micro-controller Arduino-ATMEGA328.

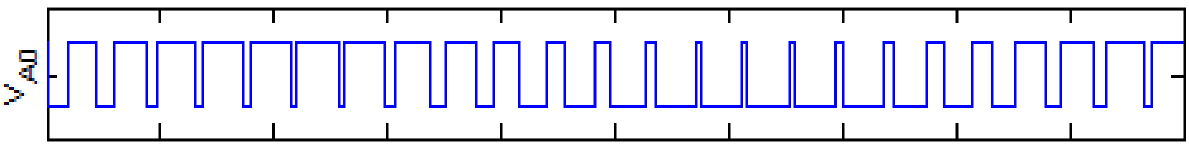
The code will be showed and I will explain the actions that the user is running, this code is inserted through the program the Arduino micro-controller and whose function is to pass the analog input signal to PWM output PWM signals in digital optical.

The program is composed by 3 sinusoidale functions, with 78 samples to create a half-period (positive signal) and after, the Arduino program inverts these samples to create a 2nd half-period (negative signal).

Program Code. *Samples for the 1st half sinusoidale signal is shown below.*

```
int sinus0[]={0,10,20,31,41,51,61,71,81,91,101,110,119,128,137,146,154,163,
        170,178,185,192,199,205,211,217,222,227,231,236,239,243,246,248,250,252,
        253,254,254,254,254,253,252,250,248,246,243,239,236,231,227,222,217,211,
        205,199,192,185,178,170,163,154,146,137,128,119,110,101,91,81,71,61,
        51,41,31,20,10,0};
```

The program creates 6 pulse signals to control the IGBT's. These signals depend on table sinus.



Plot 14. *Pulse signal to control 1 IGBT for 1-phase.*

2. Connection with the microcontroller.

Appendix 1: Schema of microcontroller.

The microcontroller is used to control the PWM.

This micro-controller contains 6 analog inputs and 6 digital optical outputs. This program will consist on the generation of 3-phase sinusoidal signals of frequency 50 Hz, the amplitude of these signals will be calculated for the value that I desire by using the input signal, the input signal will have a voltage being (0 - 5v) and the analog input pin 0.

In this program I will have 3-phase signals which I are going to divide by 2 (positive and negative).

The signals of phase 1 will be connected to a micro-controlled analog and the positive input will be connected to the pin=1 and the negative input pin=2.

The signals of phase 2 will be connected to some analog positive input of the micro-controller, it will be connected to the input pin = 3 and the negative input pin = 4.

The signals of phase 3 will be connected to some analog positive input of the positive micro-controller, it will be connected to the input pin = 5 and the negative input pin = 6.

The 6 digital optical signals will be:

Phase 1 - pinMode (output) = 5
Phase 1 + pinMode (output) = 6
Phase 2 - pinMode (output) = 9
Phase 2 + pinMode (output) = 10
Phase 3 - pinMode (output) = 11
Phase 3 + pinMode (output) = 3

The value of ADC conversion will be included in a range: 0-1023 (0-5v).

For the table within half the period 78 samples, I will have this performing due to a deficiency in the used memory and I can only keep the values for the first 60 degrees. And then calculating. I have a microchip with lots of memory and whose function is to generate PWM signals. I have time values which are necessary for the calculation of phase samples (2.3) and the angles of the sine wave. This calculation is very slow and more agility to use a program code for calculating (line to line-28-45).

The following code is running the timer for the OWN method, this process is performed using a computer program to make it easier and faster.

With this, by using an 8-bit timer and an inverted PWM oscillator signals generated, as a result, I obtain the first negative values in the following pins:

pinMode (5, OUTPUT); Phase 1
pinMode (6, OUTPUT); Phase 1 +
pinMode (9, OUTPUT); Phase 2
pinMode (10, OUTPUT); Phase 2 +
pinMode (11, OUTPUT); Phase 3
pinMode (3, OUTPUT); Phase 3 +

Finally the program is executed as an endless cycle of mid-term (78samples), in which I change the polarity of the phase 1 and generate the values, then perform 52 samples for phase 2 and then turning negative conduct the phase 3, 26 samples change from positive to negative and opposite.

3. Parts of the Microcontroller.

Now I have a photo in which it is shown the parts of the diagram controller and schedule of connections.

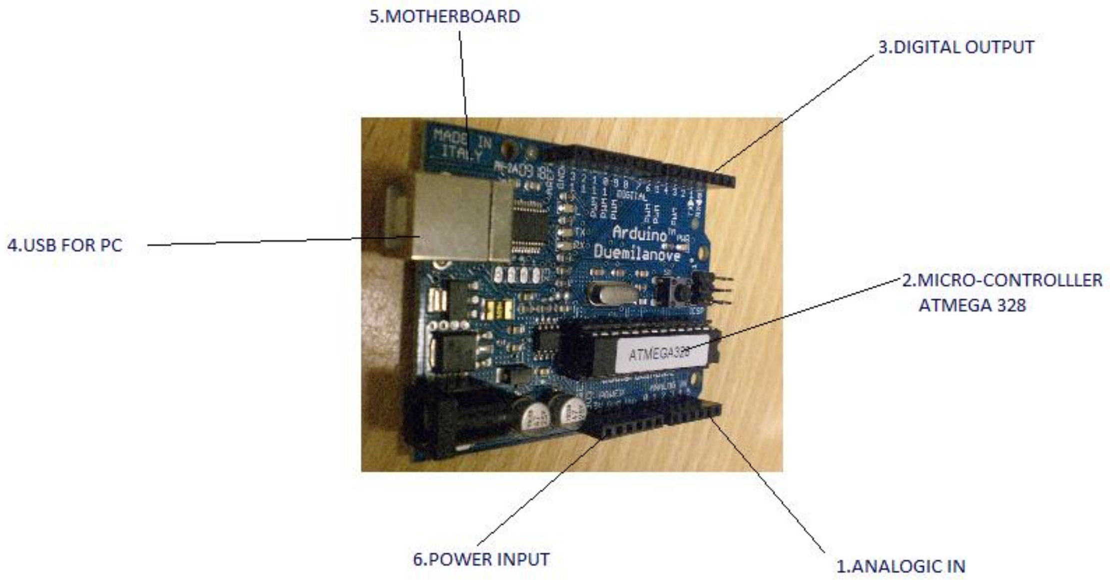


Figure 19. Schedule of connections.

4. Conclusion.

Arduino program has been a good tool because it has helped me as a comparison source of signals, and thus, I could obtain the PWM signal. Each phase of a need for PWM and PWM - the signal and, in PWM inverts the PWM signal , is not possible to stablish the right settings for the times values of the program. This compares each value with the value in the previous period, there is a logical channel that is not inverted and when the real value of the counter is equal to the reference value, the invested value in the channel is changed to logic zero until the end of the PWM signal period. At least, it is necessary to give a new reference value of logical type, for each period of PWM to generate the wave. That value is calculated from the values of the sine wave and multiplying with 255 to archive value in the range of 0 to 255.This value represents the duty cycle. All these calculations are made through the Arduino program, it also records all the data.

The program has been a tool that has helped me to save time on calculations and has recorded all the data and has compared them to generate the PWM signal to the output microcontroller.

5.5. Power board.

Appendix 2:Schema Power-board.

1. Theoretical part.

I used the power board because it is impossible to figure out the signals taken straight from microcomputer. I have to connect the outputs to the power board with microcomputer using optical fibers and I have to observe the signals from outputs of inverter board.

1.1. Description[8].

The X2100 Power Board Module contains different control parts for driving either three phase induction machine, synchronous machine and brushless dc motor. It has inrush control system for protecting against overload and high current. It consists on a full bridge register that produce PWM signal.

This board has thermal devices that measure temperature for protecting this system and it also has Power Factor Correction that is made by the controlling main current drawn. The module works with phase voltage of 150 V or phase voltage of 230 V for low input current.

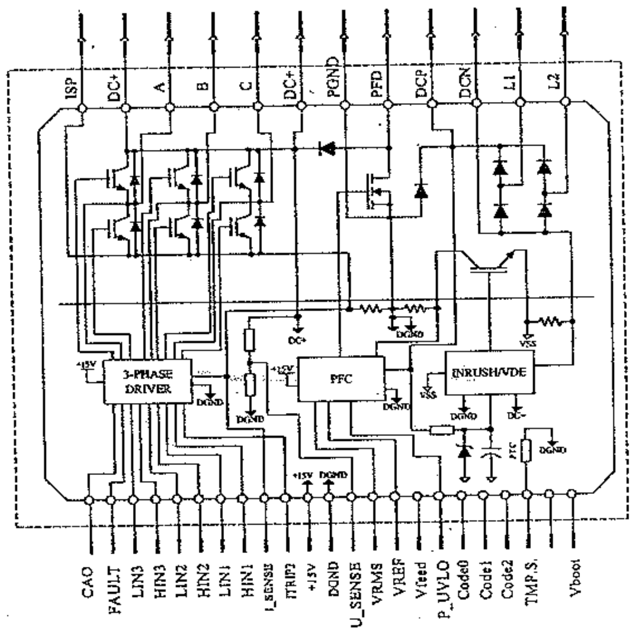


Figure 20. Power Board connections.

X2100 Power Board consitis on different parts (Inrush/VDE, PFC, 3 phase driver).

1.2. Inrush/VDE[9]

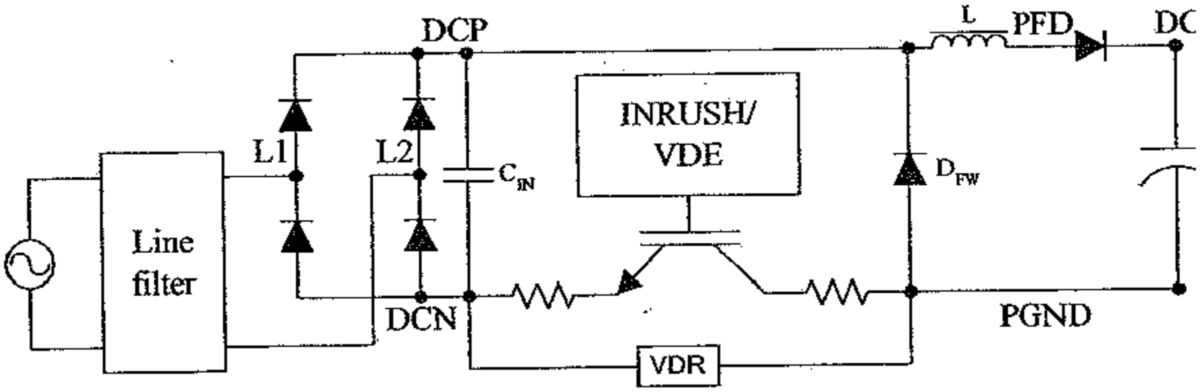


Figure 21. Inrush/ VDE schema.

The module includes all the full bridge diode that rectify the line voltage, a pulse capacitor is placed between DCP and DCN for filtering.

If the voltage exceeds in the resistors that is between the emitter of the inrush-IGBT and DCN, the IGBT will stop working so the dead time will be existed. When the IGBT is exposed by lightning transient, the limit voltage shouldn't be changed. So VDR is connected between DCN and PGND that is necessary if the capacitor voltage is higher than 960 V, during the transient. And the diode (D_{fw}) is only used to discharge inductor during over current in the inrush IGBT.

1.3. PFC[10].

PFC includes a boost converter, an inductor, a capacitor and a switch. When the boost which turns on, the current flow through the inductor and it begins to be increased and the capacitor is providing the load. If the switch closed, the capacitor is forward biased so the inductor starts to be discharged by this capacitor. The capacitor also is necessary to hold up DC link voltage when there isn't given the power from grid.

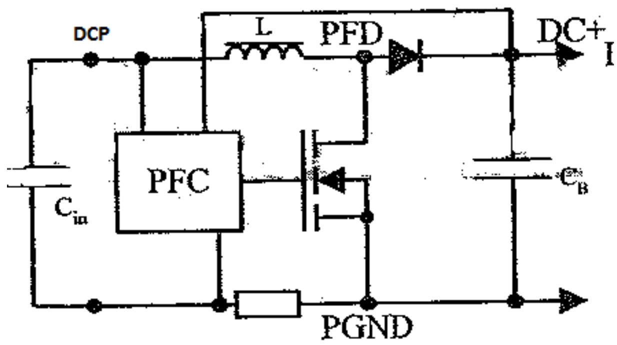
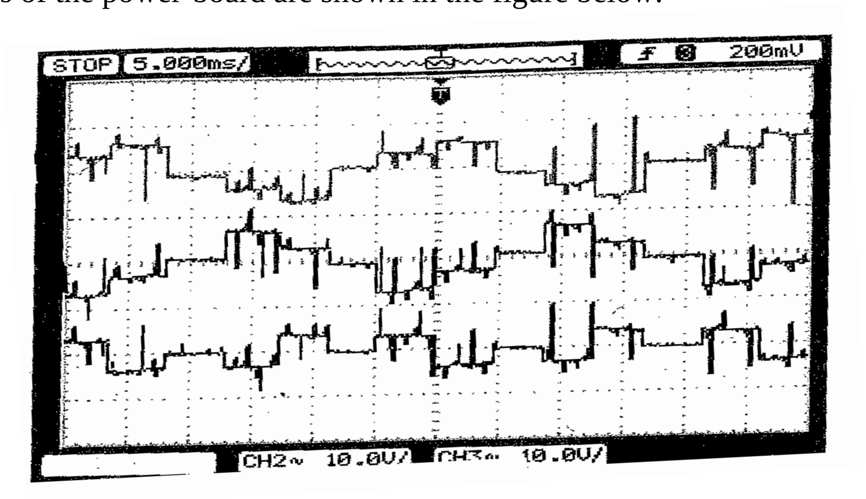


Figure 22. Power factor corrector.

The DC Link voltage is across the bulk capacitor that is controlled by PFC-IC, if the inductor current is wanted to control, this voltage must be bigger than the peak value of system voltage.

1.4. Conclusion.

The conclusion of my power-board is that I have not been able to calculate the signals from output of inverter board because the power board did not work correctly. But the expected results of the power-board are shown in the figure below.

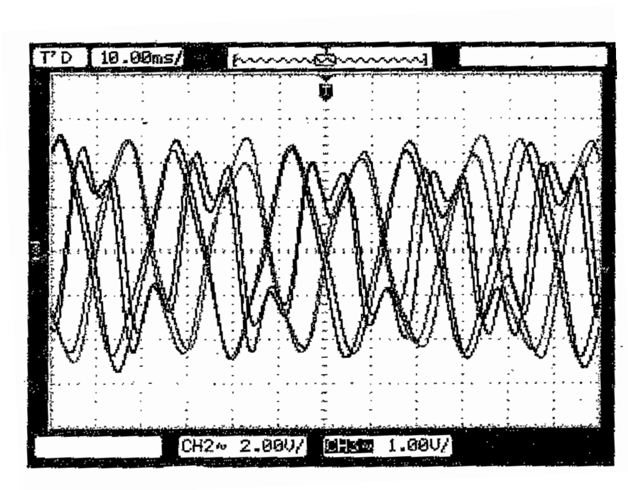


Plot 14. Results of power board.

The power board is also connected to the low- pass filter, which will be designed and used to eliminate harmonics. If everything would go on well and I would have a well working power board, I could have had an ideal voltage in the oscilloscope.

I have many worked the theoritical part. my results concerning the induction machine seem true, moreover, for the other parts, I have make some measures.

In the perspectivation to improve the project, I will make the measurement necessary.



Plot 15. Expected three phase voltage after the low-pass filter.

[8,9,10]Wind Mill Technology Project. This information was given by one of the teachers.

2. Tests and measurements: PWM Signal and Power Board.

2.1. Operation.

The powerboard received a DC signal between 0 and 5V. When the input voltage is 0, the amplitude of the sinusoidale is 0. Otherwise, when the input voltage is 5V, the amplitude is 5V.

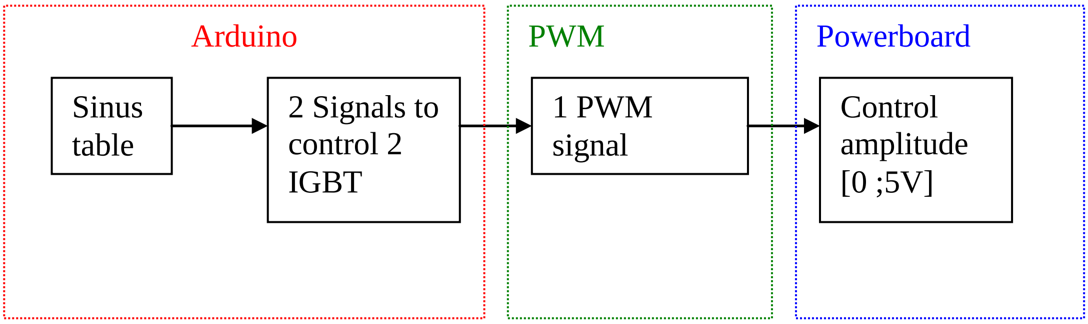


Figure 23: Principle to create 1 sinusoidal signal.

2.2. Measurements.

2.2.1. Devices used in laboratory.

These are photos which show the elements used in the laboratory and how they are connected to each other.

The next picture shows the measurement with the oscilloscope, the output signal of the micro, here, the digital output signal of phase 1.

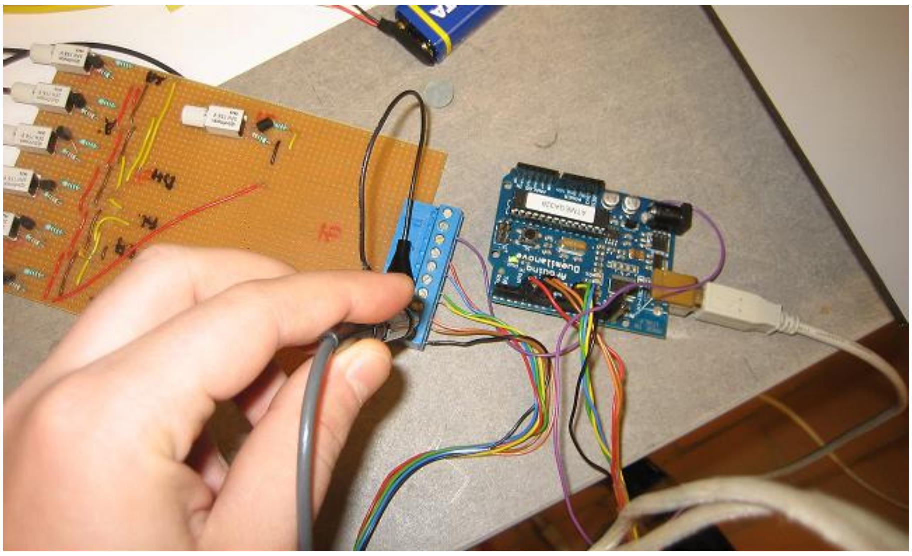


Figure 24. Phase 1 output signal.

In this picture, it is showed the power-board with all its elements.

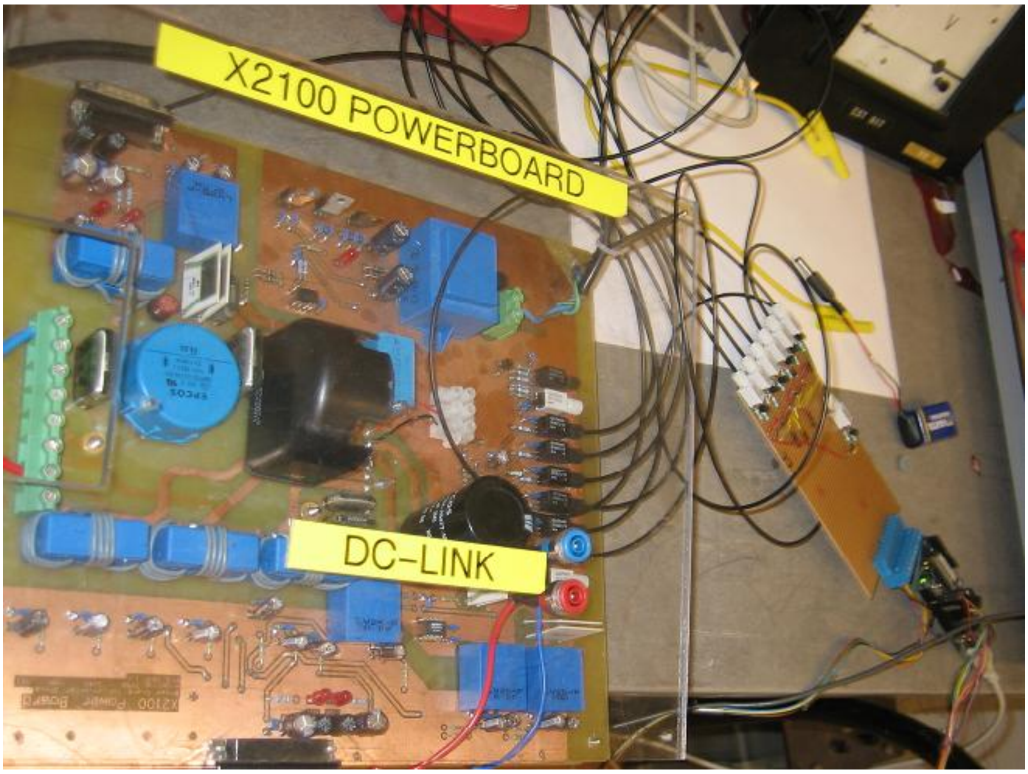


Figure 25. Power board.

Below, the different signals obtained in the laboratory. That logical signal is my theoretical sinusoidal refrence voltage.

Figure 26. Logical signal that I have obtained in the laboratory.

In this picture, the time of logical 1st signal is appropriate to adjusted duty cycle. I see that the time of pulse is the same, but setting of duty cycles differs for every phase. This graph can be compared with the one that has been showed before.

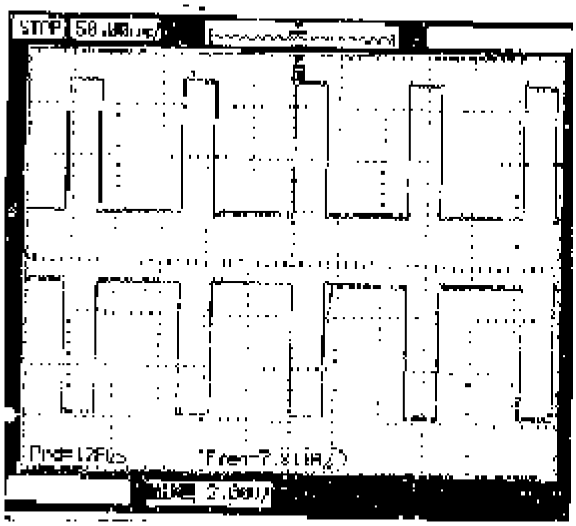


Figure 27. First logical signal.

2.2.2. Straight from microcomputer outputs.

Below in the next pictures, I show the different signals. Firstly, I have to adjust microcomputer to generate signals and I have to use time delay between the generating of the new cycle, with time delay I observe in the oscilloscope that duty cycle is changing in one period as the signal is increasing, and after that, the signal is decreasing.

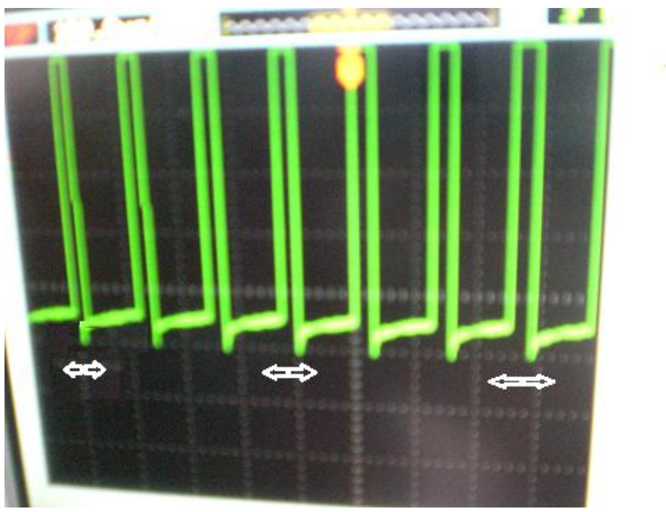


Figure 28. The duty cycle is increasing in one period.

Figure 29. The duty cycle is decreasing in one period.

The dead time was not calculated, but it was explaine in the PWM theory.

<u>3. Conclusion</u>

The conclusion of this part is that the graphs after the micro shows outputs optical signals with time delay and in these signals are increasing duty cycle at the beginning and these signals are decreasing duty cycle to end in one period, in this case observe that the results obtained in the practical part match the results I had to get a theoretical part.

In my case, as it was explained above, the power board did not work correctly. So, what it is wrong with the power board, is that I could not measure the output of the power board, because the range of my signal is from 0 to 5 V, so this range is not big enough to generate the harmonics.

6. Conclusion.

The project, that I explained in the whole report was a complex study during the last 3 months.

I have had some problems like the comprehension of some objectives, and the performance some components like the Labview, the Arduino program and the powerboard. Moreover, the achieved results in theory didn't allow me to work in the laboratory, because in the case of the filter, I should have used a higher value of inductance as I calculated. With the power board, I could not also obtain the output signal, because of the bad performance of the power board in low frequencies and low voltage. The induction machine, as it is a new machine, has also given me a lot of problems during testing. Due to all those inconvenients, I could not finish the main aim of the project, the connection to the grid using the transformator.

I have had problems with time. To know the right values of the equivalent circuit took me a long time, due to I did not have the exact results to compare to, no references.

One of the main problems was the English language. Although, that problem helped me to make a bigger effort, so I improved my English.

My perspective in this project would be to connect the different parts all together, and get the right results in laboratory. I knew that I did not have enough time to study the transformer, because the teacher told me this at the beginning of the project. So I don't know if my wind mill model works in the right way.

I thank the help that I have recieved from teachers.

7. List of lecture.

1. Books.

- [Fundamentals of Electric circuits, 2nd edit, Ch.K. Alexander, M.N.O SAdiku.]
- [Modern Control systems, 11th edit R.C. Dorf R.H. Bishop]
- [Principles of Electric Machines and Power electronics 2nd edition PC Sen]
- [Electrical Machines, drives, and power systems, 6th edition, Theodore Wildi]
- [Grid integration of Wind Energy conversion systems 2nd edition, John Wiley & Sons,Ltd]
- [Wind Energy Systems for Electric Power Generation. Manfred Stiebler (2008). Springer-Verlag Berlin Heidelberg.]

2. Websites.

- http://biblioteca.uns.edu.pe/saladocentes/archivoz/curzoz/Form.%20M%E1quinas%20Asincronas.pdf
- http://rabfis15.uco.es/lvct/tutorial/41/tema19/tema19-4.htm
- http://www.scribd.com/doc/305836/maquinas-electricas-la-maquina-y-el-motor-induccion-trifasico
- http://www.arduino.cc/es/

8. Time schedule & working plans.

1) Introduction

Making a planning was new for me. I have had some problems. Nevertheless, I knew a plannification software that has helped me a little bit: Ganttproject.

2) Divided the work

Firstly, I have divided the work in four parts:

- Induction machine
- AC-to-DC converter & DC link
- PWM = DC-to-AC
- Labview & microcontroller

3) Meetings:

- Supervisor meetings: one times per weeks. I sent an mail at the supervisor to decide the hour for the next meeting.

And during the meetings:

- searching and studying about topics
- making some measurement
- deciding the task for the next meeting

We have devided the project in three parts:

- Theoritical : I study the information about induction machine, converters and transformer
- Practical: to make measurements to find values and compare with theoritical.
- Report

4) PLANNING:

Appendixe2: Planning

To start the project, I have used some litterature:

- Electrical and wind mill books.

- Website of wind mill companies.

And I used my courses like CES, PEM and PRW.

- Softwares : labview , feedback, P-spice , Ganttproject

9. List of symbols.

B: density of magnetic flux

C: capacitor

D=Duty cycle

E_r: induced voltage on the rotor

f_s: Synchronous frequency

f_2: Rotor frequency

f_{dc}: Frequency for dc voltage

H(jaw):transfer function

J:Inertia

L=inductor value

m:weight

m_a:coefficient of the depth of the modulation

m_f:frequency ratio between of triangular
switching signal and desired control frequency

n:asynchronous speed

n_m:rotor speed

n_{sync}:synchronous speed

p: number of poles

P_{mech}:Mechanical Power

P_{shaft}:power on the shaft

P_{ag}: Air gap power

P_{el}:input power

P_{cu1}: lost power on the cupper stator

P_{cu2}: lost power on the cupper rotor

P_{sc}:

R_{tjc}:thermal resistance case mounting surface

R_{tcs}:thermal resistance junction

Rt_{ss} :thermal resistance between the plate during the cooling bridge

R_2:rotor winding resistance

R_{TH} :Thevenin Resistivity

RLC=low pass filter

R_{eq}: equivalent resistance

R_{sc}: short circuit resistance

r : rate

R_c:the core resistivity

R_1: stator winding resistivity

R:resistance

s: slip of rotor

T_j:max permissible temperature on the diode bridge

T_a:surrounding temperature

t:time

T_i:integral time

t_d:deceleration time

T_d:derivative time

τ= torque

τ_{mech}:Mechanical Torque

w_{mech}:Mechanical Frequency

I_1:stator current

I_{sc}:

Z_{sc}:short circuit impedance

P_f:Power factor

P_0: vacuum power

R_1: stator resistance

I_0: vacuum power

P_{FE}: iron power

E_{ff} :Efficiency

I_{dc}:DC input current for stator

P_{fw}:Friction and wind age power loses

X_1:stator inductance

X_m: magnetism reactance

X_2:rotor inductance

X_{TH}:Thevenin inductance

X_{sc}:short circuit inductance

V_p: primary voltage

V_{ADC}:Voltage on Analog to Digital converter input

V_{dc}:DC input voltage

V_m:max voltage between line to line

V_{A0}:Voltage between A points and 0 point on the inverter circuit

V_{B0}:Voltage between B points and 0 point on the inverter circuit

V_{C0}:Voltage between C points and 0 point on the inverter circuit

V_{AB}:Voltage between A points and B point on the inverter circuit

V_{BC}:Voltage between B points and C point on the inverter circuit

V_{CA}:Voltage between C points and A point on the inverter circuit

V_{in}:input DC Voltage

V_{on}:output AC voltage

V_{eq}: equivalent voltage

V_{TH}:Thevenin equivalent voltage

V_s:secondary voltage

$V_{peak\,rotor}$:Peak voltage at given speed

V_{dc}:DC voltage after the rectifier.

V_{in}:Input voltage at law pass filter.

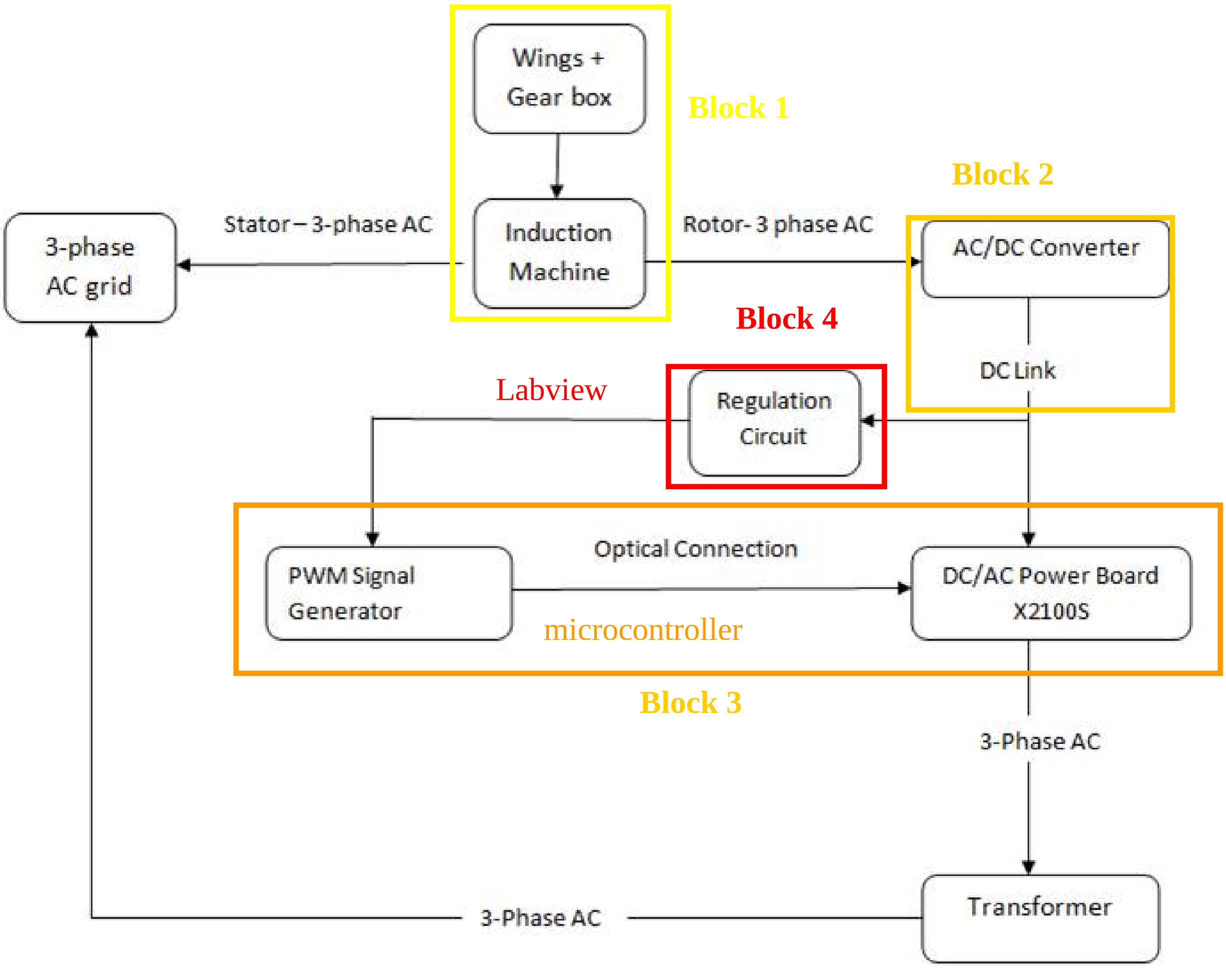
$\overline{Z_1}$:stator impedance

$\overline{Z_2}$:rotor impedance

$\overline{Z_{TH}}$:Thevenin equivalent impedance

10. Project presentation.

This is the base of my project, here, I show the four parts in which the study is divided.

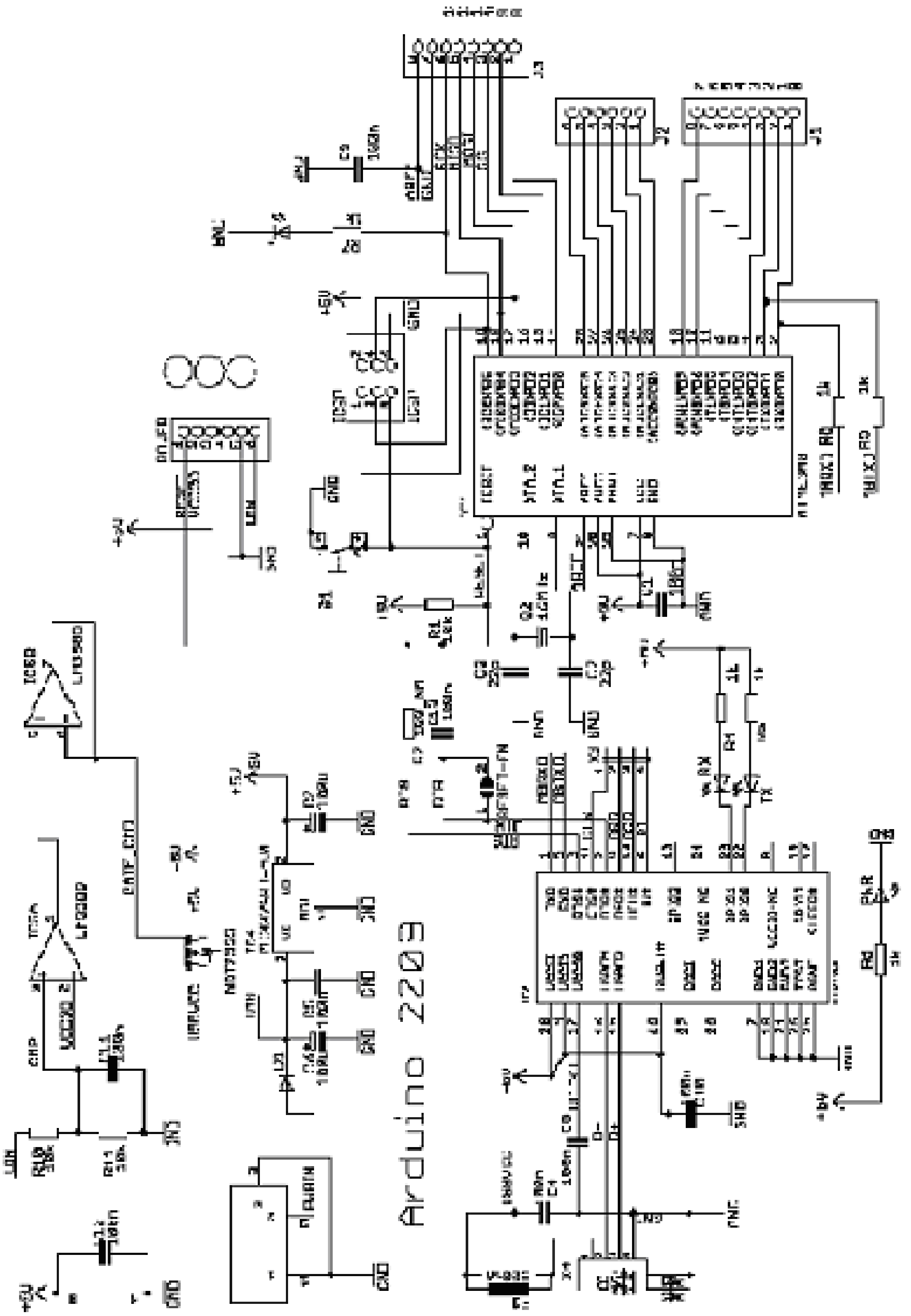


11. Process description.

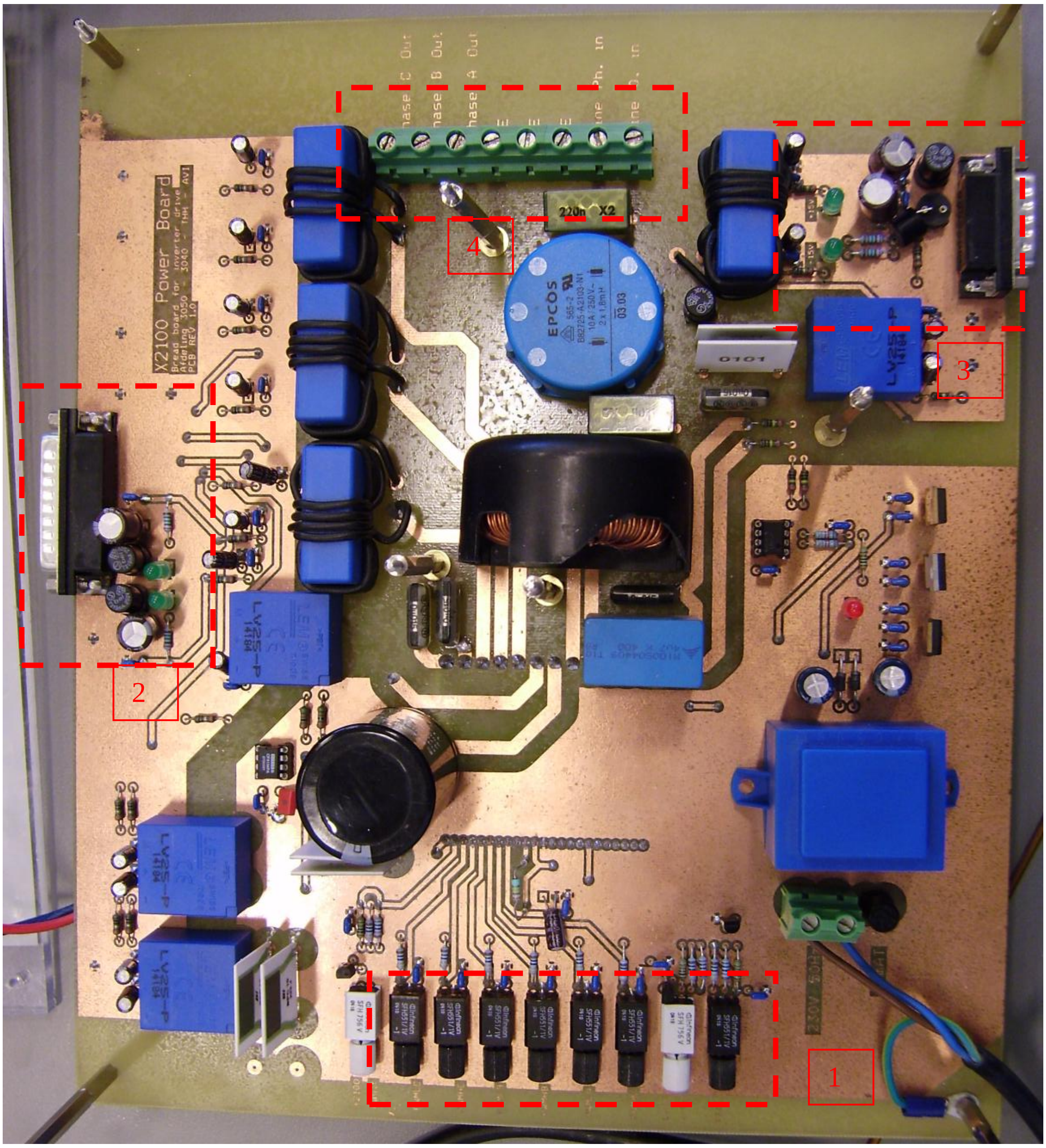
Previously to the hard work, I spent a long time researching information for the project. But it was seen that there were a lot of information. And I decided to split up the project as it is seen in the schema, with its theoretical part, and its calculations. After this step, I decided which schedule should be followed, to work in a faster way. I started with the induction machine, and at the same time, the other small groups worked in their theoretical topics. I passed to the next step ac/dc rectifier, after the report of the induction machines was concluded. After that, I focused on the other steps. One of them, Pulse Width Modulation Inverter regulation circuit and its LabView control system. At the end of the work, the last step was writing the report of the whole project. I separated the report in topics, and then, one person collected all of them, to write the final report in the same format.

The work in this project has given me a deep knowledge in electrical and electronical systems. Furthermore I learned a new learning technic.

12. Appendices.

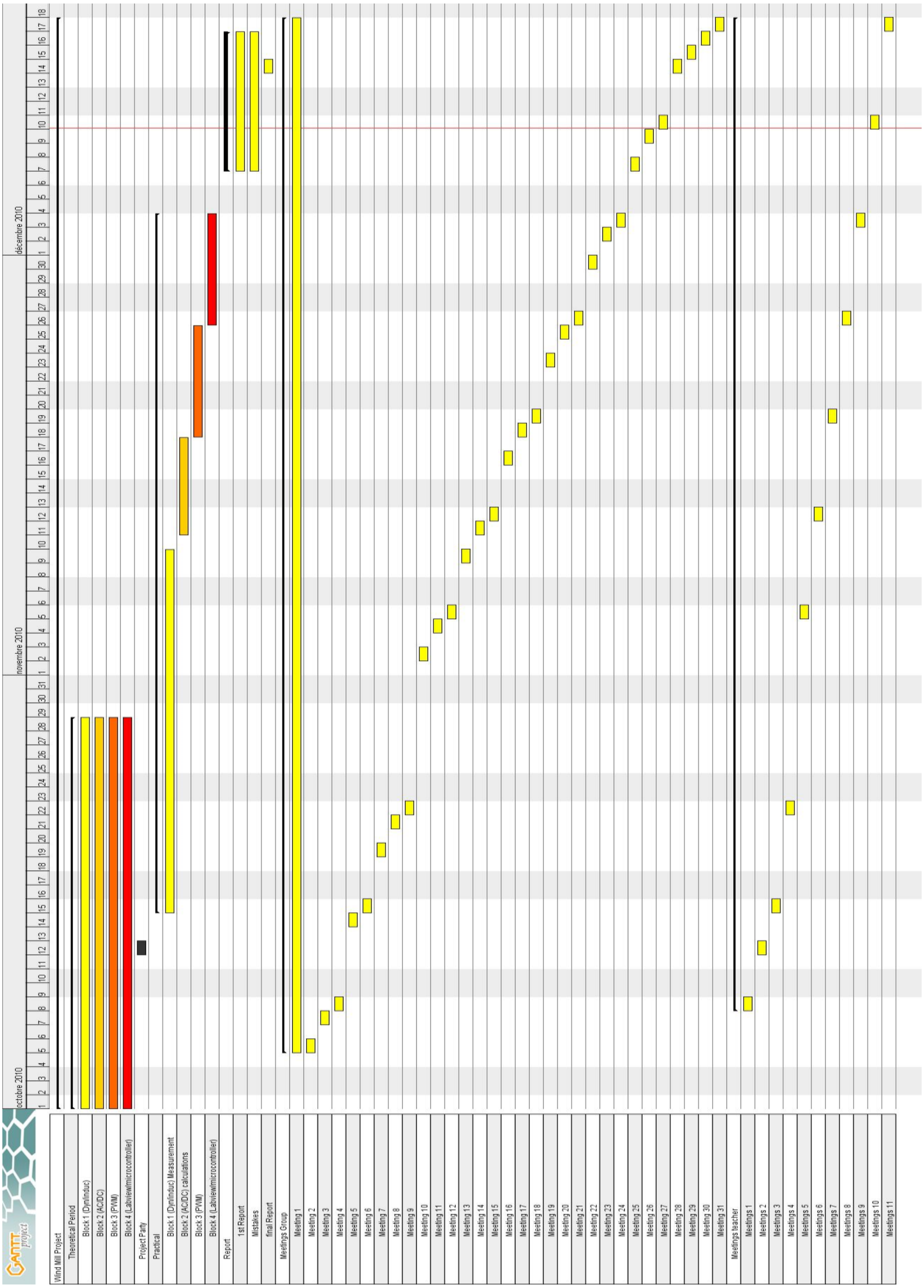


Appendix 1. Schema microcontroller



1: PWM Signals from dspace interface Fiber optical I/O
2: Signals to dspace interface Phase measurement board
3: Signals to dspace interface line measurement board
4: Power to motor

Appendix 2. Schema Power-board



Appendixe 2: Planning

UNIVERSITY OF SOUTHERN DENMARK