

**LAPPEENRANTA UNIVERSITY OF TECHNOLOGY**

LUT Energy

**REPORT OF THE MASTER'S THESIS**

**"The Design of a DC to AC Mains Converter's Pulse Density Modulated Endstage  
and its Prototype"**

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## TABLE OF CONTENTS

Abstract.....	1
Introduction.....	1
Aim of the project.....	2
Principle of the device .....	2
The cycloconverter .....	3
Simulation.....	4
The prototype.....	5
Conclusions.....	7
References.....	8

## **Abstract**

The device presented in this thesis is a part of a DC-AC converter, which is used to transform 750 VDC to a single phase (230 V<sub>RMS</sub>, 50 Hz) mains voltage with galvanic isolation. The DC voltage is converted to high frequency AC voltage using a resonance converter and fed to an isolation transformer. After galvanic separation, the HFAC voltage is converted to mains voltage using a cycloconverter presented in this thesis.

The design is aimed to minimize losses, so the device would be competitive with non-separating converters. This is done by minimizing the amount of components on the current path and by using soft switching in all cases.

Finally, a prototype is introduced, which was build to see the real functioning and problems of the design.

## **Introduction**

In scattered settlement areas the costs of electrical distribution can be decreased by using the biggest DC voltage for distribution as the EU low voltage directive allows. This is based on the fact that the distribution losses are decreased and a smaller amount of distribution transformers is needed. As the DC voltage is set on the highest level, which the regulations and the cable insulations allow, it is possible to have a much longer distance between user and distribution transformer than in a normal 400 VAC distribution system. Finally the DC voltage is converted into 50 Hz AC voltage at each user with a DC-AC converter. The DC system has many problems with security, which are most easily solved by using galvanic separation between user and the DC voltage network.

The thesis was based on an earlier bachelor's thesis (Karttunen et. al. 2009), which introduced a DC-AC converter with galvanic separation. The secondary voltage of the converter was transformed into 50 Hz mains voltage using a cycloconverter modulated with pulse density modulation (PDM). The aim for this thesis was to design and optimize such a cycloconverter and to build a prototype of it.

### **Aim of the project**

Converters with galvanic separation usually have a DC voltage stage after the transformer. This voltage is again transformed into 50 Hz mains voltage by using a converter, modulated with pulse width modulation (PWM). The disadvantage of this topology is the hard switching of the power stage transistors. This leads to switching losses, RF noise and increase of cooling demand. The thesis searches for possibilities to realize a converter which converts the secondary voltage of the insulation transformer directly to AC mains voltage. The modulation method used is pulse density modulation.

The advantages of this topology are the absence of the DC middle stage and reduction of switching losses. The topology however is new, hard to control and there existed very little research information of it. Even though the main topology of the converter is simple, a working control of it is difficult to realize because of a big amount of variables and the speed and accuracy demands.

The biggest problems and challenges of the topology are found out and tried to be solved in the most efficient way. A prototype was also designed and built to find real problems that could not be found on simulations. The design of the transformer is presented more exactly in another thesis (Juntunen 2010).

### **Principle of the device**

The whole converter is a system, in which the DC voltage of the distribution network is converted in high frequency AC voltage. This is done by a resonance converter, which creates 100 kHz AC voltage with an amplitude of 470 V. The resonance converter is operated with soft switching, using the zero voltage switching principle (ZVS). The output voltage of the resonance converter is fed to an insulation transformer, which serves for galvanic separation. The transformer again feeds the cycloconverter coupled to the secondary side of the transformer. The task of the cycloconverter is to choose positive and negative half waves from the transformer to the output. The output voltage is filtered with a low pass filter. In this way the high frequency from the transformer is converted directly to 50 Hz mains voltage. The maximum power of the converter was aimed to be 1 kVA. The principle of the converter is shown in figure 1.

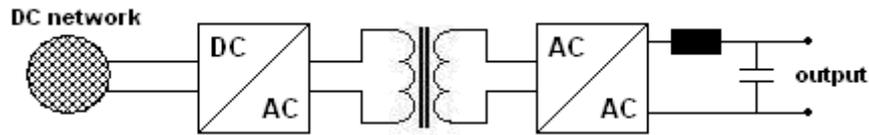


Figure 1. Principle of the whole DC-AC converter.

### The cycloconverter

A cycloconverter is a device that transforms a frequency to a lower number. In this case it was done by choosing half voltage waves from the transformer and coupling these to the output to form a pulse chain. The switching is tried to be done always at zero voltage, so the switching losses are minimized. Using pulse density modulation (PDM) the pulse chain can form a 50 Hz voltage, when it is low pass filtered.

The modulator compares the output voltage of the converter to a reference voltage. If the output is too low, it chooses positive pulses. If the output is too high, It chooses negative pulses or leaves the output in a freewheeling state.

The converter was designed to be able to unipolar and bipolar operation. In bipolar operation the output is feeding a pulse all the time. This means that the transformer is always coupled to the output. In unipolar mode the output can be left in freewheeling state for a certain time. In the unipolar case there has to be a way for the possible inductive current. The circuit of the cycloconverter with its current paths is presented in figure 2.

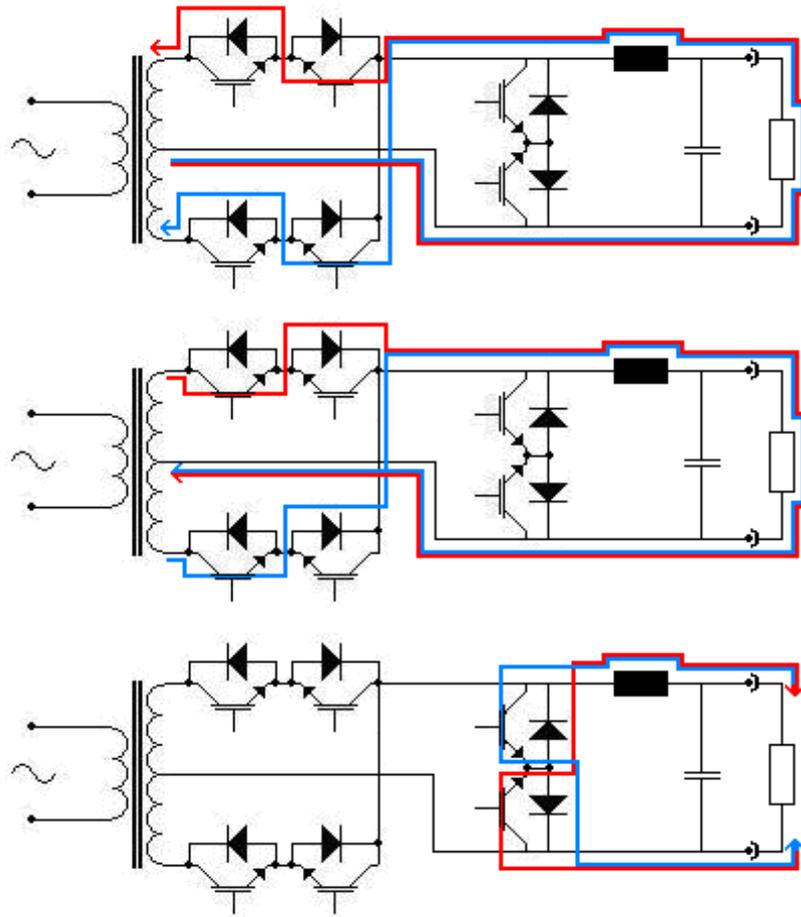


Figure 2. The circuit and current paths of the cycloconverter.

### Simulation

The simulation model was completed as a well working system. It was capable to produce a low distorted sine wave with all loads and power factors. The output voltage of the simulation model is shown in figure 3.

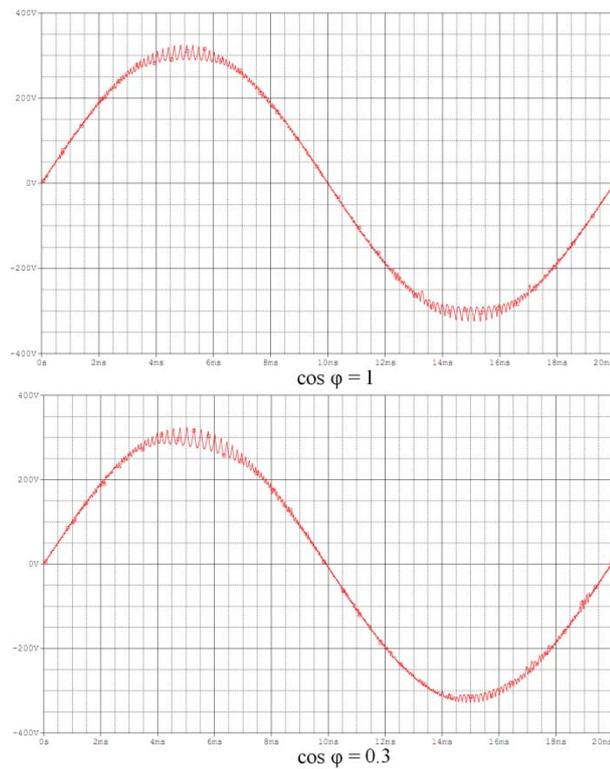


Figure 3. The output voltage of the simulation model with 1 kVA load and power factors of 1 and 0,3.

### The prototype

After the simulation model seemed to work stable and robust with all loads, it seemed to be possible to build a working prototype. The prototype was carried out with the same circuitry and component values as the simulation model. Even though it supposed to be an identical system, its operation differed very much from the simulation model. Especially the resonance converter behaved very unstable, and the output voltage was quite chaotic. The secondary voltage is shown in figure 4 (at 270 VDC input).

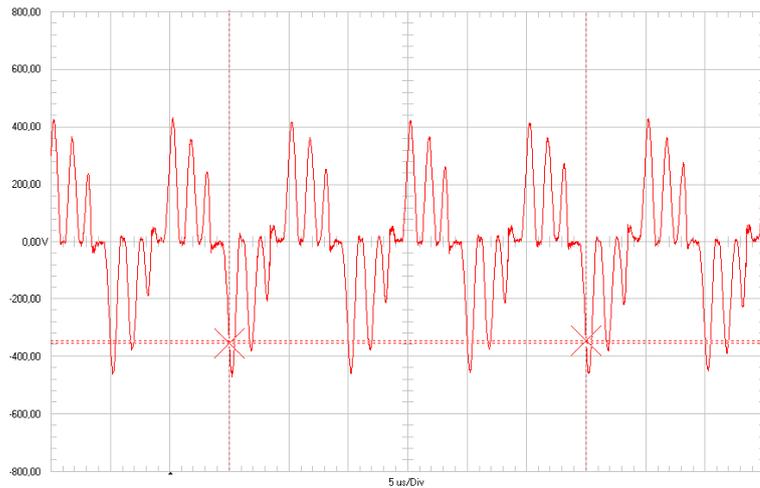


Figure 4. The secondary voltage of the transformer.

Because of the randomly altering voltage it was impossible to do all switching at zero voltage. This resulted in high losses and too low current and voltage output. It also seemed to be impossible to use over 500 VDC input voltages because the resonance converter produced very high voltage peaks which would have destroyed the transistors. In bipolar mode the input voltage could only be 270 VDC. The bipolar mode was therefore not used any further.

Because the input voltage could not be as much as the system was designed for, and because of the random shapes of the secondary voltage half waves, it was impossible to produce the wanted output voltage. Therefore the continuing measurements were done by an output voltage demand of  $120V_{RMS}$ . The output voltage is shown in figure 5.

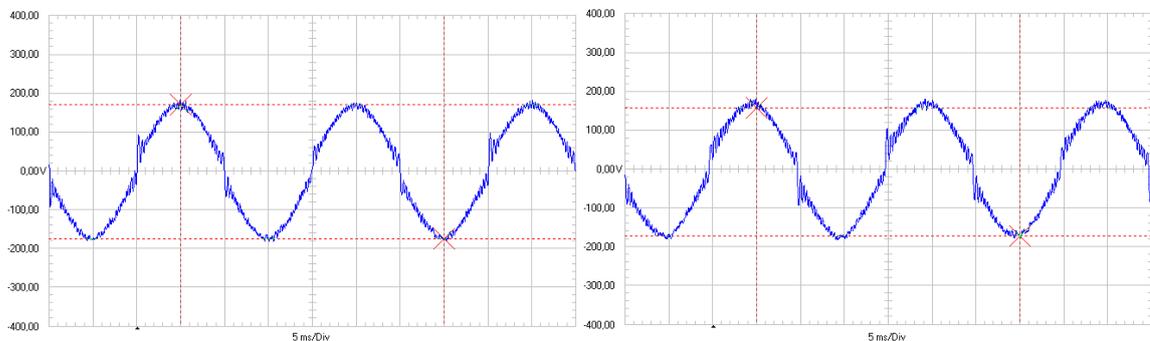


Figure 5. Output voltage in unipolar mode,  $120V_{RMS}$  demand, 50 VA, Power factor 1 (right) and 0,3.

The maximum output power which the converter could produce without problems was 50 VA. If the load was bigger, the maximum voltage became less than 120 V which lead the sine wave to clip. The increase of the input voltage on the other hand would have lead to high voltage peaks and ruining of the transistors. Because of this the measurements at higher power were impossible.

## **Conclusions**

The topology of the earlier project was changed to operate better also with reactive loads. A simulation model of the converter was created to find possible problems and challenges. In the end the simulation model was working well in all circumstances and according to the result, it should have been possible to build a well working prototype.

However, the results of the prototype differed very much from the results of the simulation model. Unfortunately the topology which worked very well in simulation appeared to be very unable to produce the wanted voltage and current.

The simulation model was assumed to include all disadvantages and faults of the topology and components, but still it appeared to differ very much from the real model. Especially the unstable behavior of the resonance converter was unexpected. In the end this ruined the operation of the whole system, and resulted in a bad efficiency and lack of voltage and current output. The disadvantages of all components should have been taken better into account in the simulation model. Because of this the reasons for the unstable behavior of the resonance converter were not discovered. The resonance converter itself was also not a part of the thesis, so it was researched only slightly.

The cycloconverter itself worked as planned. It was possible to pick 5  $\mu\text{s}$  long half waves from the transformer to the output. Because of the random behavior of the secondary voltage the switching was done partly hard though. This resulted in big switching losses and lack of voltage and current output. The unipolar control of the cycloconverter worked much better than the bipolar control. The output voltage had smaller losses, distortion and voltage peaks. The freewheeling unit worked without problems and big losses. Because of

the random voltage behavior it was also necessary to use TVS protectors with the secondary switches.

It is possible that the topology presented in the thesis is not a reasonable option in reality. The co-operation of the resonance converter and the cycloconverter is a very challenging task. Realizing this as a real and robust system has many difficulties. A possible alternative for this topology would be the option to use a DC middle stage and a PWM converter. This would have the disadvantage of hard switching losses, but it is easier to control. Much of research information is also already available for this topology.

## References

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