Design and Implementation of a Modular Multilevel Converter

ECE 4600 Progress Report

Group 02

Members:
Joel Taylor
Jesse Doerksen

Supervising Professor:
Dr. Shaahin Filizadeh

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1. Introduction

The objective of our project is to design and implement a single phase modular multilevel converter using power MOSFETS as switches. Our MMC design is made up of 21 levels, each level containing two submodules. These levels will be stacked together in series to create our converter. We will be operating our converter from 60VAC and 200VDC. Our project is divided up into three main sections, research and mathematical analysis, simulation using PSCAD and design and implementation of hardware. Our project is progressing on time and we have completed the first two major sections. We are currently working on the physical hardware design on the project.

2. Progress Summary

One of the major parts of our project was selecting a suitable number of levels for our MMC. We decided to use 21 levels for multiple reasons. The first reason being that using 21 levels produces voltage levels within our 5% total harmonic distortion. This was a requirement that we placed on ourselves at the beginning of the project. The second reason for using 21 levels was to obtain our secondary voltage level high enough to meet the ratings of our transformer. We performed these calculations using MATLAB SIMULINK, a software tool that we have learned to use throughout our studies and summer work.

One of the problems that we encountered was finding a transformer for the AC side of conversion. This transformer will be used to step down 120VAC to around 60-70V, a voltage that can be used with our converter. We were looking at a 300 VA, 120V/60V transformer from Digi-Key which would work well with the 21 level MMC we originally planned and could meet our power rating specification of 250 VA. The problem with this transformer is that if we use it we will require our submodules to have larger capacitors which are more expensive and the transformer itself is also expensive. Our initial solution to this problem was to instead use a transformer in the lab that would require lower capacitor values and save us money by not having to buy a transformer. We did not want to use the transformer from the lab because it is a three-phase transformer that we would have to put in parallel, the secondary voltage will be 69 V which forces us to increase the number of levels to 23, and the transformer has high power loss. Also the power rating will be about 140 VA which is less than our specified 250 VA. We then
met with Dr. Filizadeh to discuss our dilemma and he pointed out to us that we could use an inductor instead of a transformer. We decided to take his advice and use an inductor because we then did not have to meet the power rating of the inductor therefore having less constraints on our project. Now we can use 21 levels for our MMC with an AC voltage supply of 60V.

Another problem that we have encountered is the RTDS GTA1 card. We are using the RTDS to control and to plot the real time performance of our converter. The GTA1 card is the input card that we plan to use, only has 12 inputs and the university only has two cards which is a total of 24 inputs. This is a problem because we need two inputs per level. Since our MMC has 21 levels we require 44 inputs. We talked with Dr. Filizadeh about this problem as well and decided that we would ask RTDS Technologies to borrow two GTA1 cards.

We also encountered a problem with obtaining an adequate DC power supply. The DC power supply in the LabVolt setup could supply up to 120V. We required 200V for the 21 level MMC. We considered purchasing a larger power supply but they were very expensive. Dr. Filizadeh told us about a DC power supply in the power lab that could supply up to 250V. We decided that we would use this power supply. The only complication with using this power supply is that it is not movable. This means we will have to run our MMC in the power lab close to this power supply.

Before ordering a large number of our power MOSFETS we ordered 25 of them in order to perform testing on them to make sure they were exactly what we needed. These switches worked to our desired specifications, so we started looking for the rest of the components that we needed for our design. When it came time to ordering all the components our original power MOSFETS were discontinued. This meant that we had to find a replacement switch for our project. We were able to find a very similar switch from the same manufacturer that will also meet our specifications. The only disadvantage to the new power MOSFET is that it is slightly more expensive.

Jesse Doerksen did not have to do much research since he had previous knowledge of MMC from summer work. He created a Simulink case to calculate the total harmonic distortion (THD) and RMS of the secondary voltage depending on the number of levels in the MMC. It was found that the minimum number of levels to meet the specification THD less than 5% is 17
levels. Twenty one levels were chosen for the design, which corresponds to a maximum RMS voltage of 71 V. Jesse Doerksen created a simulation case in PSCAD for a single phase 21 level MMC rated for 250 VA. The transformer winding voltage ratings were set to 120/60 V. An open loop control system was used to see if the values of the components would work. Everything seemed to work fine. After discovering the problem with the transformer, the simulation case was changed to work for a 140 VA, 120/69 V transformer. This MMC has 23 levels. This system works well in the open loop configuration, the transient response of the active power for a step in phase angle is very good. A closed loop control system was made, but the transient response was much slower. It was difficult to tune this controller to make it stable. After deciding to use a single inductor instead of a transformer, the simulation needed to be changed again. Jesse Doerksen went into the 21 level MMC case and replaced the transformer with an appropriate value of inductor, and changed the voltage of the AC power supply to 60 V. The system was tested to make sure the control system was working.

The work preformed by Joel Taylor included a great deal of the research on MMC. He was responsible for looking up the current methods of conversion as well as how MMC conversion works. In addition to research Joel Taylor was largely responsibly for putting together the documentation for the project. This includes putting together documents for the proposal and written report, formatting these documents, and proofreading them and making appropriate changes. The majority of the simulation work that is now finished was assigned to Jesse Doerksen because his job in the past summer was working with the software that we used. Joel Taylor’s main focus for the project is documentation and hardware design and implementation. Now that the simulations are completed Joel Taylor will begin to build the MMC as described in the future work section.

3. Future Work

The future work involves the integration and testing of the hardware. The submodules will be assembled on breadboards. Each submodule will consist of two MOSFET switches and one capacitor. A resistive divider will be used to help measure the capacitor voltage level. The gates of the switches will be connected to MOSFET gate drivers. We will need a lot of breadboard space to assemble the entire 21 levels. A single phase of a 21 level MMC consists of 80 MOSFET switches and 40 capacitors, and the resistors and gate drivers are needed as well.
We will place as many submodules as we can fit on one breadboard, then keep repeating the same design.

The input lines of the gate drivers will be connected to a GTDO card on the RTDS. Four GTAI cards will be used to read the capacitor voltages from the resistive dividers, as well as the multivalve current. The resistive dividers are used to scale the voltage so that it is within the ratings of the GTAI card.

The control system software will be implemented in RSCAD. RSCAD is software used to program the RTDS system. The nearest level control, NLC, and balancing control algorithm, BCA, will be created as custom components using the ‘CBuilder’ module in RSCAD.

When the hardware is assembled and the software is complete, testing can begin. We will start with one breadboard full of submodules for the upper multivalve and an identical breadboard for the lower multivalve. We can test each group of submodules in this configuration and make sure each group works the same way. Then we can put the groups in series to get the full 21 levels.

Initially, the controls available to the user will be the modulation index $m$, and the voltage angle difference across the transformer, $\theta$. These will be used in open loop control as direct inputs to the voltage reference generator. In this control scheme, the reactive power flow is controlled by the modulation index $m$, and the active power flow is controlled by $\theta$.

At this point the system should be able to satisfy the requirement of being able to transmit power in either direction between AC and DC power, performing inversion and rectification, respectively.

The next step is to implement a closed loop control system. This control system will use 2 PI controllers to control $m$ and $\theta$. One PI controller will have input ($Q_{ref} - Q$) and output $m$, the other will have input ($P_{ref} - P$) and output $\theta$. The positive direction of power flow will be from DC to AC, so that $Q > Q_{ref}$ will cause $m$ to decrease, and $P > P_{ref}$ will cause $\theta$ to decrease, which is the proper direction to correct the error.
## Appendix A: Parts Ordered/Received

Parts Ordered and Received

<table>
<thead>
<tr>
<th>Part</th>
<th>Model Number</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power MOSFET</td>
<td>NTD4960N-1GOS-ND</td>
<td>25</td>
<td>$7.99</td>
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<tr>
<td>10kΩ Resistor</td>
<td>S10KQCT-ND</td>
<td>100</td>
<td>$2.61</td>
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Parts Ordered

<table>
<thead>
<tr>
<th>Part</th>
<th>Model Number</th>
<th>Quantity</th>
<th>Price</th>
<th>Delivery Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power MOSFET</td>
<td>NTD4906N-35GOS-ND</td>
<td>100</td>
<td>$38.72</td>
<td>2 Weeks</td>
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<td>4.7mF Capacitor</td>
<td>P5159-ND</td>
<td>50</td>
<td>$56.76</td>
<td>2 Weeks</td>
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<td>Gate Driver</td>
<td>TC4428CPA-ND</td>
<td>50</td>
<td>$49.40</td>
<td>2 Weeks</td>
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<td>3.9mH Inductor</td>
<td>M8384-ND</td>
<td>1</td>
<td>$7.70</td>
<td>2 Weeks</td>
</tr>
<tr>
<td>10mH Inductor</td>
<td>M8386-ND</td>
<td>2</td>
<td>$7.70 each</td>
<td>2 Weeks</td>
</tr>
</tbody>
</table>

Total cost of parts: $178.58