METU Electrical and Electronics Engineering Department

EE463-STATIC POWER CONVERSION I

TERM PROJECT – SIMULATION REPORT

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Introduction

The aim of the term project is designing a DC Motor circuitry that converts AC input voltage to required DC output voltage. In this simulation report, different topologies such as Single Phase Thyristor Rectifier, Three Phase Thyristor Rectifier and Three Phase Diode Rectifier + Buck Converter will be introduced and compared. Their simulation results, advantages and disadvantages will be discussed. According to their comparison, topology selection will be explained. Then, component selection based on thermal situation will be presented for chosen topology.

Theoretical Comparison Of Topologies

	Vout(rms)	THD Of Input Current	Number Of Elements
Single Phase Controlled Rectifier	$\frac{2\sqrt{2}}{\pi}$ *Vin* cosα	48.5 %	4 Thyristors + Gate Driver + Other passive elements
Three Phase Controlled Rectifier	$\frac{3\sqrt{2}}{\pi}$ *Vll* cosα	31 %	6 Thyristors + Gate Driver + Other passive elements
Three Phase Diode Rectifier + (Buck Converter)	$\frac{3\sqrt{2}}{\pi}$ *Vll*D	40 %	7 Diodes + 1 Mosfet + Gate Driver + Other Passive Elements

Table 1: Theoretical Comparison Of Topologies

Three different topologies for AC to DC conversion are presented in table 1. From the average output voltage point of view, Three Phase Diode Rectifier and Three Phase Controlled Rectifier are dominant as compared to Single Phase Controlled Rectifiers. While considering THD of input current, it is obvious that three phase rectifiers have a big advantage compared to single phase rectifiers. Actually, this is the expected result because 3rd order harmonics and its multiples are canceled for three phase rectifiers. On the other hand, control of third topology is much easier as compared to second topology.

Simulation Results

1-) Single Phase Thyristor

In single phase thyristor topology the construction is relatively simpler than the other two topologies but as it can be seen above, THD and ripple values are not very desirable. And there will be a much higher voltage with the three phase applications. Due to these reasons single phase thyristor topology will not be the best choice.

Although this topology will not be used in the project implementation, here are the simulation results of this topology with a RLC filter.

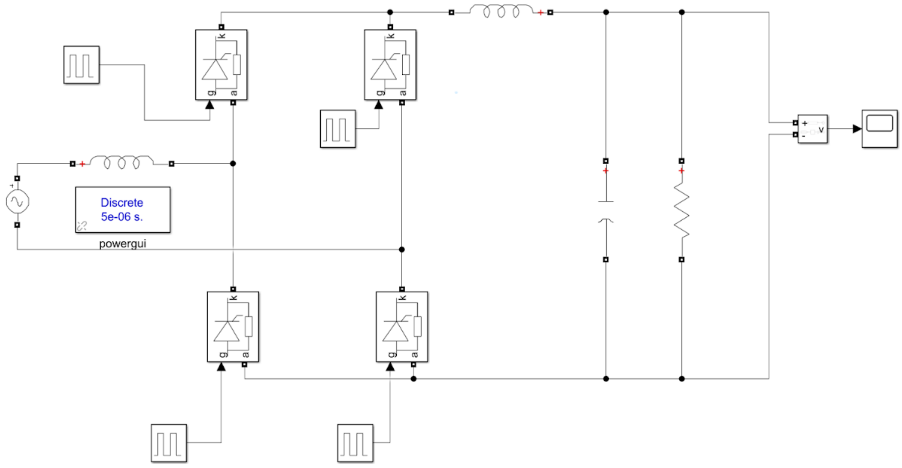

Figure 1: Circuit of the Single Phase Thyristor Rectifier with RLC Filter

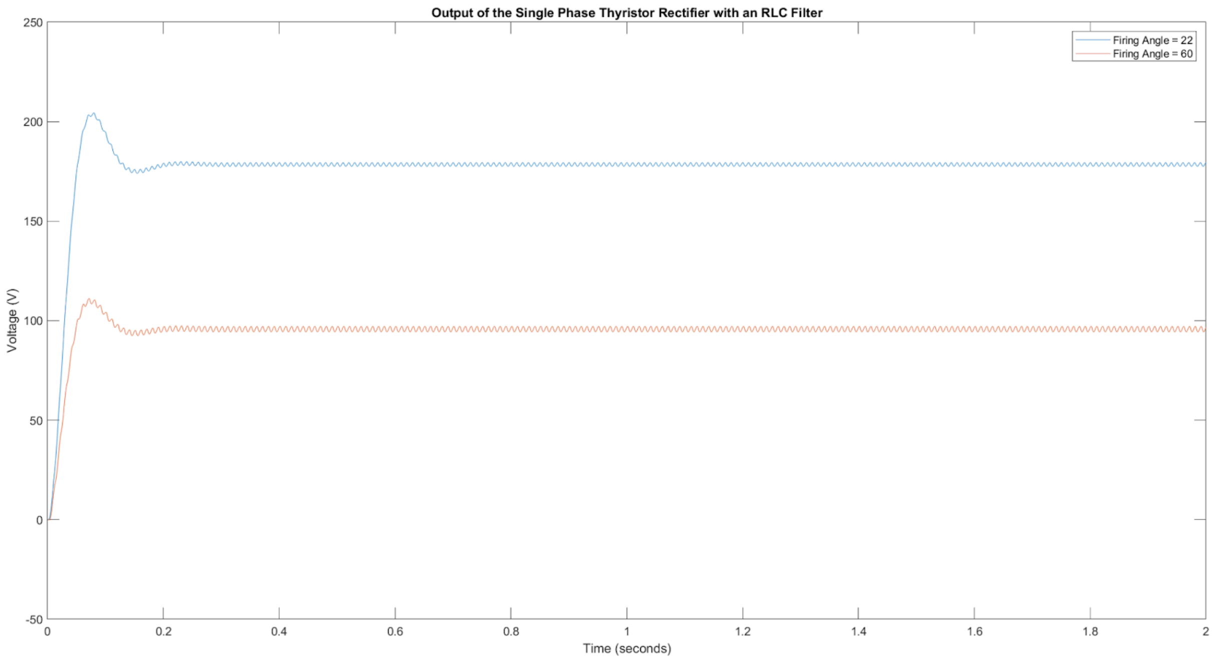

Figure 2: Simulation Result of the Single Phase Thyristor Rectifier with RLC Filter

In this topology, output voltage can be varied by varying the firing angle. At firing angle of 0° it has the maximum voltage (equivalent to a regular diode rectifier), as the firing angle increases output voltage decreases. So in this topology the regulation of the voltage is relatively simpler and it requires less components. Although this topology seems very useful it will not be the best topology since a single phase rectifier introduces more harmonics and there will be unwanted distortions and ripples. And controlling the firing angle very precisely as in simulations is difficult to achieve in real life. In this project, selections are chosen to have an error safe system that can be controlled in a way that we are more knowledgeable.

2-) Three Phase Controlled Rectifier

Three phase thyristor rectifier has a big advantage of THD minimization because of cancellation of 3rd harmonic components. On the other hand, its ripple voltage is very good and small compared to single phase rectifiers. However, it is not small enough as compared to three phase diode rectifier + Buck Converter topology. Moreover, control of the three phase controlled rectifier is complicated and more difficult than three phase diode diode rectifier + Buck Converter.

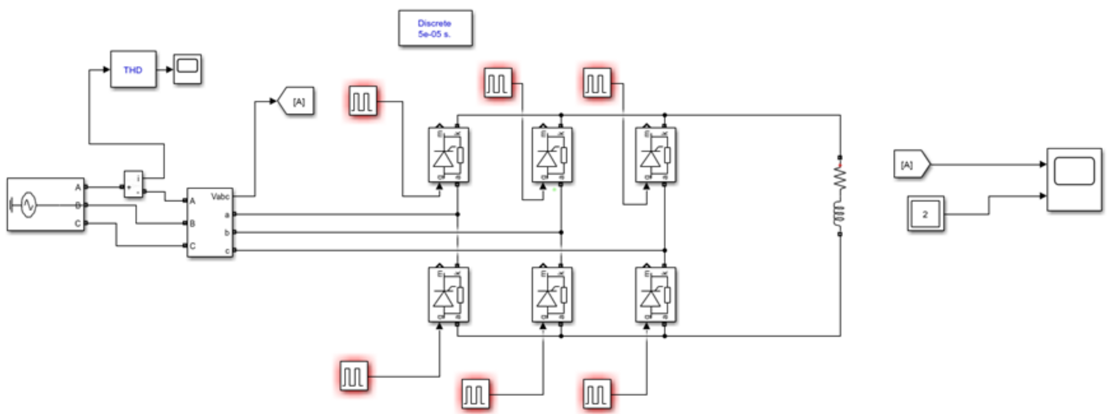

Figure 3: Circuit of the Three Phase Thyristor Rectifier

Here are simulation results of output voltage graphs for different firing angles.

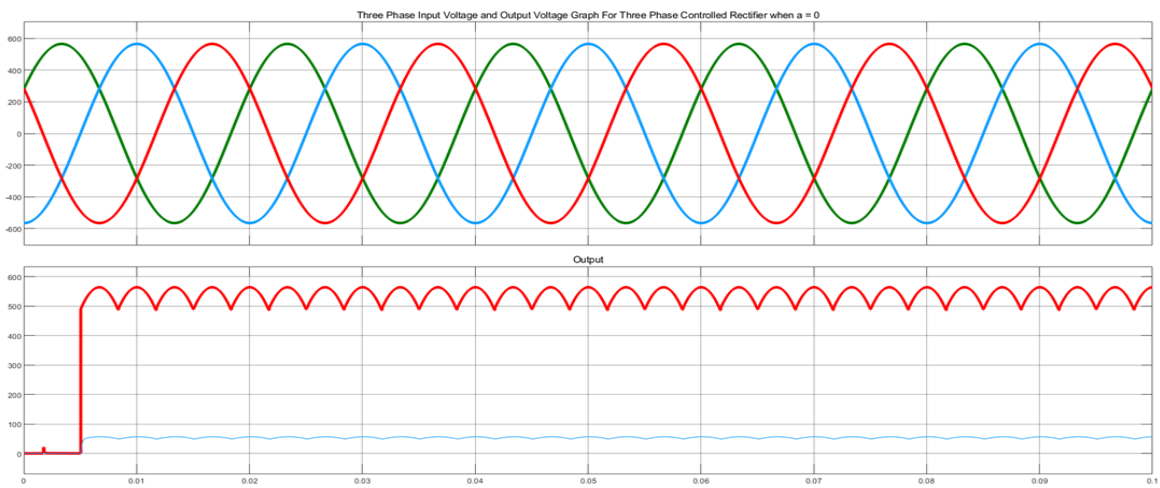

Figure 4: Simulation Result of the Three Phase Thyristor Rectifier Firing Angle =0

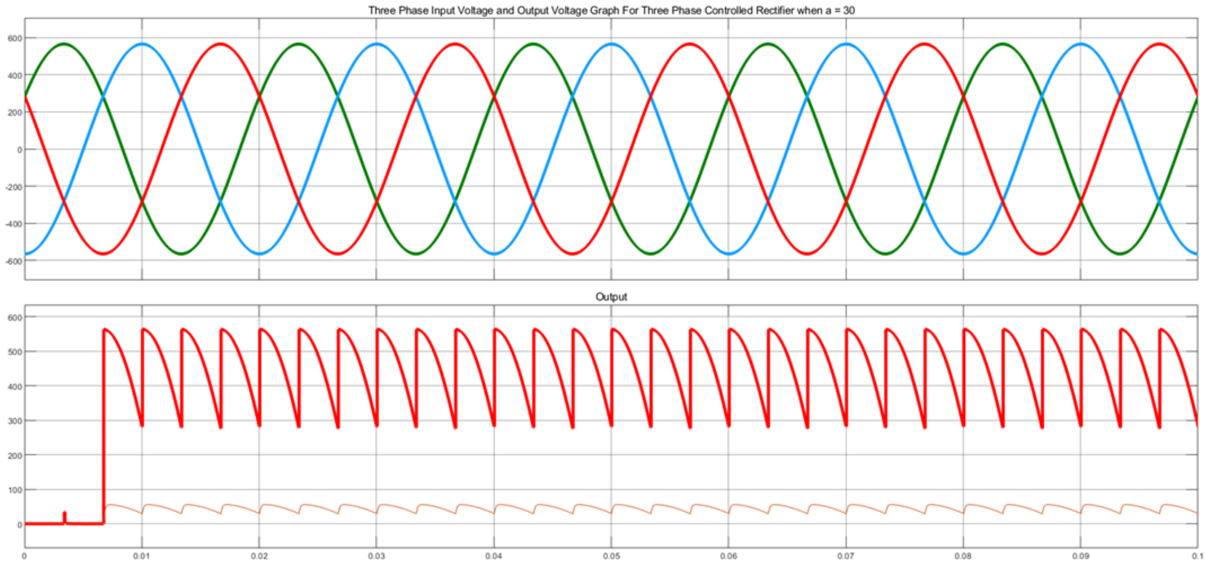

Figure 5: Simulation Result of the Three Phase Thyristor Rectifier Firing Angle =30

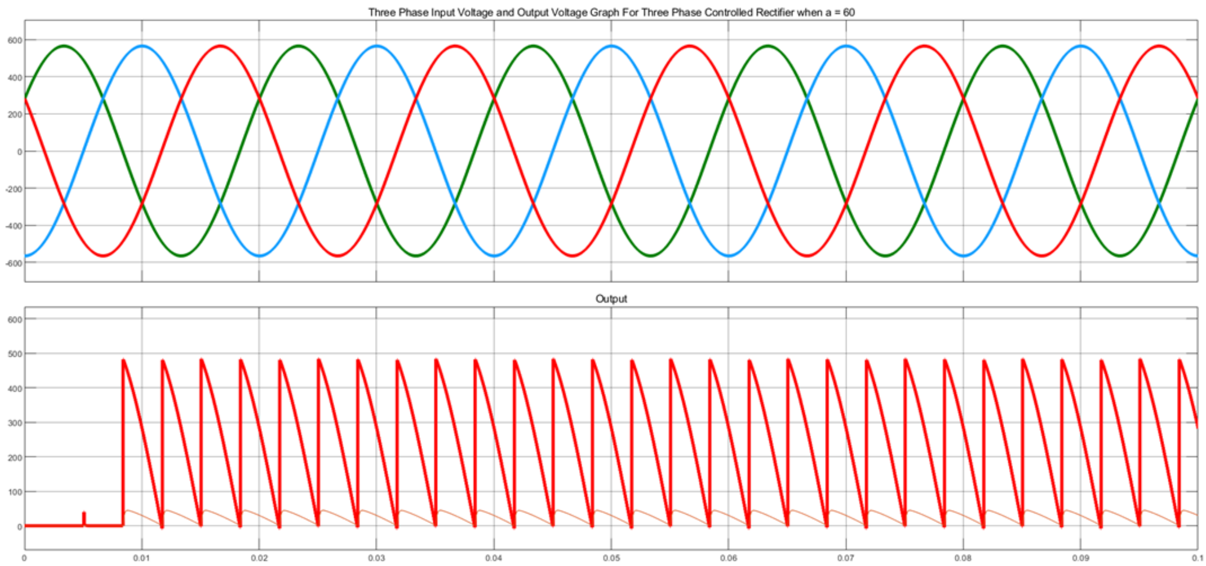

Figure 6: Simulation Result of the Three Phase Thyristor Rectifier Firing Angle =60

For this topology, output voltage can be controlled by adjusting the firing angle. From the simulation graphs, peak of output voltage and average output voltage decreases as firing angle is increased.

Here are the THD graphs for different angles.

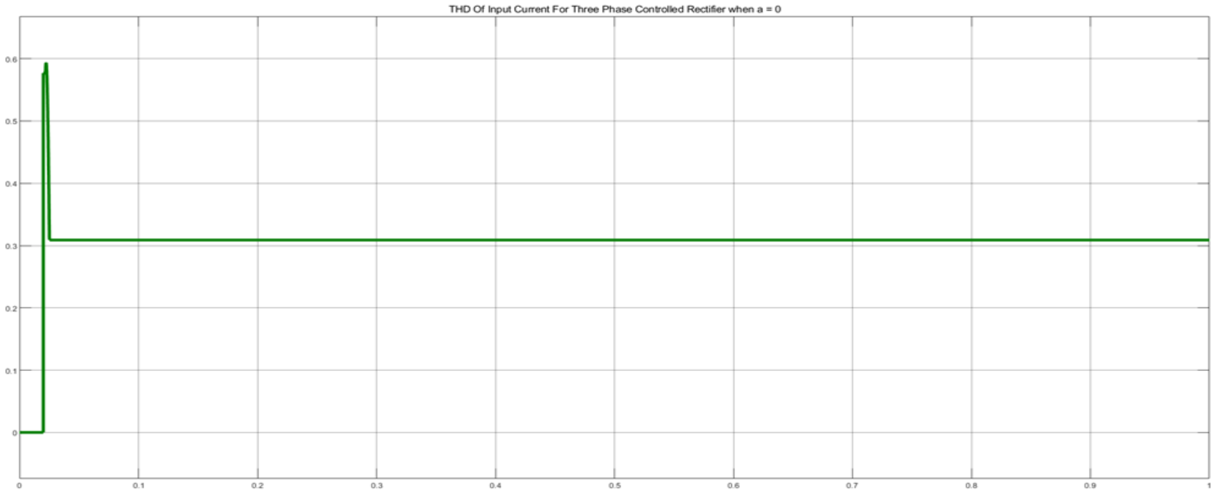

Figure 7: THD of the Three Phase Thyristor Rectifier Firing Angle =0

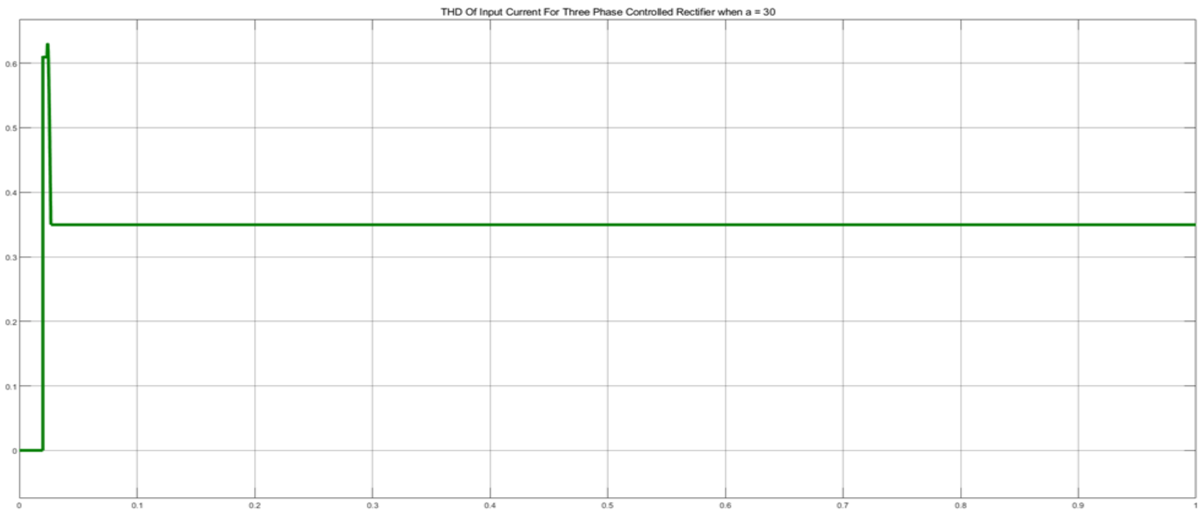

Figure 8: THD of the Three Phase Thyristor Rectifier Firing Angle = 30

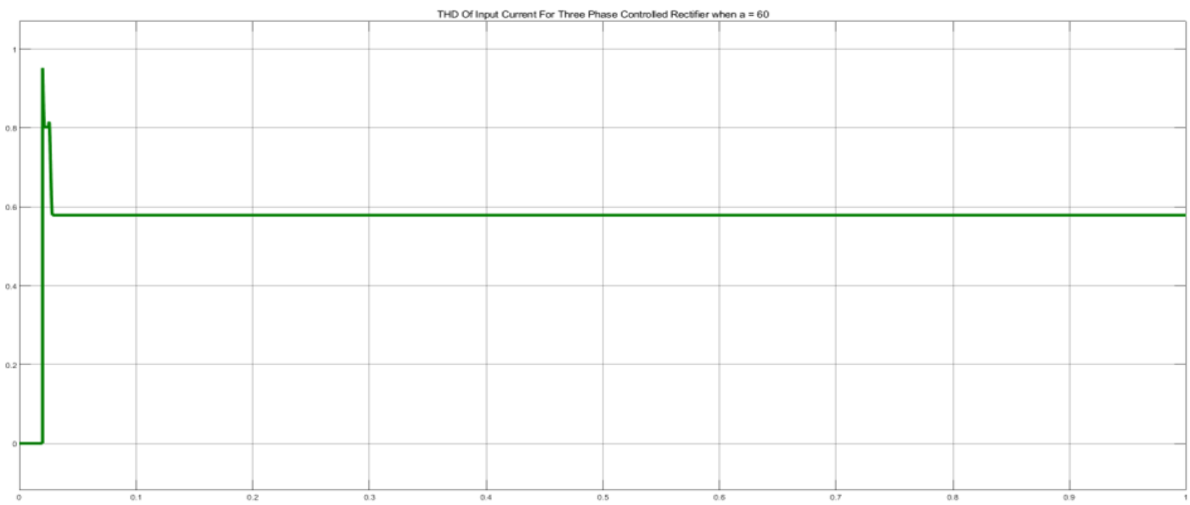

Figure 8: THD of the Three Phase Thyristor Rectifier Firing Angle = 60

It is obvious from the simulation graphs that THD increases as firing angle increases. Although it has a small THD and small ripple voltage, controlling part of it is difficult compared to Buck Converter control. Therefore our choice will be the next topology which is “Three Phase Diode Rectifiers + Buck Converter”.

3 Phase Diode and Buck Converter

In this topology, 3 phase diode rectifier and buck converter topologies are used together. The overall circuit of the system can be seen in Figure X1.

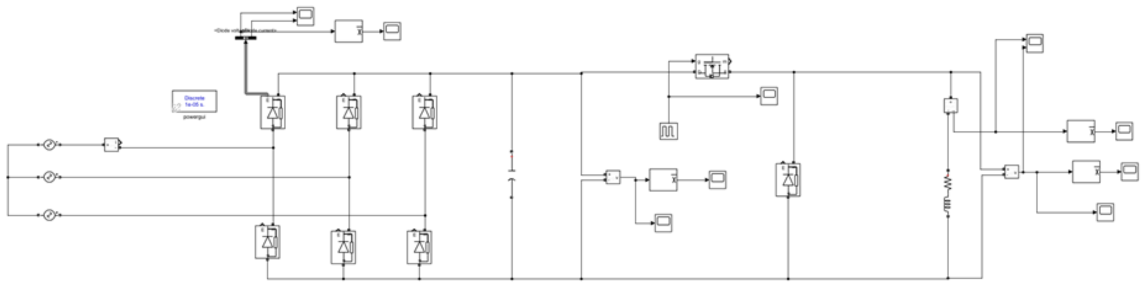

Figure 9: Circuit of the Three Phase Diode Rect + Buck Converter with Motor Model

Three phase diode converts 3 phase AC input to DC output with the help of diodes in each leg of the input. Each phase has a 120 degree phase difference. At the output there is a DC link capacitor that balances instantaneous power variation between input and output. The DC Capacitor output and mean of it can be seen from Figure 9 and 10.

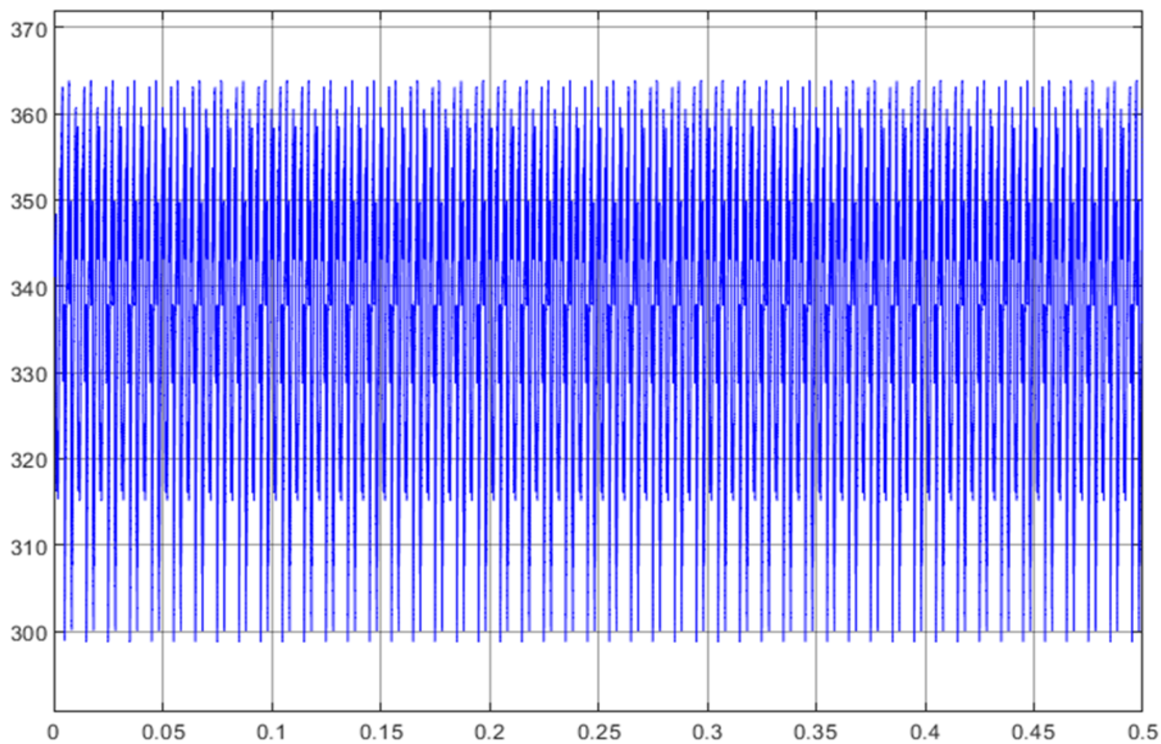

Figure 10: Mean Voltage 3 Phase Diode Rectifier with DC Link Capacitor

The DC link capacitor is connected to a DC/DC converter and the load of the system is a DC motor. DC/DC converter decreases output ripple with help of switching process. MOSFET is opened and closed with 1kHz switching frequency.

A DC Motor can be driven by a square wave and since the mean of this signal and current is important, there is no LC filter at the output. A non-synchronous buck converter topology is used in this design because there is a high voltage application and forward voltage of the diode will be compatible with the MOSFET's body diode. Moreover, control of the non-synchronous buck converter is easier than the synchronous one.

When the motor reaches the steady state, 2kW output power is expected. Since the maximum voltage is 180V, there must be 12A current over output load. The output voltage, mean of output voltage and mean of output current can be seen in Figure 11, 12 and 13 respectively.

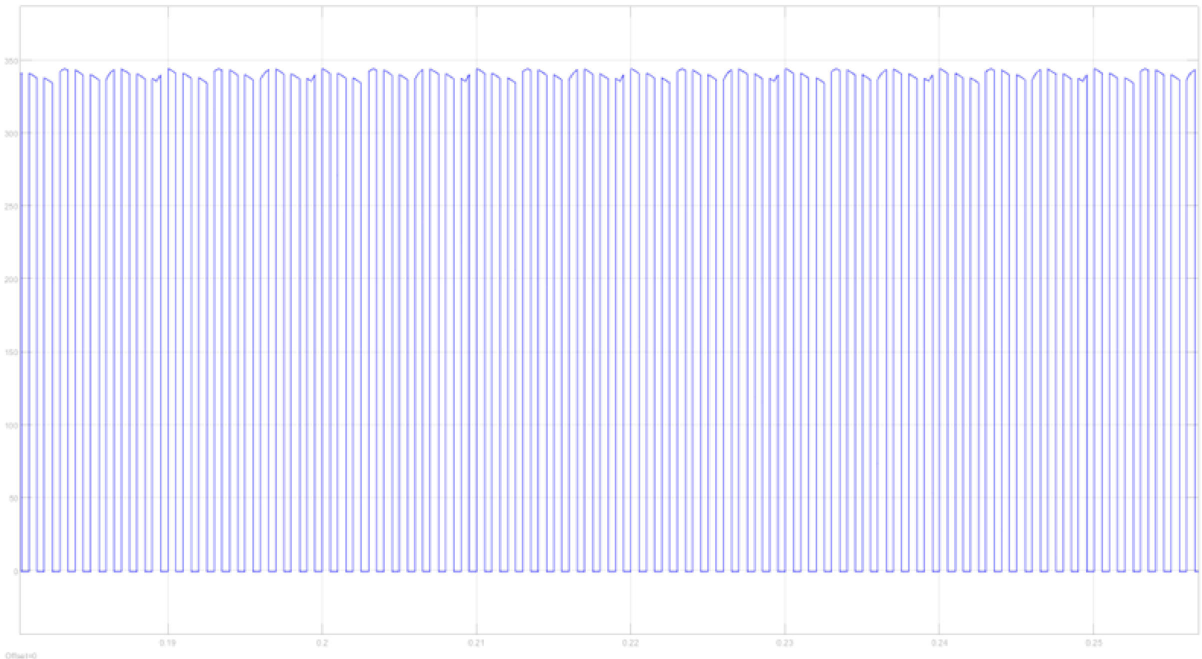

Figure 11 – Output Voltage of Buck Converter

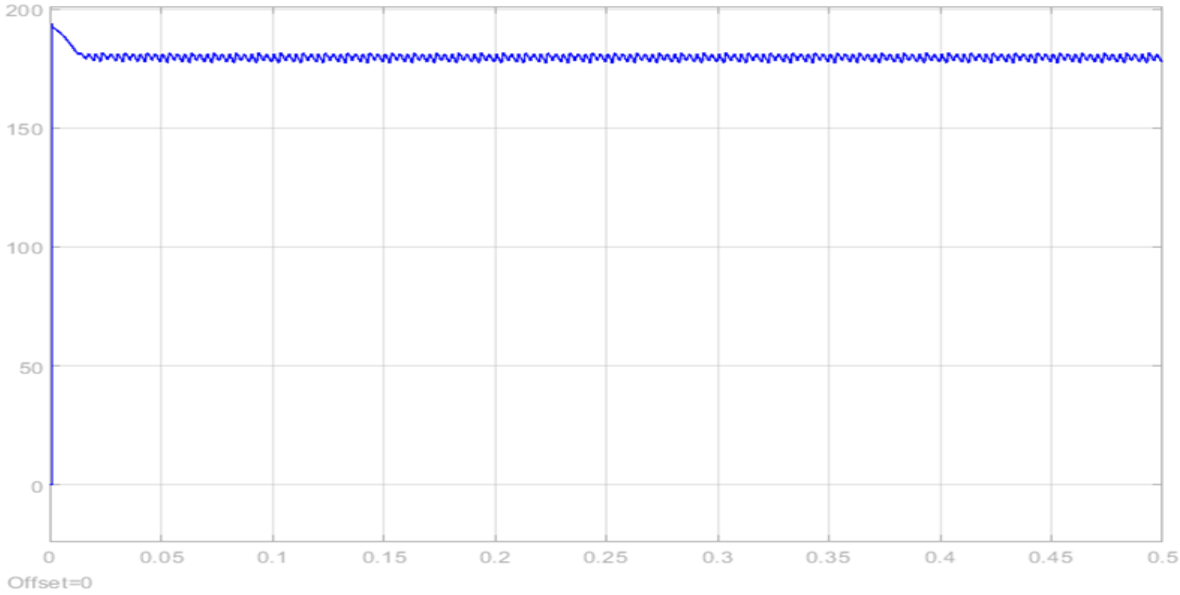

Figure 12 – Mean Output Voltage of Buck Converter

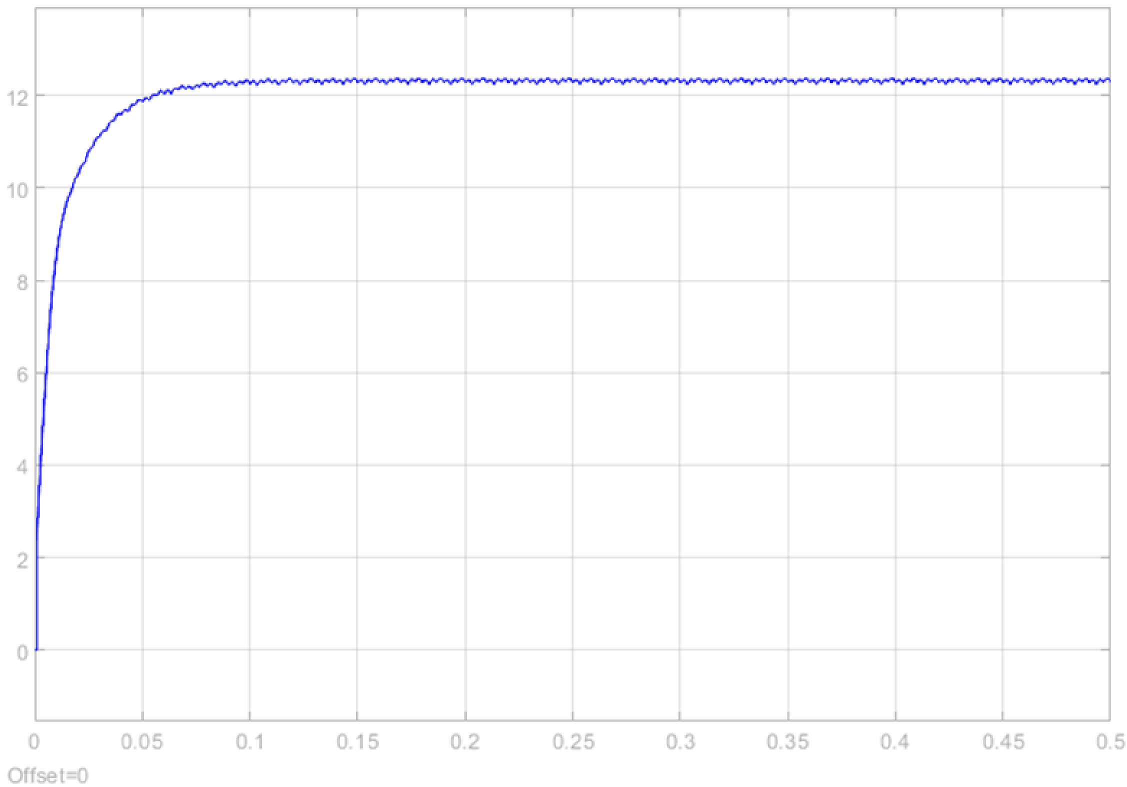

Figure 13 – Output Mean Current of Buck Converter

This is the maximum voltage level for DC Motor. Therefore, maximum current will be 12A and in this case, duty cycle will be 53%. For duty cycles more than 53%, output voltage is exceeded the rate of DC motors. So the duty of the system will be around 0 to 53%.

To choose devices properly, current and voltage ratings of diodes and MOSFETs are important. In the worst case, Vds voltage and Id current of MOSFET can be seen in Figure X7 and X8 respectively. Maximum voltage is 350V and Id is 14A.

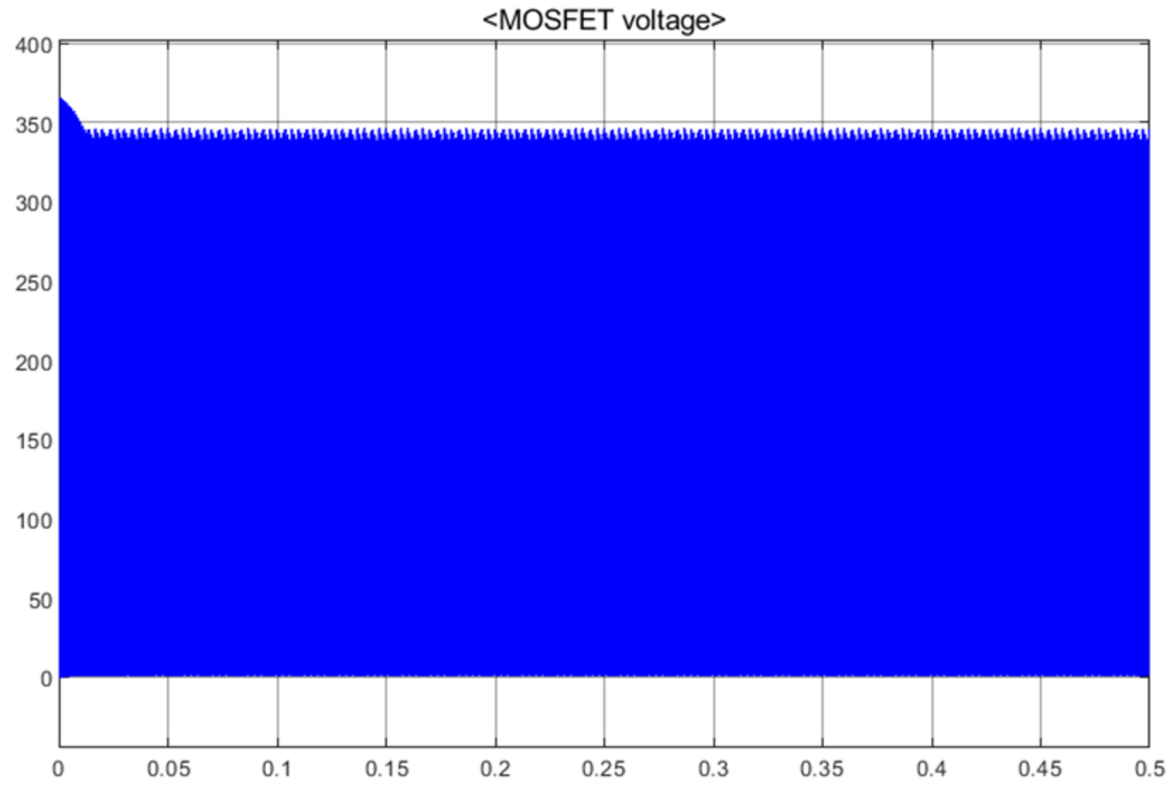

Figure 13 – Vds Voltage of MOSFET

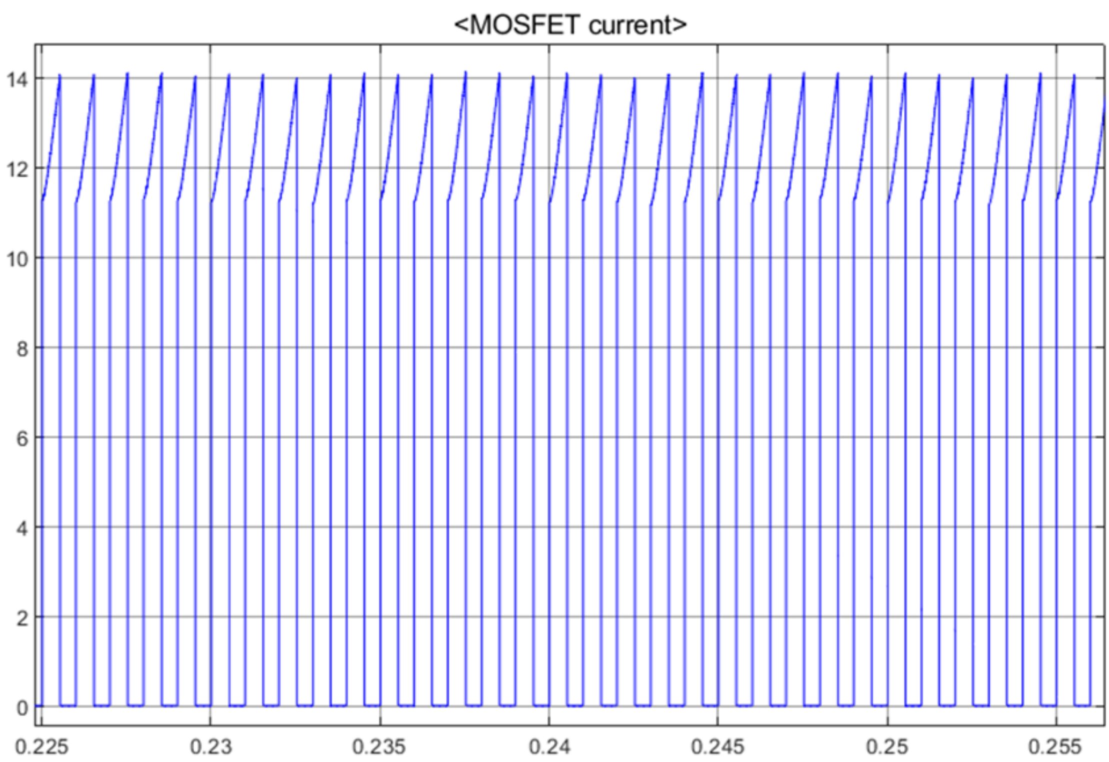

Figure 14 – Id current of MOSFET

For the freewheeling diode $V_{Reverse}$ and If value can be seen in Figure 15 and 16. Reverse voltage is same with reverse of MOSFET and forward current is same with output current of the system since freewheeling when the switch is OFF.

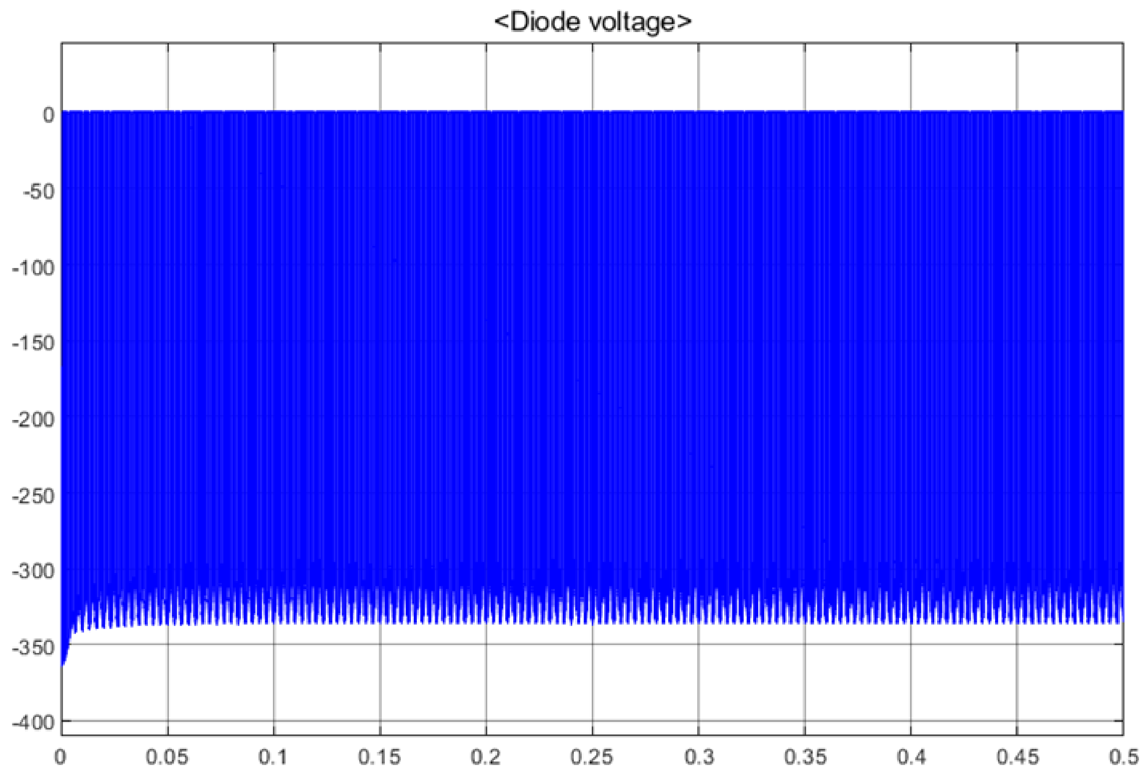

Figure 15 – Reverse voltage of Diode

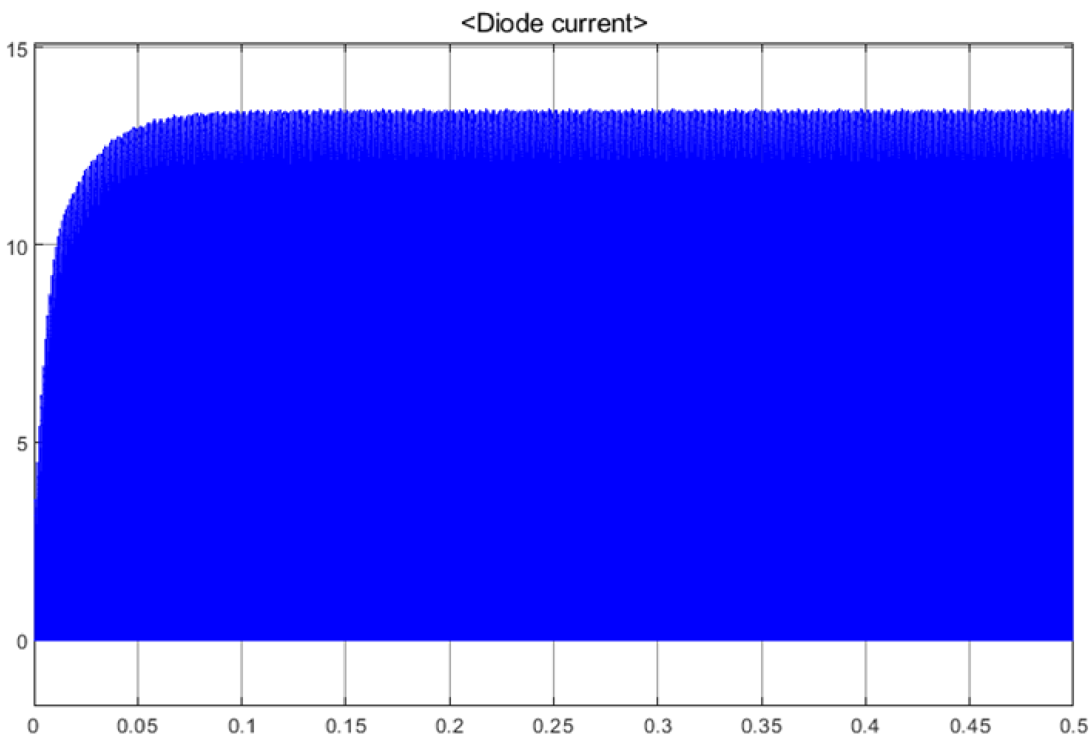

Figure 16 – Diode current during freewheeling

Motor Modelling

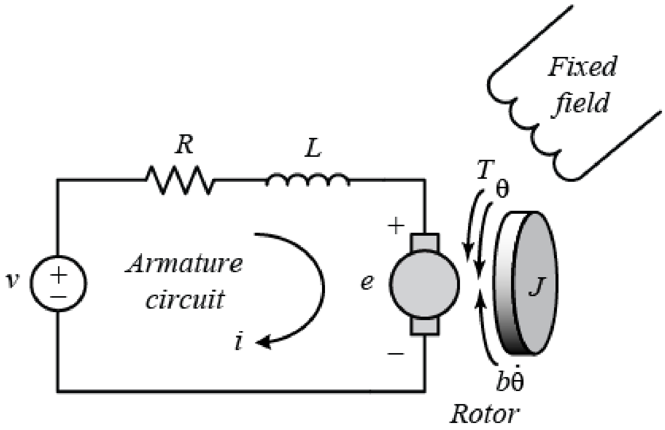

Figure 17 – DC Motor Model with Separate Excitation

DC motors can be modeled as an electrical circuit as in the figure x above. It has an armature resistance and armature inductance due to the armature windings and it has a DC voltage source which is proportional with its rotational speed. In this project field windings will be separately excited by an external DC source so modeling the field winding will not be needed.

In this project Crompton Parkinson F362A114 motor will be used and it has the winding values as below

Armature Winding: 0.8 Ω, 12.5 mH, Interpoles Winding: 0.27 Ω, 12 mH

Interpoles windings are used to cancel the reactance in the winding coils so that the effect of commutation will be lowered so armature reaction will be reduced. Furthermore it reduces the self inductions effects. Interpoles windings are connected in series to the armature windings so the total winding impedance will be 1.07 Ω, 24.5 mH. So motor model in simulink will be constructed as below circuit

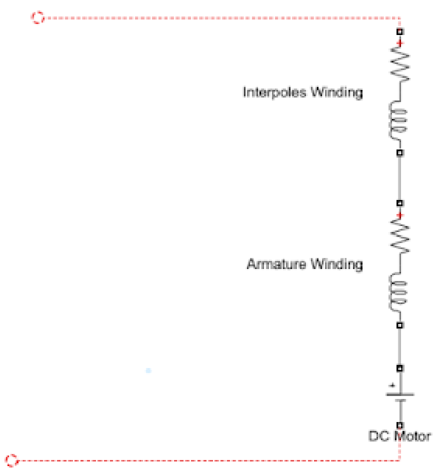

Figure 18 – Motor Model in Simulink

This circuit will be connected at the output of the chosen topology’s simulations. Since there is a large inductor motor acting as a low pass filter which is constructed by RL, so there might not be a need for an additional low pass filter. The current through the DC motor will be decent enough to use it.

Component Selection

To achieve 2 kW output power for the bonus there should be a required current for it. Maximum applied voltage is given as 180 V as in the requirement list. So for 2kW output supply there should at least be 2000/180=11.2 A current through, let's round this number and call it 12.

Since the armature voltage of the motor will be zero at the start it will draw much more current at the starting phase but we will try to achieve a soft start process so that the motor will start slowly since the voltage applied to the motor will be low, which is achieved with a low duty cycled buck converter, therefore starting current will not be very high compared to the final steady state current after starting the process. After the starting phase since there will be armature voltage, the current drawn will stabilize. The simulation of the starting phase is done at the Simulink and we saw that the maximum required current value at %4 duty cycle is 13 A.

Therefore it can be said that selection of a 20 A maximum rating will be a logical and educated choice. Our component selection will be based on this and based on the applications-usage we will decide the other parameters, such as low switching loss for high switched components and low conduction loss for low switched components or voltage ratings should be analyzed carefully.

Bridge Rectifier

For the full-bridge three phase rectifier, there are lots of compact modules which are small in size but they have all the necessary components inside so instead of using base components separately and constructing the full bridge rectifier. “GUO40-12NO1” will be used which is a compact rectifier with 5 legs, its datasheet is given in the appendix [1]. It has a 1200 V 40 A rating which is suitable for our case and since we have a 50 Hz operation at the rectifier side we don’t need very switching efficient components so this is a very good choice for this operation.

SiC MOSFET

For the Wide-Band semiconductor bonus a SiC mosfet may be used in the circuit. A decent component which can be suitable for the project is“LSIC1MO120E0120”. It is relatively inexpensive and its rated voltage and current satisfies the requirements (1200 V, 27A). SiC mosfets are a better choice since they have less heating problems and they are more efficient both in switching and conducting. Datasheet of the “LSIC1MO120E0120” can be found in the appendix[2].

Regular MOSFET

Since it's a relatively new technology the SiC MOSFET is expensive as expected, so in the first trials of the construction, a regular MOSFET will be used which is “IXFH30N60X” it has a decent rating such as 600V and 30 A. Since it is used in switching it is important to has a low t_{rr} and it has a decent value. Its datasheet can be found in the appendix.[3]

Freewheeling Diode

Freewheeling diode is conducting when the MOSFET is off at the buck converter. And according to the simulations it should withstand 30 A and 400V and it should also have low t_{rr} to reduce the switching loss since switching frequency is high at the buck converter (1kHz-10kHz). The diode “DSEP 30-06A” is a suitable choice for this project; its data sheet can be found at the appendix. [4]

Fuse and Fuse Holder

We will use a 20A glass fuse to protect the circuitry when 20 A is exceeded (which is close to the max value in the design) fuse will burnout and open the circuitry so that the components will not burn. Burning a 0.2 $ fuse is better than burning a 25$ SiC MOSFET. Fuse holder is soldered to the pcb (or perfboard) and it is used to insert the fuse.

PWM Controller and Gate Driver

In this project, to obtain a digital controller and PWM in one device, Arduino Nano will be used. To isolate the Arduino pin from the power side of the system, there must be an isolated gate driver. TLP250 is an isolated optocoupler gate driver. Its datasheet can be found in the appendix [5]. With the help of LED inside the IC circuit, it gives isolated voltage from input to output. TLP250 also provides the MOSFET enough voltage (up to 35V) and enough gate current (up to 11mA) to open MOSFET. There is no connection between input and output. When there is a problem at the power side of the system, this can not affect the pins of Arduino.

Conclusion

In this project simulation, three different topologies to convert AC Voltage to DC Voltage for DC Motor Drive are analyzed. Their output ripple voltage, input THD current and average output voltage are compared with each other while choosing the most beneficial topology. All of these topologies are introduced by simulation seperately. Moreover, characteristics and features of DC Motor are introduced. After deciding the topology, suitable mosfets and diodes were chosen according to required current ratings, voltage ratings and switching frequency.

Future Work

In the later stages of this project, power and thermal analysis will be calculated. Parameters of MOSFET, diode and 3 phase rectifier diodes placed to simulation and more realistic simulations will be studied. Real circuit will be constructed and real results will be compared to the simulation results. Moreover, controller circuit and controller block will be designed and added to Simulink simulations and observed. Optimum control circuit will be obtained according to these and experimental results. According to the stability of the system, SiC MOSFET will be tried to obtain a more efficient circuit. Furthermore, for Single Supply Bonus, Zener Diode Regulator topology and some other topologies will be investigated.

APPENDIX

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https://cdn.ozdisan.com/ETicaret_Dosya/592380_927141.pdf [2]

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https://pdf1.alldatasheet.com/datasheet-pdf/view/32418/TOSHIBA/TLP250.html [5]