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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

EE463 HARDWARE PROJECT REPORT

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AC to DC Motor Drive

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***Abstract*—This document provides a simply modified method to convert AC voltage to DC to drive a DC motor by using a three-phase diode rectifier and a buck converter controlled by pwm.**

Keywords—Simulink, Buck Converter, DC motor.

I. Introduction

In this report design process of a AC to DC converter, which controls DC Motor, is examined. As a topology, Full Bridge Diode Rectifier (FBDR) and Buck converter without LC filter is used. The main advantage of this topology is that the input DC voltage of the buck converter is supplied by the FBDR which does not require any triggering pulse circuits which makes the design much more complex. Also, output DC voltage of buck converter is controlled by duty cycle of IGBT driver circuit.

II. Converter Topologies and Selected Topology

We have few main topologies which are half wave controlled rectifier, full wave controlled rectifier and FBDR with buck converter that can be used in this project. There are other other topologies but we focused on only mentioned three of them. We selected out topologies according to some general points like simplicity and bonuses which will be mentioned next parts.

Half wave controlled rectifier looks like simpler than other topologies but controlling of thyristors is problematic event. Thyristor driver ICs are available but drivers of these ICs are complex. Driving thyristors by Arduino is possible but Arduino will not be effective for this current and speed probably. Also, harmonics are very problematic in wave rectifiers. However, buck converter has no much harmonics. In buck converter, triggering gate of MOSFET or IGBT is easier than triggering of thyristors. Because of these reasons we decided to use Buck converter for our purposes. Our whole circuit schematic can be seen from Figure 1. Different from our plans, we did not implement LC filter of buck converter because smoothness of output voltage waveform is not big issue in our motor driving case. Therefore, due to avoiding complexity and cost, we excluded LC filter of Buck converter.

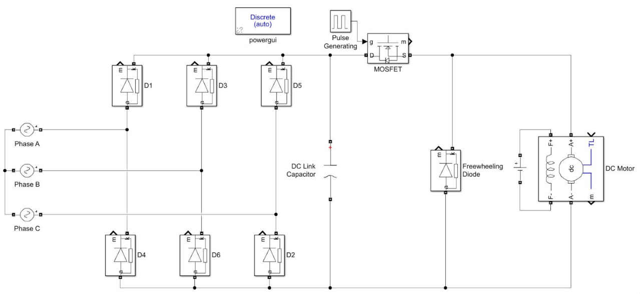


Figure 1. Simulink Model of Implemented Circuit

III. Simulation Results

In this part, we simulated our circuit by using Simulink. Simulation is important part of this project because before hardware implementation, it allows us to see our mistakes. In order to obtain desired results some of the parameters was changed during the simulation. Our Simulation schematic can be seen from Figure 2. We used proper components and blocks in our simulation and we also used DC Machine Component in order to obtain more realistic results.

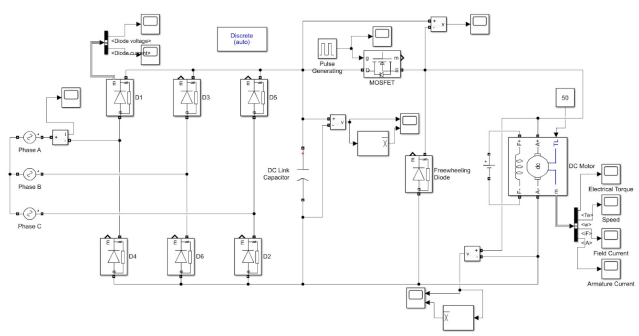


Figure 2.Simulation Diagram from Simulink

Note that simulation results is updated in final report because we excluded LC filter as we mentioned and we changed switching frequency of our IGBT to 25 Hz due to some problems which will be explained next parts.

Note that input voltages in our simulations are 230 Volts RMS with 120 degrees phase difference.

Firstly, we simulated only 3-phase FBDR with resistive load and then we added DC link capacitor so that we could see the effect of DC link capacitor. Output voltage is in Figure 3.

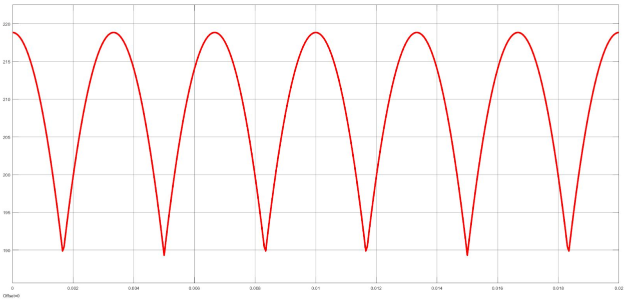


Figure 3. Output Voltage of 3-Phase FBDR

As can be seen there is voltage ripple which in between 190 - 219 Volts. This kind of ripple is not good for operation. Therefore adding DC link capacitor to output is good idea to eliminate this undesired ripple. Output voltage with DC link capacitor added can be seen from Figure 4.

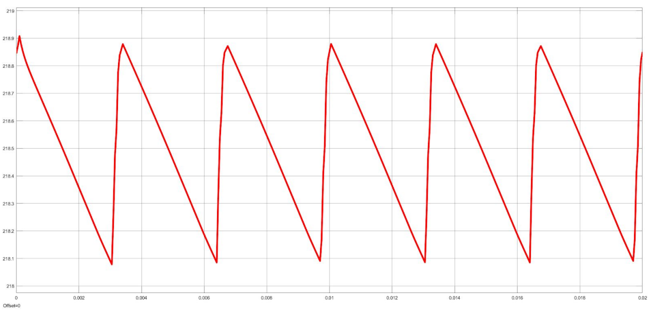


Figure 4. Output Voltage of 3-Phase FBDR with DC Link Capacitor

With output capacitor, voltage ripple in the circuit dropped to less than 1 Volt which is more than enough for our operation.
After putting DC link capacitor to output of 3-phase FBDR, we added buck converter to our circuit. For switching of converter, firstly we preferred MOSFET but in implementation we changed to IGBT. Reason of this will be explained in next parts.

Gate trigger of the IGBT comes from pulse generator block diagram in Simulink. By changing duty cycle of this pulse, we can change average value of DC output. Changing DC output voltage is important in this project because motors draws high current at the beginning of the operation. In order to prevent from this current, we should start our motor softly by changing duty cycle of IGBT.

To observe our circuit for different operations, we used different duty cycles which are 10%, 50% and 90%. Output voltage of buck converter, motor speed and armature current schematics can be seen from following figures.

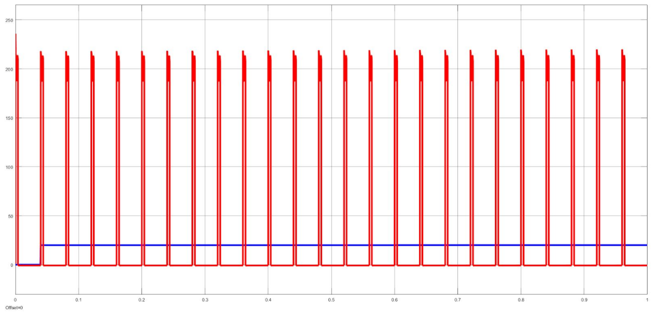


Figure 5. Output Voltage and Output Voltage Mean of Buck Converter with 10% Duty Cycle

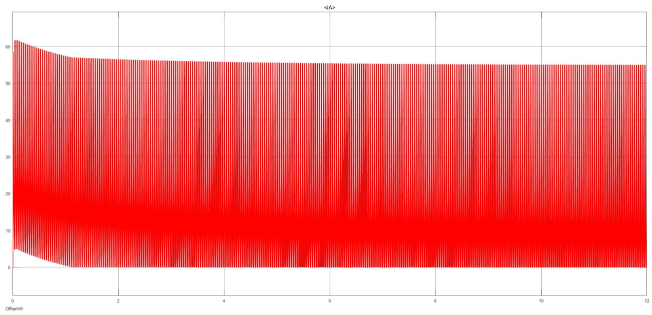


Figure 6. Armature Current of Motor with 10% Duty Cycle

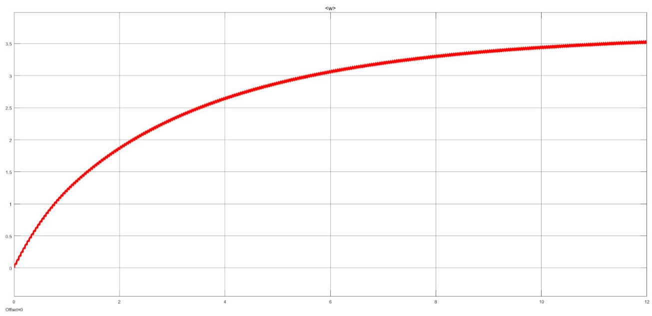


Figure 7. Motor Speed(ω) with 10% Duty Cycle

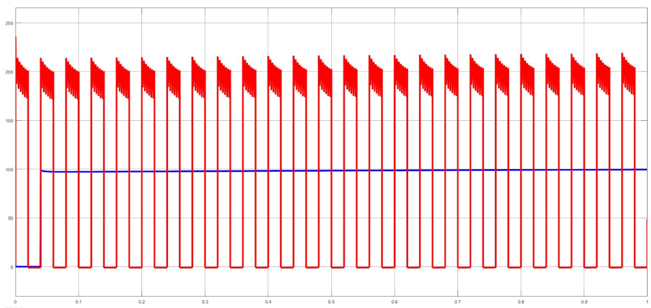


Figure 8. Output Voltage and Output Voltage Mean of Buck Converter with 50% Duty Cycle

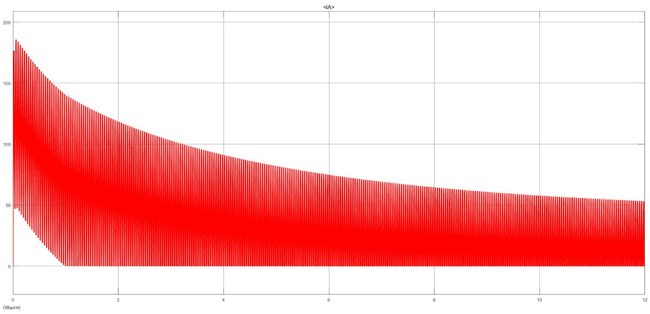


Figure 9. Armature Current of Motor with 50% Duty Cycle

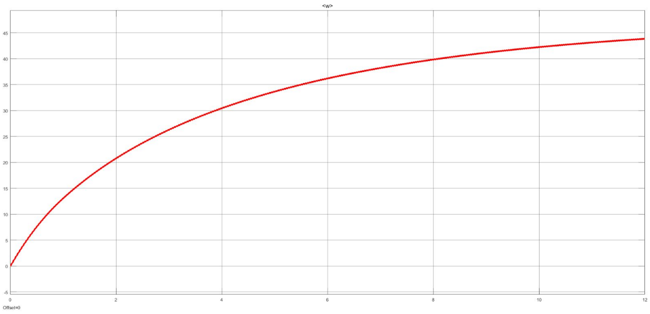


Figure 10. Motor Speed(ω) with 50% Duty Cycle

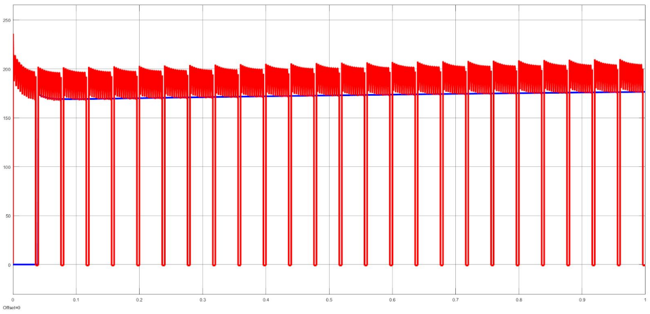


Figure 11. Output Voltage and Output Voltage Mean of Buck Converter with 90% Duty Cycle

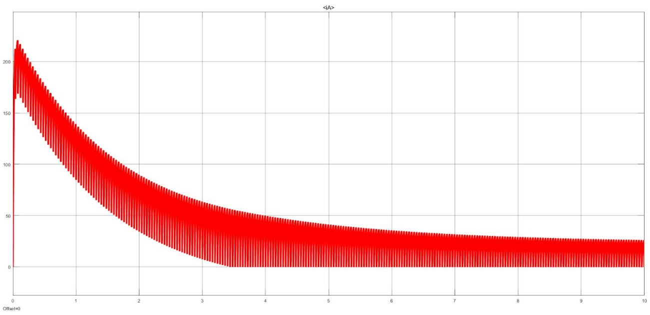


Figure 12. Armature Current of Motor with 90% Duty Cycle

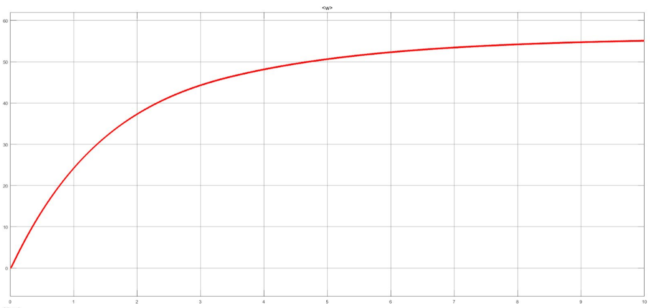


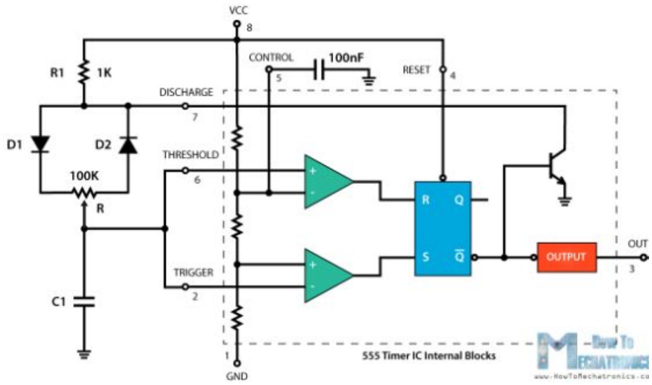
Figure 13. Motor Speed(ω) with 90% Duty Cycle

As can be seen, motor speed increases with duty cycle of IGBT gate signal as expected. Another observation from simulation results is that, when we increased duty, cycle starting output current is high. Actually, this is why we need soft start by changing duty cycle. In 10% duty cycle, peak value of armature current is roughly 60 A. This value is 180 A and 230 A for 50% and 90% duty cycles respectively. We obtained soft start in this project by starting the motor with small duty cycles. We obtained adjustable duty cycle with 555 timer circuit which will be explained in next part of this report.

Design of AC to DC converter

555 PWM Generator Circuit

In order to trigger the IGBT, we used a pulse width generator circuit with 555 timer. You can see the circuit schematics of the pwm generator unit in Figure x.



The fundamental working principle of the design is based on the voltage on the capacitor C_1 which is applied to positive and negative input pins of the separate comparators inside the 555 timer such that the output is high while the capacitor is charging through R_1&R and low while the capacitor is discharging through R. Therefore, by changing the values of R_1, R_2 & C_1, the different square-wave duty cycle could be obtained. By using D_1&D_2, HIGH time of the output is determined by the C_1, R_1& the left side resistance of the potentiometer and LOW time is determined by C_1 and right sight of the potentiometer. Also note that since the capacitor charges and discharges over R_1, the duty cycle frequency is also dependent on R_1&C_1. In order to obtain a flexible frequency range, we used a potentiometer instead of a constant resistance as R_1. Frequency and duty cycle percentage equations are given below.

$$t_1 = 0.693 * (R_1 + R) * C_1 \quad (C_1 \text{ charge time}) \quad \text{E.q x}$$

$$t_2 = 0.693 * R * C_1 \quad (C_1 \text{ discharge time}) \quad \text{Eq. y}$$

$$T = t_1 + t_2 = 0.693 * C_1 * (R_1 + 2R) \quad \text{Eq. z}$$

$$f = \frac{1}{T} = \frac{1.44}{C_1 * (2R + R_1)} \quad \text{Eq. x}$$

$$D(\%) = \frac{R + R_1}{2R + R_1} \times 100\ \% \quad \text{Eq. m}$$

In order to make a complete soft starting operation, we need to obtain a zero percent duty cycle when left side of R has maximum resistance. Using a R>>R_1, we reached this target. You can see the oscilloscope screen for 0%,50% and 100% duty cycles from Figure a,b,c, respectively.

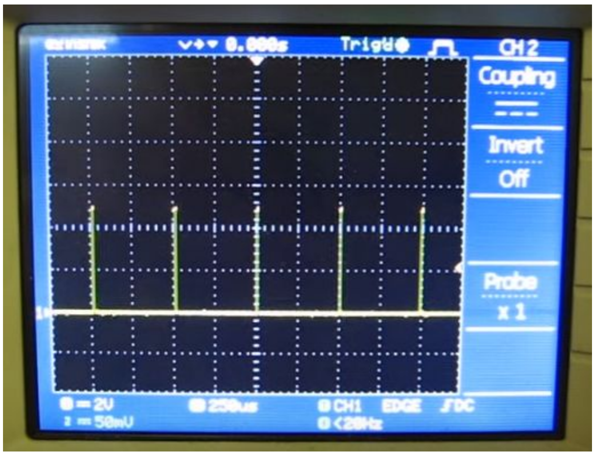


Figure 14: Waveform of 0% duty cycle on oscilloscope screen.

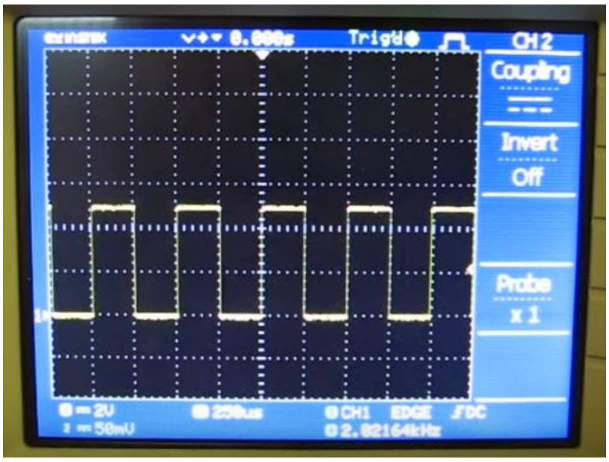


Figure 15: Waveform of 50% duty cycle on oscilloscope screen.

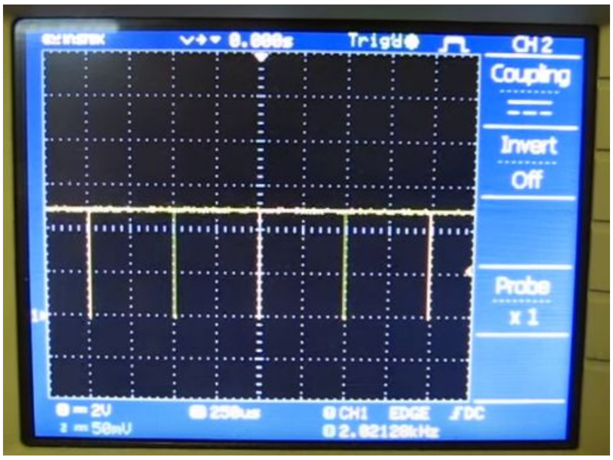


Figure 16: Waveform of 100% duty cycle on oscilloscope screen.

Design of Gate Driver Circuit

Although we designed a duty cycle generator to trigger gate of IGBT, supplying is another case. To trigger the gate of IGBT effectively, thus, obtain a strict and sharp on off operation, we needed to supply gate of IGBT with higher current that of supplied by 555 timer. Moreover, this driver circuit is used for isolation purpose between the high voltage and low voltage side of the design. You can see the circuit design of the driver in Figure m.

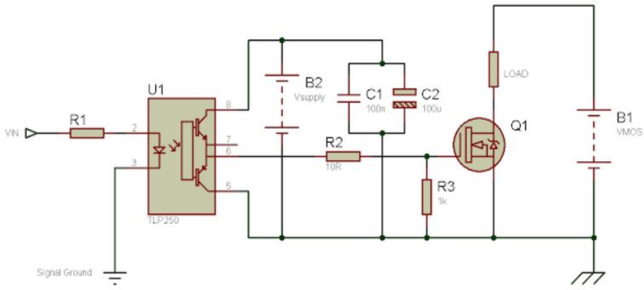


Figure 17: Circuit schematics of the gate driver with TLP250 optocoupler.

As seen in Figure m, the input of the gate driver is generated pwm signal. Applying a signal, a LED turns on and off, then, according to the input signal, a non-inverting signal is obtained at the output of the TLP250. The DC supply voltage of the circuit is 15V. It is observed that the output voltage collapses below 14V DC supply voltage. C_1&C_2 are used in order to stabilize the input supply voltage of the integrated circuit of the TLP250. Also, R_2&R_3 are used to prevent turn-on and turn-off the mosfet accidentally due to external noises. Due to the Miller capacitance of mosfet, it can be opened by a floating input. Thus, by using R_3 as a pull-down resistor, the low stage of the mosfet is guaranteed.

IV. Component Selection

In this project we used 3-phase full bridge diode rectifier, DC link capacitor, IGBT, freewheeling diode, stripboard and proper heatsinks. Detailed explanations of each component are given below.

Note that in component selections we preferred high margins so that we can safely operate our circuit

<u>3-Phase Full Bridge Diode Rectifier</u>

We choose DB35-16 as our full bridge diode rectifier. Since it is harder to implement bridge rectifier with single diodes we preferred to buy 3-phase full bridge diode rectifier as a single component and used it.

In simulations we expected maximum current in our circuit as 20 A and maximum voltage is 200 V. As can be seen from Table 1, specifications of DB35-16 is more than enough to encounter such current and voltage.

As expected, it worked very well in practical implementations and project demonstration.

Table 1. Important Parameters of 3-Phase FBDR

VVRMS (V)	1000
VRRM (V)	1600
IFAV (A)	35 (at 55 °C)
IFSM (A)	450 for 50 Hz
VF (V)	< 1.05 V
trr (ns)	1500
Rth (junction to case) (°K/W)	1.8

DC Link Capacitor

In order to make output voltage of FBDR smoother and obtain better voltage waveforms we needed a DC link capacitor at the output of FBDR. For this purpose, we used 820 uF 450 V capacitor and it worked very well in our practical implementations.

IGBT

In order to adjust DC output, we needed switching and for this purpose we used IXGH24N60C4D1 IGBT. Important parameters of IGBT is given below.

Table 2: Important Parameters of IXGH24N60C4D1 IGBT

VCE (V)	600
ICM (A)	130
TJ (°C)	-55 - + 150
VGE(th) (V)	6.5
RthJC (°C/W)	0.65
RthCS (°C/W)	0.21

Freewheeling Diode

Freewheeling diode is needed in our circuit because when IGBT becomes off, if there is no freewheeling diode current of the motor is forced to become zero and these situation causes huge voltages which is very harmful for both our circuitry and DC motor. However, in our project we preferred inappropriate diode which means it's current rating (3 A) is smaller than our average armature current. This causes some undesired effects. For example, since all current cannot flow from diode, it tries to flow through IGBT and this causes switching problems with our IGBT. Therefore, at first times we could not properly adjust output DC voltage. We solved this problem by operating in DCM. Because it allows armature current to flow through IGBT with extra time. For that reason we had to reduced switching frequency of IGBT to 25 Hz which is quite low value for such motor driving operations.

Important parameters of our freewheeling diode is given below.

Table 3: Important Parameters of Freewheeling Diode

IF(AV) (A)	3
VRRM (V)	1000
trr (ns)	75
VF (V)	1.7
TJ max (oC)	150
RJA (°C/W)	20
RJL (°C/W)	8.5

Test Results

Firstly, we tested our circuit by RL load in Power Electronics Laboratory. We arranged R and L loads in a way that each one of them consumed 2 kW power. Output current and voltage waveforms can be seen from Figure x.

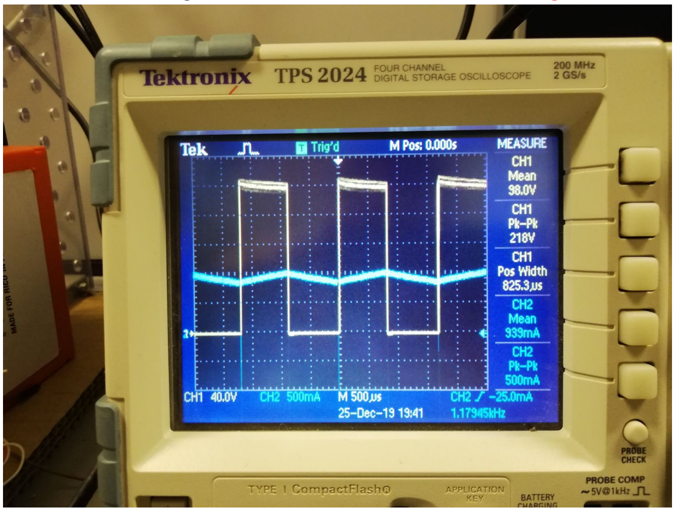


Figure 18: Output Current and Voltage Waveform of RL Load

Note that this result is taken when our switching frequency was 1.7 kHz and as mentioned before this frequency caused some problems and then we changed it to 25 Hz, it is mentioned in conclusion.

Demonstration Results

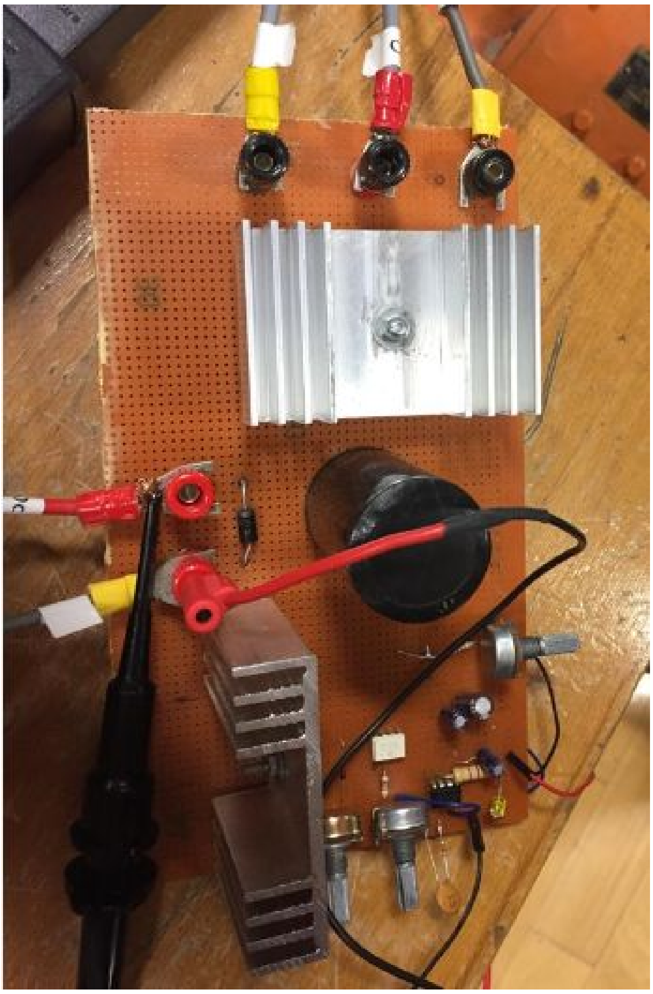


Figure 19: Top view of the all circuit

Our converter worked well in demonstration. We managed to drive DC motor with 1240 rpm with 200 V DC output. Later on, we wanted to see whether our converter will drive the motor with output kettle. Our converter also managed to drive DC motor in that case and we gained “Robust Design Bonus”. At the end of 5 minutes motor driving with kettle, temperature of our IGBT reaches nearly 100 °C which is not harmful for our circuit components.

Some voltage and current waveforms from simulation is given below.

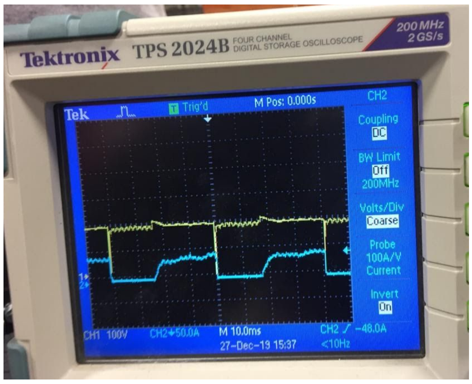


Figure 20: Output Current and Voltage Waveform while driving motor

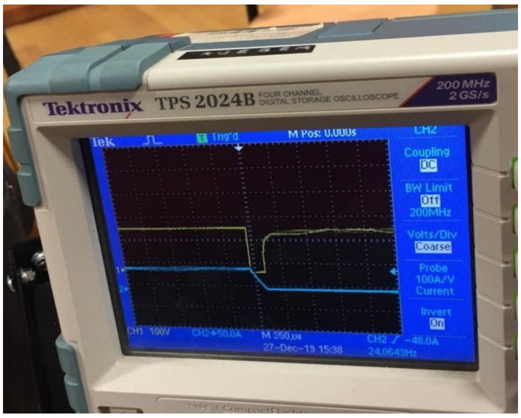


Figure 21: Output Current and Voltage Waveform while driving motor closer view

In this figure above you can observe unbalancing in voltage waveform at switching point.It caused by low frequency operation.

Figure 22: Our thermal performance when load is connected

The temperature of the circuit increase to a certain value on figure above and then remained steady.

Figure 23: Input voltage and current values on variac

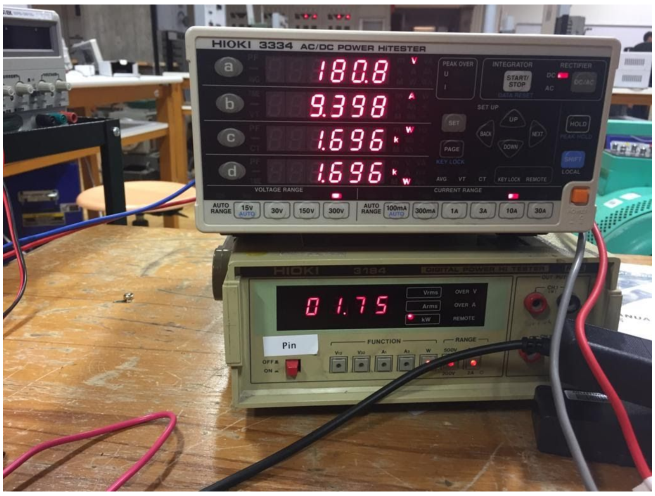


Figure 24: Output current ,voltage and power values

V. Cost Analyses

As with all engineering designs, we have made trade off between quality, time and money. Sometime we prefered money by neglected quality but sometime we prefered quality and time by spending more money. For example we have used full wave rectifier as component instead of making with diode. Making with diode is economical but it take more time and performance. Another example is that we have used expensive ıgbt to guarantee circuit withstand load current value.

Component	Pieces	Price
IGBT	1	18 tl
Full wave rectifier	1	12 tl
820 nF Capacitor	1	15tl
Heat sink	2	10tl
555 timer circuit component	some	10 tl
optocoupler circuit components	some	10tl
Copper board	1	10tl
cable	some	3tl
Fwd diode	1	1tl
Total cost		89 tl

VI. Power Analyses

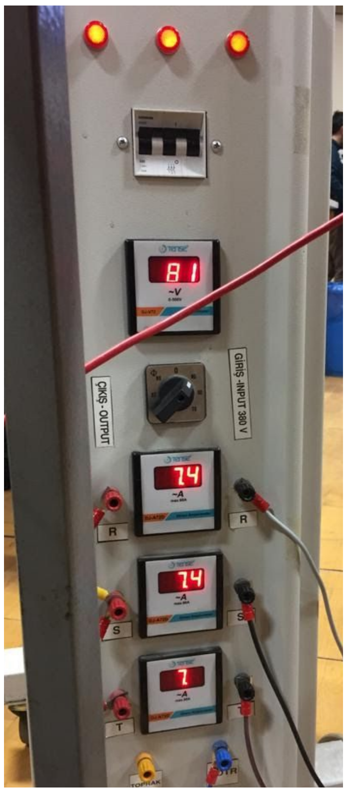


Figure 25: Input voltage and current values on variac

$S = 3 * V_{rms} * Irms$ =3*81*7.4=3*599.4 =1798 VA for input

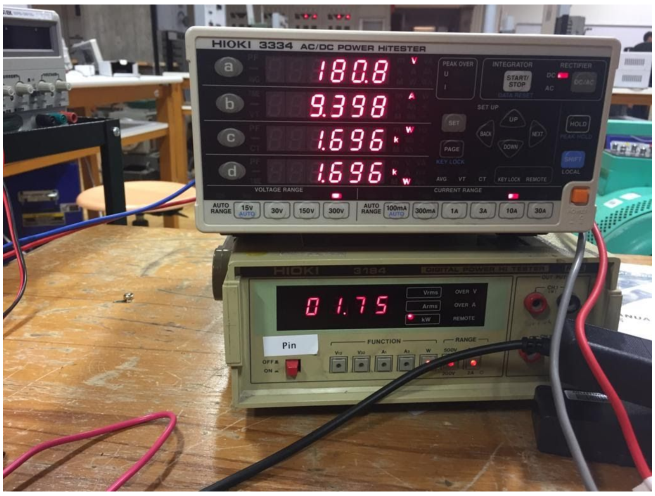


Figure 26: Output current ,voltage and power values

Figure above show our output value but it is in 100 percentage operation so voltage value is max and power is max.

$Sout = V_{rms} * Irms$ =180.8*9.398 =1700 VA

Input power isn't equal to output power because of loss in driver circuit. Most of them is converted to thermal energy on switch, diode etc.
To calculate power value we must know delay between current and voltage.

VII. Conclusion

In this project our aim is driving motor with soft start operation. Input is ac voltage from variac, output is adjustable dc voltage. While we doing project, we have encountered so much problems. I will mention some of them. Firstly, we have observed that theoretical information isn't enough only, practical experience is very important in power electronic. For example, we have prepared mathematical model in simulation. Capacitance value looks like suitable but we have seen that there is no such a product in capacitor market. Therefore when selecting material, market experience is necessary. Also when we design circuit, we have design full wave rectifier by using diode. In simulation there is no any problem. However after simulation design , we have learned that we can use integrated three phase full bridge rectifier.. Full wave rectifier is available in market as only one component. Knowing the materials and be aware of the kinds of components is very important and easy way. When we are not aware of the components we may spend a lot of time for a part of circuit. Also it have been observed that the values written on component cannot always reflect the truth in practice for all component. When it is bought something in market, generally sellers said that even if it says value on that material it will not withstand the current written on. Therefore, we have prefered greater values than our rated values to save component and circuit. All of them shows that market experience is indispensable in power electronic. Secondly, we have realized that component selection is important part of project. Normally a dc buck converter can be found in many internet sites and it has basic circuit operation and logic, but it didn't operate in many condition. For example, we have confused diode problem. We have used small current carrying diode as fwd but it affect our circuit very badly. Since fwd diode carry smaller current than necessary, load cannot discharge at one periode time. Therefore, load try to discharge on igbt diode. This current causes the switch (igbt) not to close in one periode time. Because of this problem, frequency in low voltage side cannot be reflected to high voltage side. Normally, there is no any problem in lv side but switch does not open and close at time. We can't explored this problem. Therefore we have used another way to solve it.We decreased frequency to very low value (25 Hz). Decreasing frequency solved our problem. Because at a larger period, the current in the load is slowly discharged and the current of the low value diode is sufficient to discharge. Therefore we can reflect lv side frequency to hv side. However it causes another problem in circuit like unbalancing. It shows that component selection is very important for truth operation. Also, component selection is very important due to the size of the circuit. When we use big capacitance , although we can decrease ripple voltage to zero, but capacitor size can double the size of the circuit. It isn't good way so you must keep in balance something in circuit. Thirdly, we have learned that driving motor is very crucial thing in engineering. Not only important is running motor but also important is safe and extend the life of component. Moreover, we have realized that heat is very significant topic in power electronic circuit. When the circuit getting hot, component operation can change and it can affect circuit.Overheat can damage component and can burn circuit. Normally our circuit can supply current to boil water in kettle. However when time goes by circuit heats and can stop circuit.

VIII. References

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