

Research Article

# Microcontroller based Hybrid Power Electronics Trainer using PWM Techniques

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## Abstract

The project is focused on the main concepts of the power electronics field and the related application of some major components studied in these courses. Initially, different circuits will be designed according to given experiments list and they will combine up to make a trainer together. The Proteus software will do the designing. Last but not the least the main factor, which will be making our project trainer different from the other will be the circuitry of the micro controller through which we will be controlling some angle delays and the timing factor of Power Electronic IC's circuit with software implementations. In the future, we will be watching our trainer in different universities. We hope that students should get better knowledge about these labs through our trainer than the present ones.

**Keywords:** VFD; SPWM; Buck; Boost; Dimmer

## Introduction

In the present world, the person with the practical knowledge is more valuable than the one who reads book and ratify the concepts instead of implementing those in the labs. Our project is highlighting the course of power electronics and at the present condition of the lab; we tried to develop a trainer with some important concepts of the course and highlighted experiments, which are not being considered much important at the present. The innovation, which is provoked in our trainer that makes it best than the other trainers, will be its design and the control of SCR through the micro controller. Some of the real life applications are also a part of our trainer which will motivate our future engineers to make something on their know something better than the world has before implemented. The main difference between our trainer and the present lab-volts trainers in the lab is the cost, the design of the circuits, space problem and last but not the least the participation of the student in the experiment performed on the trainer

## Scope of the Project

- 1) The cost of the project is effective and it is the main factor which is differentiating it from other trainers

- 2) Understanding of the circuitry and components Will be easy on this trainer because of its design. All Circuitry will be viable to students.
- 3) The circuit Will be printed on them as they are been made on the textbook.
- 4) Advanced power electronics circuit typologies and controls: from intelligent gate drives for MOSFETs and IGBTs to new converter/inverter circuitry.
- 5) Micro Controller is used to control the angle delays of Power Electronic IC's.

## Methodology

- 1) Circuit designing on software (PROTEOUS, MATLAB)
- 2) Code implementation (IDE)
- 3) Software simulations
- 4) Implementation of circuits of PCB boards
- 5) Comparison of results with the software.
- 6) Trainer structure drawing (COREL DRAW)
- 7) Circuits attachments to the designed structure.

## System Description

This trainer is designed to highlight the different circuits of the power electronics. The trainer is comprising of 10 different circuits with their practical implementations. For sure the supply to the circuits is given internally but for demonstration we have

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included knobs on the top surface for best guidance of the students. We are controlling the timing factor of the power electronic IC's and some waveform through the use of microcontroller. For this purpose, we also need to compensate with the price of the trainer so that it could be cheap then the present trainers. For that we are using the Arduino-Nano Micro-controller. In this trainer we have focused the designs of the circuits and for that we have write the compatible codes for the present designs of the trainer.

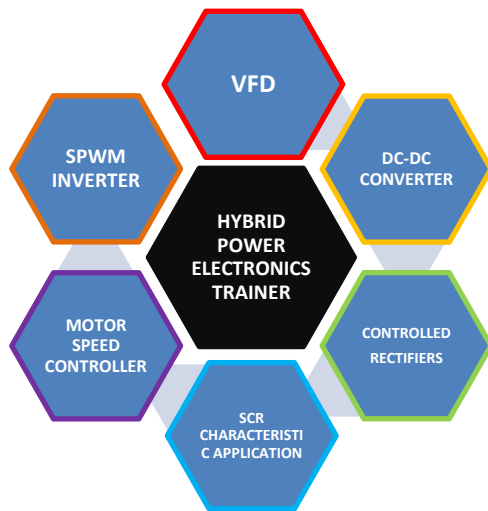


Figure 1: Block Diagram

Below is the experiment list, which are performed on this trainer.

- 1) Diac and Triac characteristics experiment
- 2) Buck Regulator
- 3) Boost Regulator
- 4) SPWM Invertor
- 5) IGBT characteristic and motor speed control experiment
- 6) MOSFET characteristic and motor speed control experiment
- 7) Single Phase Variable Frequency Drive
- 8) Single-Phase thyristor converter with resistive load
- 9) Single-phase thyristor Full converter

**Single phase variable frequency drive (VFD)**

Inductive loads like motors are not happy at operating with the frequencies that are not within their manufacturing specifications and show signs of inefficiency if compelled to operate under such undesirable conditions. For example, a motor specified to operate at 60 Hz will show abnormal behavior if subjected to operating frequency of any other frequency.

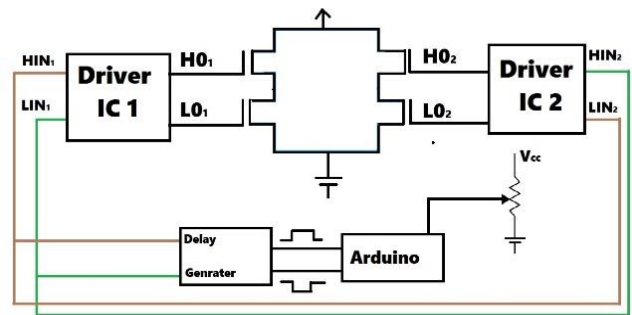


Figure 2: VFD Block Diagram

Heating up of motor, inferior or sophisticated than the required speed and high ingesting of power with reduction in life span are the outcomes of operating inductive loads at unspecified frequency.

**Spwm inverter**

Inverter is a device, which converts a DC voltage into an AC voltage. The input and output voltage and frequency all depend on the designing of the circuit. Inverter power supply makes use of power electronics technology. Numerous fields such as power, electronics and microcontroller are int its span.It is one of the host spots of today's industry and numerous techniques have taken into account for its designing.

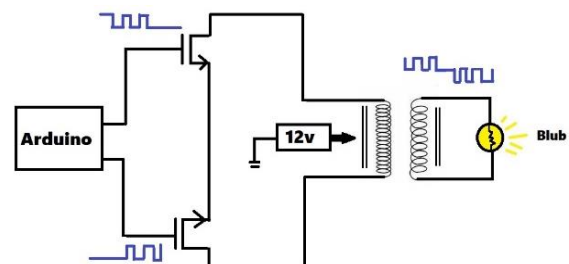


Figure 3: SPWM inverter Block Diagram

**DC-DC converters**

The transformation of the Electric power from one arrangement to another requires need of Power Electronics and switching physiognomies of Power electronics devices. The Static Power Converters helps us in achieving our areas. The industry of power electronics has progressed from past few decades along with the necessities like increased battery life, brighter and full HD displays and increased talk time on phones. Power consumption has been utmost requirement of the industry. To oblige with the growing demands engineers have developed efficient conversion circuits which have resulted in the growth of interdisciplinary field of Power Electronics

**Buck Converter:** Just like step down AC transformer, Buck Converter is a step-down dc-dc converter. It includes two switches (transistor and diode) for

directing current across inductor. The inductor gains energy from load when switch is on and then discharges it across load when the switch opens.

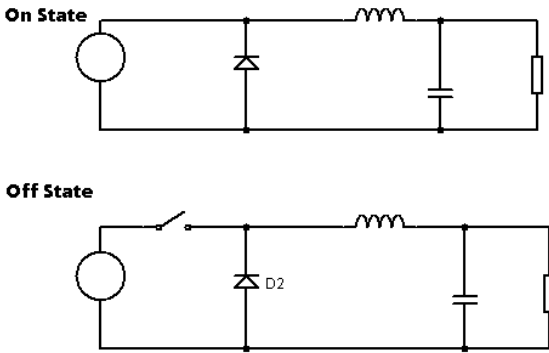


Figure 4: Basic Diagram

**Boost Regulator:** A step-up converter steps up input DC-voltage and provides at output. The components used here are almost same as that of buck regulator, yet in different arrangements

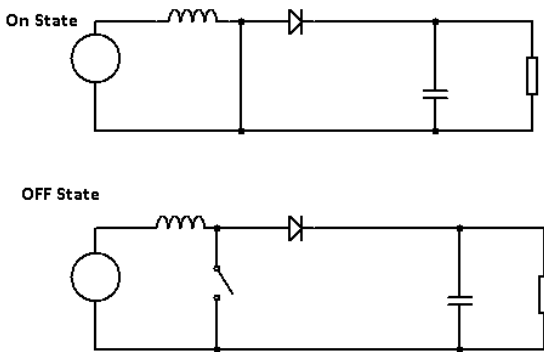


Figure 5: Basic Diagram

**Motor Speed Control using 555**

From past decades, numerous ways have been applied for controlling speed of a DC MOTOR. We control the motor by varying input voltage of a motor. In this regard, we can apply PWM method for controlling the motor.

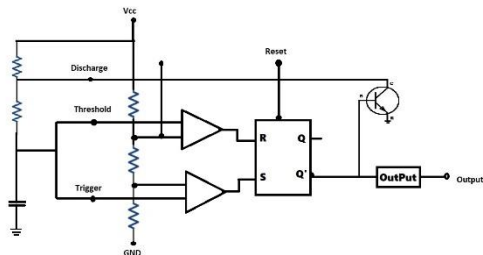


Figure 6: Astable Circuit

**TRIAC Characteristics Experiment**

Our light sources such as tube lights have their power rating. If high brightness is required, high watt bulb would have to play its role and vice versa. Instead of

changing the light bulb, light dimmer circuits are designed in order to control the brightness of a bulb. This is done through a switch known as TRIAC. Several methods are opted in order to control this device with its prongs and cons.

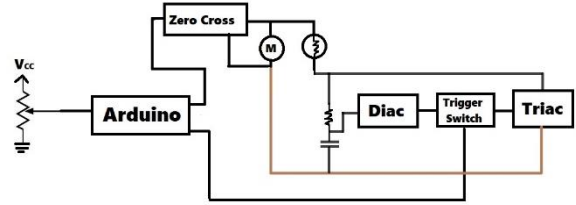


Figure 7: Block Diagram of Light Dimmer

**Controlled Rectifiers**

In power electronics, rectifiers are characterized into controlled rectifiers and un-controlled rectifiers. Diode based rectifiers are denoted as un-controlled, since they lack any extra input to control voltage or current at the output. SCR rectifiers on the other hand, fall in the category of fully meticulous rectifiers, which are made variable with the help of changing output current's angle.

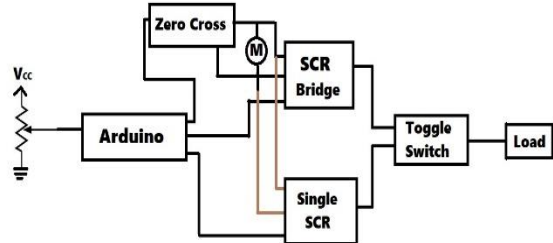


Figure 8: Block Diagram

Such rectifiers are used in devices where high power, coupled with high voltage is demanded. SCR rectifiers can be further characterized into half wave and full wave rectifiers.

**Design and calculations**

**VFD**

**Explanation**

- VCC is a low side voltage that should be between 10v to 20v.
- VDD = 5V as a common ritual, although it can be between 3v to 20v but 5v is adequate for all the circuits since most circuits tend to have 5v outputs.
- As the driver IC i.e. IR2110 is a non-isolated type, VSS and COM both are connected to common ground (don't think of both as independent).
- High input to HIN means a high HO, which means we want to drive high-side MOSFET.HO values should not be considered with respect to ground but VS (high side floating point).

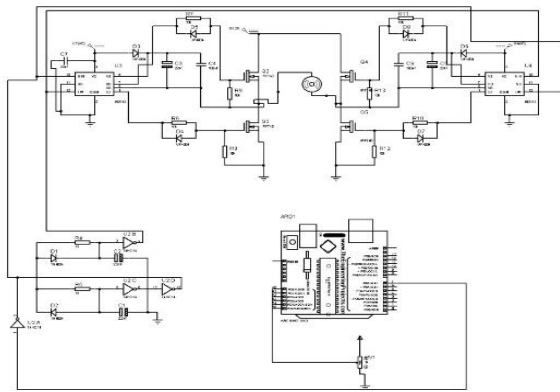


Figure 9: Software design

- The level on HO is equal to that of VB (High side floating point) when high and equal to level of VS when low i.e. zero.
- Similarly, to drive low-side MOSFET, voltage low/high is provided to LIN. Output on LO is always with respect to ground. When LO is high, its level is equal to that of VCC as compared to VSS when LO is low.
- SD pin as the above table specifies, is for shutdown control. A high voltage on pin will disable the drive.

**Hardware Setup:** An H-Bridge is a conventional method to drive a motor. In our case, four MOSFET's are hired to perform such a task. In a H-bridge two MOSFETS are used a high side MOSFETS and other two as low side MOSFET.

**Design Equations**

$$\text{RPM} = 120 / (\text{P.Poles}) \tag{3.1}$$

$$\text{RPM} = 120 \times 60 / 4 \tag{3.2}$$

$$\text{RPM} = 1800 \text{rpm} \tag{3.3}$$

$$\text{Voltage/Hz ratio} = 314 / 60 \tag{3.4}$$

$$\text{Voltage/Hz ratio} = 5.2 \text{v/hz} \tag{3.5}$$

Rule of thumb At RPM=1800 rpm Motor develops torque is 3lb ft per hp

$$\text{Hp} = (\text{Torque} \times \text{rpm}) / 5250 \tag{3.6}$$

$$\text{Hp} = (3 \times 1800) / 5250 \tag{3.7}$$

$$\text{Hp} = 1.028 \tag{3.8}$$

$$\text{power} = 1.028 \times 746 \tag{3.9}$$

$$\text{power} = 767.13 \text{Watt} \tag{3.10}$$

$$1 = p / v \times \text{P F} \tag{3.11}$$

$$1 = p / 220 \times 0.8 \tag{3.12}$$

$$p = 275 \tag{3.13}$$

**SPWM Inverter Design**

**Explanation**

- Arduino nano was more preferable in our case as it requires less space.
- Power supply of 5V (input = 12V) is designed for the Arduino's input.
- D2 is to make sure the circuit is working and D1 is for avoiding reverse voltage.

- C1 and C2 further soothes the voltage.
- At J1, transformer would be attached with its centre pin for 12V from the battery.
- Q5 and Q6 will rise the level of Arduino's voltage i.e. 3v to Vin/2 (6V).

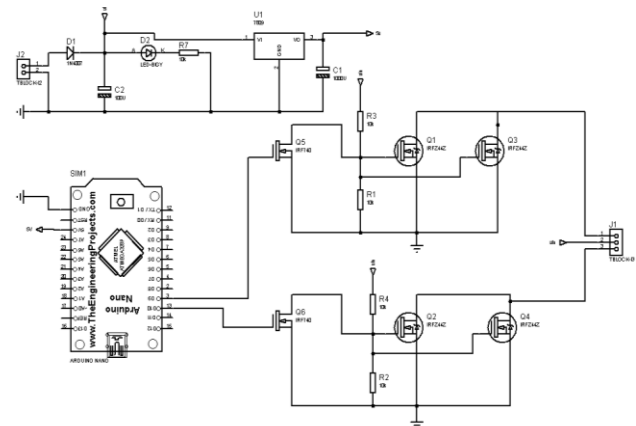


Figure 10: Software Design

**Hardware Description:** The hardware side contains two parts i.e. level shifter or switching MOSFETS and a transformer.

**Calculations**

$$\text{Total Load} = 10 \text{w} \tag{3.14}$$

$$\text{Power} = \text{Total load P F} \tag{3.15}$$

$$\text{P F} = 0.8 \tag{3.16}$$

$$\text{Power} = 10 \cdot 0.8 \tag{3.17}$$

$$\text{Power} = 12.5 \tag{3.18}$$

**DC-DC Converters Design**

**Explanation**

- P-CHANNEL MOSFET has been used as a power side switch (as it passes good ONE)
- Here BJT at Drain of MOSFET is required to completely turn it off.
- When base voltage of BJT is zero, V(gate) = 12V, So Vgs = 0 as Vs = 12V (MOSFET OFF)
- When base voltage of BJT is high, V(gate) = 0V, So Vgs = - 12 as Vs = 12V (MOSFET ON)
- $\beta = I_c / I_b$ ,
- where  $I_b = 3.3 - 0.7 / 10K = 0.26 \text{mA}$  and
- $I_c = \beta \times I_b = 26 \text{mA}$

Here Arduino will take error voltage (due to voltage fluctuations) from output of the Buck Regulator and increase or decrease PWM input to BJT from Arduino in order to adjust the output voltage to its desired value i.e 0-5V (depends on potentiometer adjustment).

**BUCK Converter:** Here we have designed a buck converter with the help of microcontroller board i.e. Arduino.

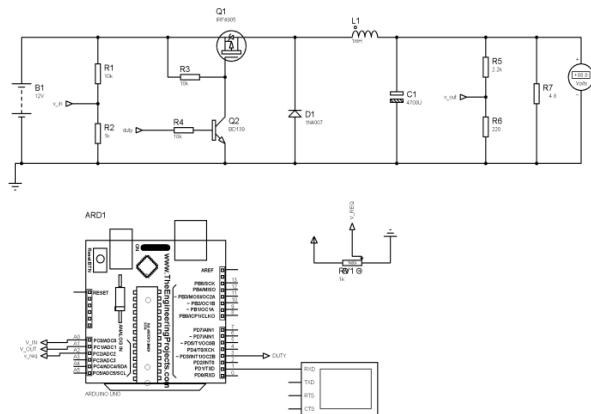


Figure 11: Software Design

**Inductor Calculation**

$$k = \text{duty Cycle} \tag{3.19}$$

$$k = V_{out}/v_{in} \tag{3.20}$$

$$k = 512 \tag{3.21}$$

$$k = 0.416 \tag{3.22}$$

$$t_{on} = 1/f \times k \tag{3.23}$$

$$t_{on} = 1/31.1 \times 10^3 \times 0.416 \tag{3.24}$$

$$t_{on} = 13\text{ms} \tag{3.25}$$

$$T_{off} = 1/f - t_{on} \tag{3.26}$$

$$L = (v_{in} - v_{out}) \times T_{off} / \Delta I \tag{3.27}$$

$$L = 100\text{mH} \tag{3.28}$$

**Output Capacitor:** A 33uF, 25V Cap is selected because it has Max ESR of 0.074 and Max ripple current of 2.8A. Max ESR provides good filtering.

**BOOST Converter:** Microcontroller board i.e. Arduino will help us in achieving our goals.

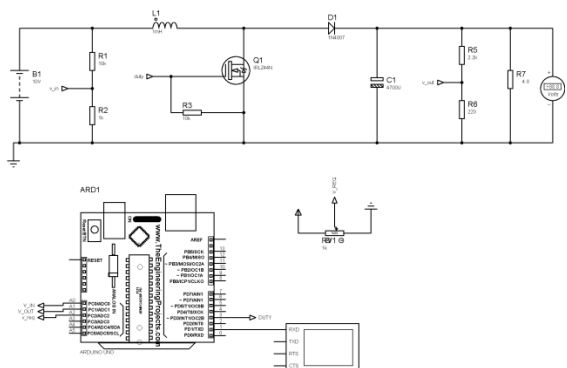


Figure 12: Software Design

**Calculations**

$$k = \text{duty Cycle} \tag{3.29}$$

$$v_{out} = v_s / (1 - k) \tag{3.30}$$

$$k = 1 - v_s / v_{out} \tag{3.31}$$

$$k = 1 - 12 / 30 \tag{3.32}$$

$$k = 0.6 \tag{3.33}$$

$$t_{on} = 1/f \times k \tag{3.34}$$

$$t_{on} = 1/31.1 \times 10^3 \times 0.6 \tag{3.35}$$

$$t_{on} = 19\mu\text{s} \tag{3.36}$$

$$t_{off} = 1/f - t_{on} \tag{3.37}$$

$$L = (v_i - v_o) \times t_{off} / \Delta I \tag{3.38}$$

$$L = 100\mu\text{H} \tag{3.39}$$

$$C = 33\mu\text{F}, 50\text{V} \tag{3.40}$$

**TRIAC Characteristics Experiment Design**

Following is circuit design for DIAC and TRIAC characteristics experiment.

- Resistance value will decide charging and discharging time of the capacitor.
- DIAC will fire TRIAC when capacitor reaches its break over voltage.
- LAMP is the load and its brightness is dependent upon TRIAC's angle.
- Lesser the angle, more is the brightness and vice versa.

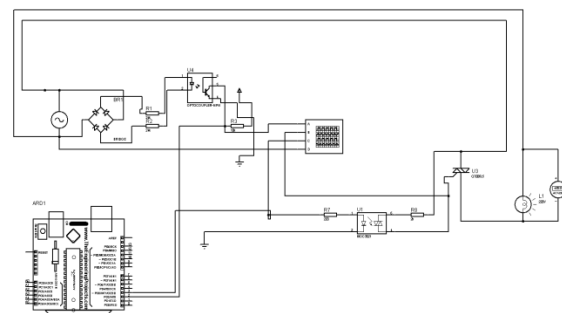


Figure 13: Software Design

**MOTOR Speed Control Using IGBT and MOSFET:**

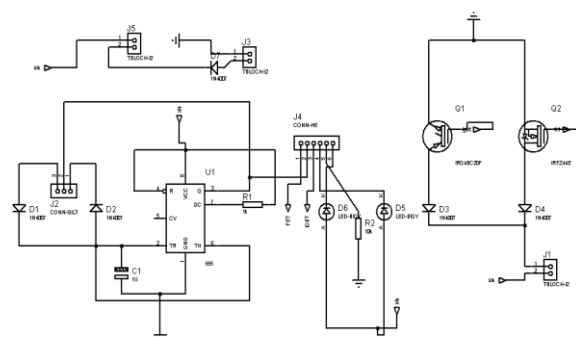


Figure 14: Software Design

**Explanation**

- With J2, a potentiometer is attached.
- D1 provides the charging path and D2 helps in providing discharging path.
- C1 decides charging and discharging time.
- 7th pin of 555 will generate PWM.
- J4 is a toggle switch which would change driver IC (IGBT or MOSFET)
- IRG4BC20F and IRFZ44N are used as drivers.

- With J1, a motor will be attached.
- D3 and D4 will prevent reverse current.
- J5 is where input will be attached.
- With J3 a ON/OFF switch will be involved.
- D5 will be turned ON if MOSFET is turned ON or else D6 when IGBT is initiated.

**Calculations**

High Time  $T_H = 0.693 \times R \times C1$   
 Low Time  $T_L = 0.693 \times C1$   
 Period for once cycle  $T = T_H + T_L = 0.01386s$   
 $f = 1 / T$   
 $f = 72.1Hz$

**Circuit Description of Half Wave Controlled Rectifier**

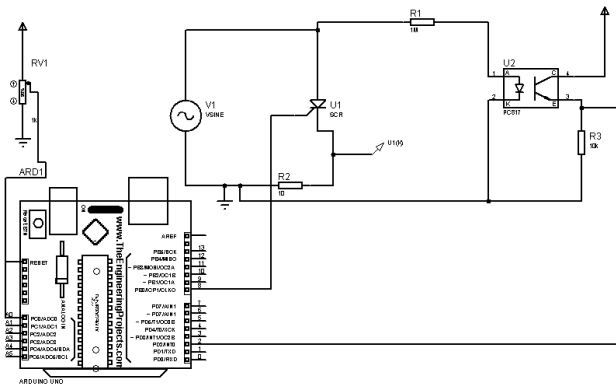


Figure 15: Software Design

**Explanation**

- R1 and U2 make up a zero cross detector, whose output is given to Arduino's interrupt pin. 55 Modeling and Simulations
- Pin 8 of Arduino will generate a pulse in accordance with positive or negative edge of input (220V) sinusoidal wave and delay generated by the potentiometer.
- U1 (SCR) will receive the pulse and allow portion of input wave to be given to the load (depends upon delay).

**Calculations**

$V_{max} = \sqrt{2}V_s$  (3.41)  
 $V_{max} = \sqrt{2} \times 220 = 314V$  (3.42)  
 $I_o(ave) = V_{max}(1 + \cos a) 2\pi R$  (3.43)  
 $a = 0 \rightarrow 180^\circ$  (3.44)  
 $R = 100\Omega$  (3.45)  
 $I_{rms} = (I_m / 2) [1 + a / \pi + \sin 2a / 2\pi]^{0.5}$  (3.46)  
 $V_o = V_m \pi (at \rightarrow a = 0^\circ)$  (3.47)  
 $V_n = V_o V_{do}$  (3.48)  
 $V_n = (1 + \cos a) 2 (0 \leq a \leq 180^\circ)$  (3.49)

**Full wave Controlled Rectifier**

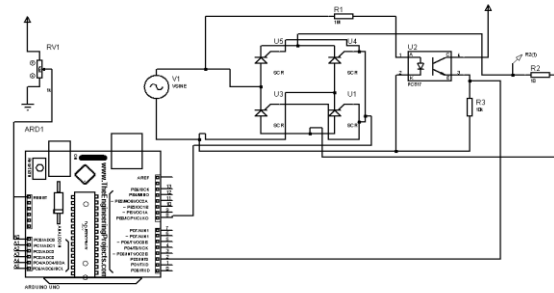


Figure 16: Software Design

**Calculations**

$V_{max} = \sqrt{2}V_s$  (3.50)  
 $V_{max} = \sqrt{2} \times 220 = 314V$  (3.51)  
 $V_{avg} = V_{max} / (1 + \cos a)$  (3.52)  
 $a = 0 \rightarrow 180^\circ$  (3.53)  
 $V_{avg} = V_{max} / RL(1 + \cos a)$  (3.54)  
 $R = 100\Omega$  (3.55)

**Results and Discussions**

Following are the results and their discussions for each particular design. Due to the pandemic, we were left with only two circuits for hardware (light dimmer and SCR circuits) and the final body for the trainer. The hardware calculations and reading were yet to be determined in fully detail but were left due to the pandemic but are fully working and videos have been made as a proof.

**Single phase VFD**

Single phase VFD is designed for a frequency of 50 Hz to 120 Hz. This can be changed through the code. Following are the results.

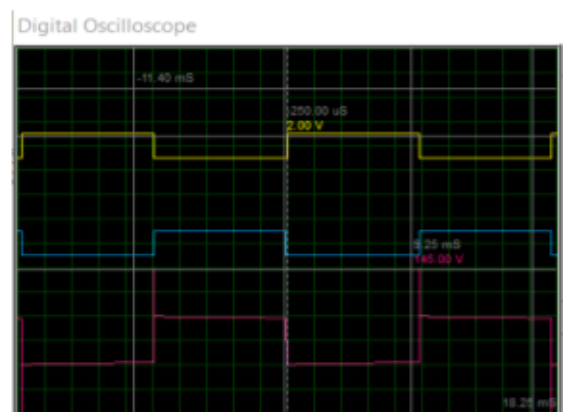


Figure 17: Waveform output from VFD

**PCB Design**

The four circles at the corners of the board are for the board's attachment to the trainer board. Some connections could not be made during design, so were left as shown in red lines. They were made after the hardware was made.



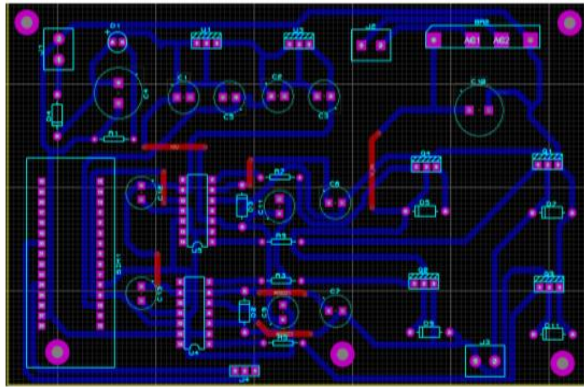


Figure 18: PCB Design

PCB Design

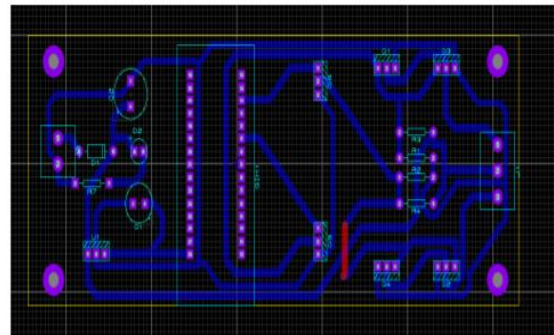


Figure 21: PCB Design

SPWM Inverter

The inverter designed was tested on hardware and show adequate results for a load of 10W with 201 Volt AC max at the output. Following are the simulation results.

Waveform At output

Both waveform are at transformers output terminals.

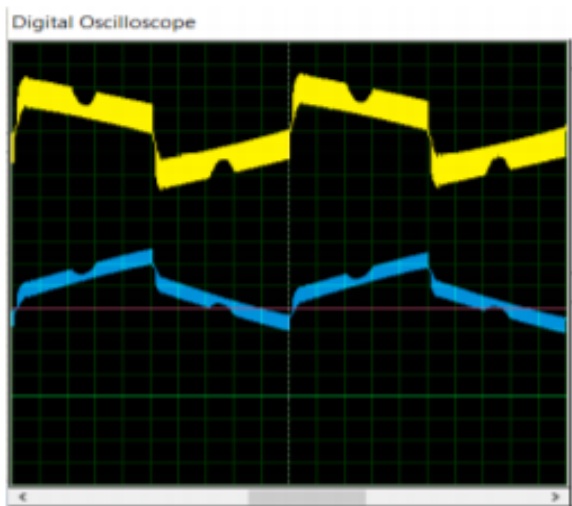


Figure 19: Waveform

These waveforms are generated through Arduino for MOSFET gates.

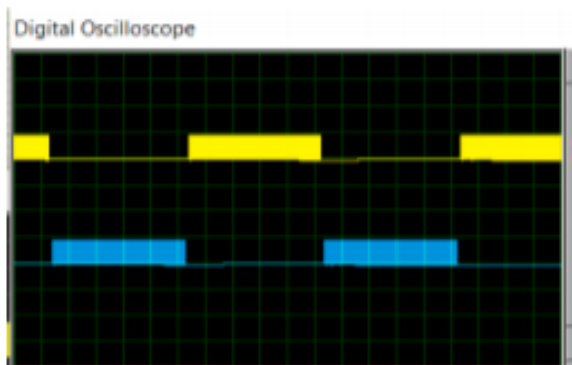


Figure 20: SPWM Pulses

DC-DC Converters

Buck Converter

Design has been explained in chapter. We can witness 11.7 V at output in case of 85%.

Virtual Terminal

Here V req is the voltage we want at the output and can be varied to 5V through potentiometer. At 95 percent duty cycle V out is 12.67 volt. Due to the consequent switching, the voltage lacks stabilization but no such behaviour was seen in the hardware testing.

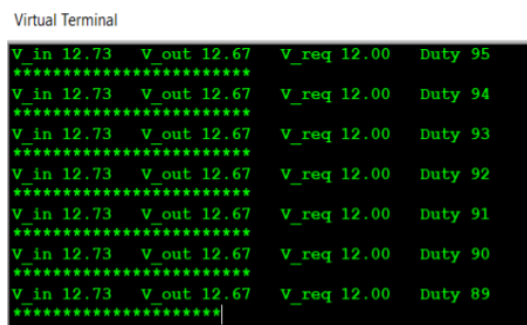


Figure 22: Virtual Window

Duty Cycle Waveform of Buck Converter

The following wave form shows 35 percent duty cycle PWM wave given to MOSFET gate.

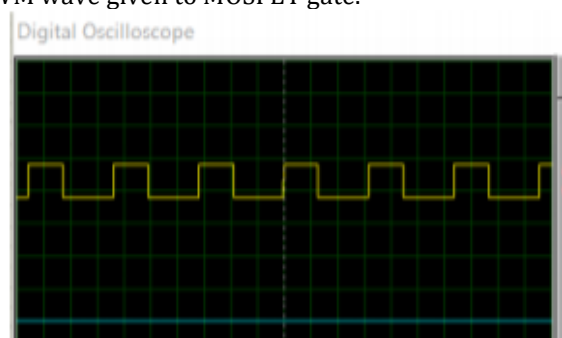
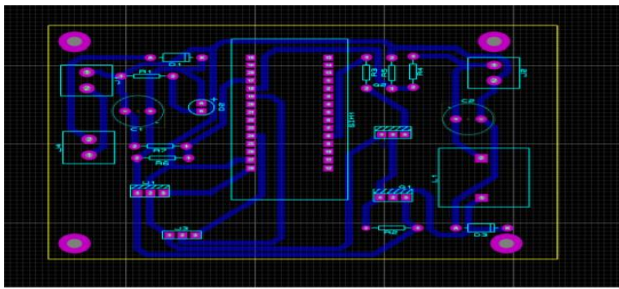


Figure 23: Duty cycle Waveform

**PCB Design**



**Figure 24: PCB Design**

**Boost Converter**

**Virtual Terminal and Waveform** of boost Regulator  
 Here V<sub>out</sub> is not the output voltage but the voltage across a voltage divider at the output. V<sub>req</sub> is the output voltage respectively.

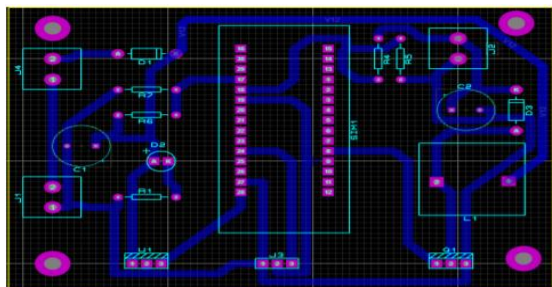
**Virtual Terminal**

```

V_in :10.05
V_Out :9.68
V_req :29.09
duty :83
V_in :10.05
V_Out :9.84
V_req :29.09
duty :84
V_in :10.05
V_Out :|
    
```

**Figure 25: Virtual screen**

**PCB Design**



**Figure 26: PCB Design**

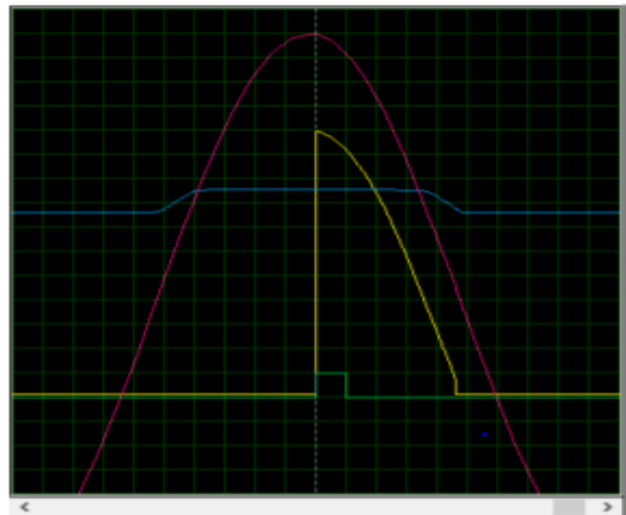
**Controlled Rectifiers**

The hardware of the controlled rectifiers could not be designed on hardware due to the pandemic but basic simulation and idea is complete for the hardware implementation.

**Waveform of Half wave**

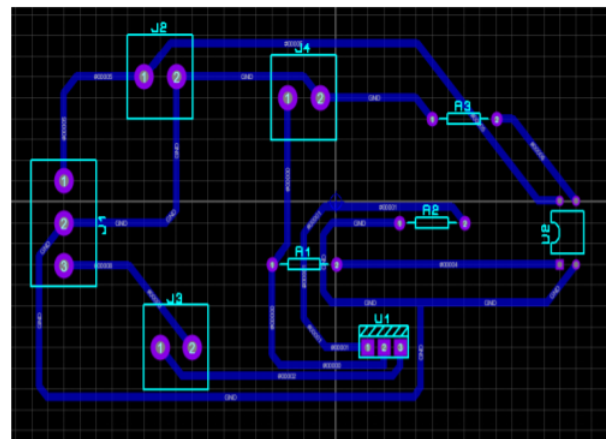
These are two waveforms taken at different angles. The first one shows output waveform at alpha - 45 degree. The blue wave shows the out.

**Digital Oscilloscope**



**Figure 23**

**PCB Design:**

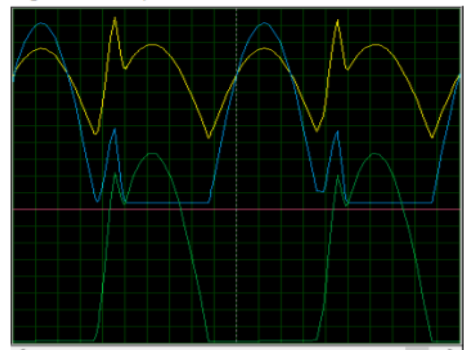


**Figure 27: PCB Design**

**Waveform of Full wave**

Following Waveform is not accurate due to some design problems; we are trying our best for the better result and still working on its design.

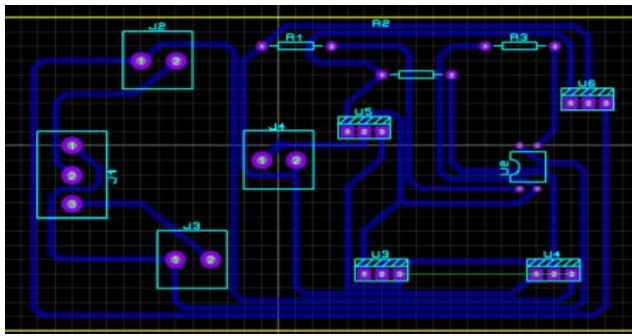
**Digital Oscilloscope**



**Figure 28**



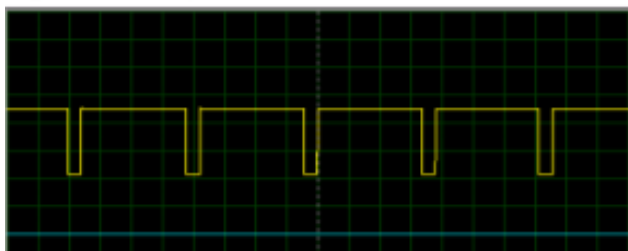
**PCB Design**



**Figure 29**

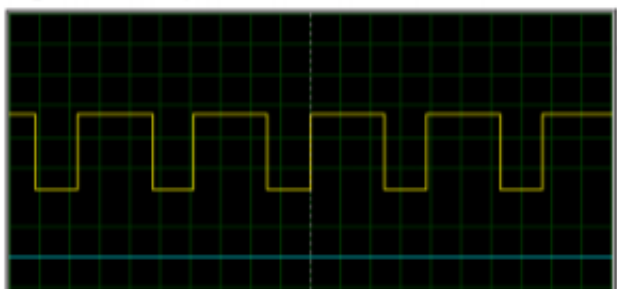
**MOTOR Speed Control Through MOSFET and IGBT: PWM Waveform:** Here are two forms at different duty cycles.

Digital Oscilloscope



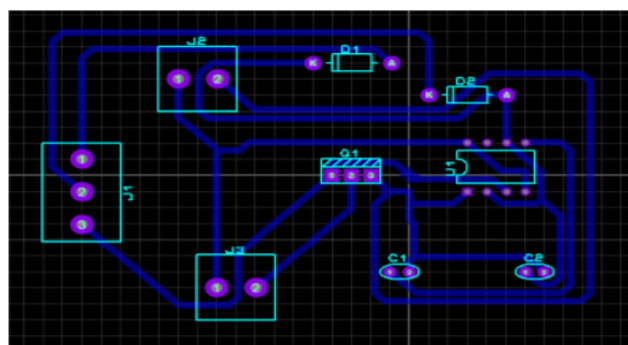
**Figure 30**

Digital Oscilloscope



**Figure 31**

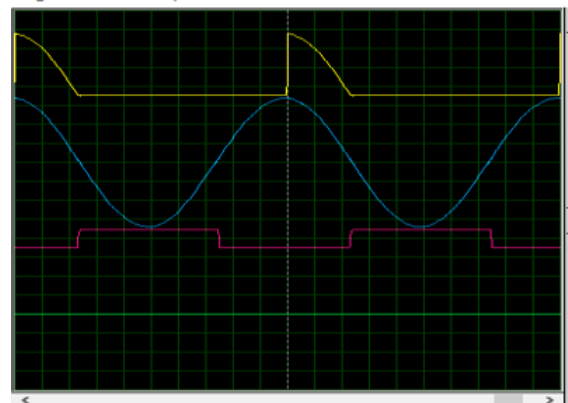
**PCB Design**



**Figure 32**

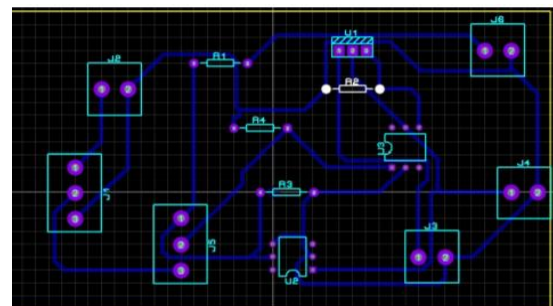
**TRAIC Characteristics Experiment**

Digital Oscilloscope



**Figure 33**

**PCB Design**



**Figure 34**

**Conclusion**

The trainer we designed is more efficient. It consists of the basic circuitry of power electronics and Microcontroller based applications. All circuits are provided with fixed voltages internally, will be controlled by switches just. The design is easy to carry and self-explanatory for the group of three people. This trainer is basically easy to handle version for the lab engineers and make their teachings more easier with the help of briefed designed present in the trainer. Moreover the Micro-controller used in some circuitry is controlling the angle delays of the SCR. Other than this we are generating pluses for spwm inverter, buck and boost circuitry. The designed is managed in such a way that we can get update to it. Micro-controller used in trainer was Arduino-NANO which was more compatible with all circuits and was cheap. For the low price trainer we find it the best Micro-controller in the market. Trainer consists of Vfd, Buck, Boost, SPWM inverter, Controlled Rectifiers, MOTOR Speed Characteristics using IGBTs and MOSFETS. These circuits are the pillars of power electronics and so we highlighted them in our trainer so it should be the best source of learning for the future engineers.

**References**

B. M. Hasaneen and A. A. Elbaset Mohammed (2008), "Design and simulation of dc/dc boost converter," in 2008 12th

- International Middle-East Power System Conference, pp. 335–340.
- M. R. Ruman, D. Paul, A. Barua, A. K. Sarker, A. Iqbal, and S. Barua (2019), "Design and implementation of spwm inverter," (ICCCIS), 2019, pp. 490–494.
- Li Huan, Li Wenjuan, and Cui Dongning (2013), "Automatic code generation of spwm for single phase inverter by model-based design," in Proceedings of 2013 2nd International Conference on Measurement, Information and Control, vol. 02, pp. 1035–1038.
- E. B. Agamloh, S. Peele, and J. Grappe (2017), "Operation of variable-frequency drive motor systems with source voltage unbalance," IEEE Transactions on Industry Applications, vol. 53, no. 6, pp. 6038–6046
- R. Rashmi and M. D. Uplane (2017), "A frequency response approach to design buck converter with over current protection," in 2017 Innovations in Power and Advanced Computing Technologies (i-PACT), pp. 1–6.