SIMULATION AND ANALYSIS OF POWER CONVERTER FOR SPECIAL APPLICATION

PRESENTATION

on

Project & Thesis Part-I (**EE761**)

BY

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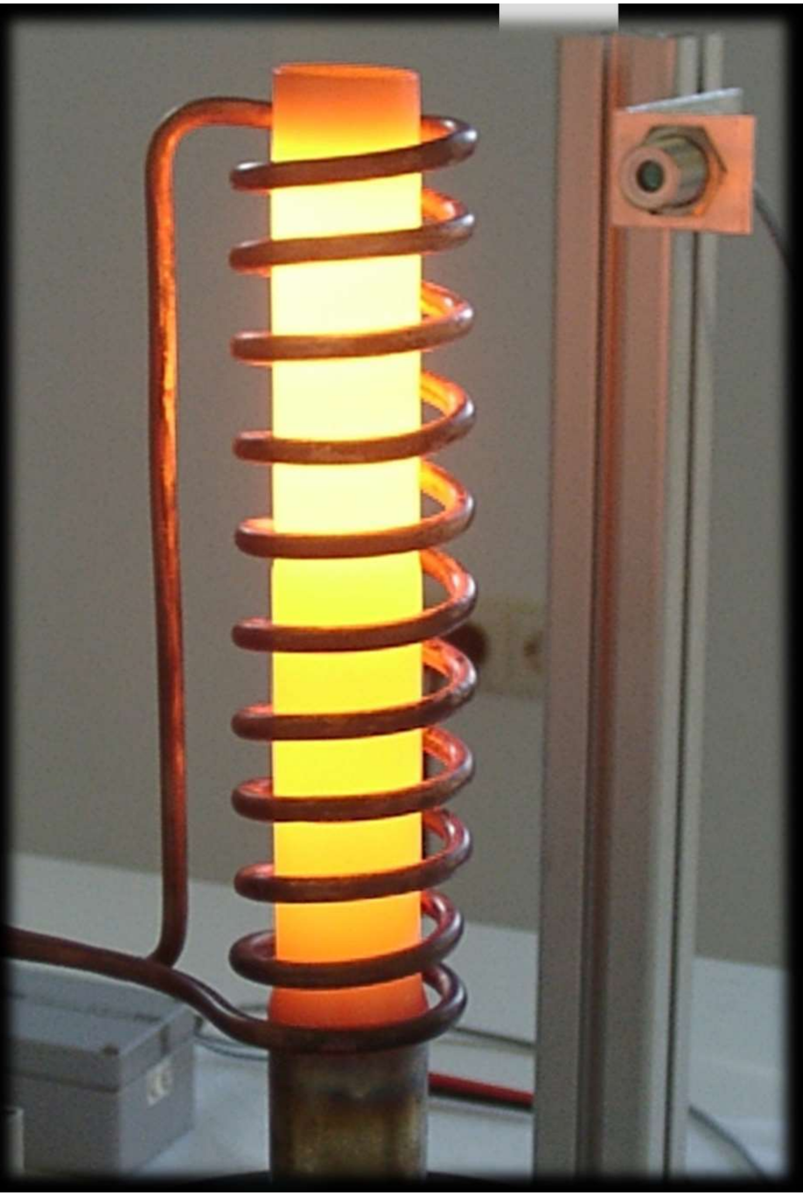

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INTRODUCTION

Induction heating is a non-contact heating process and also nowadays the heating technology of the choice in many industrial, domestic, and medical applications.

It uses high frequency electricity to heat materials that are electrically conductive.

Since it is non-contact, the heating process does not contaminate the material being heated.

It is also very efficient since the heat is actually generated inside the workpiece.

This can be contrasted with other heating methods where heat is generated in a flame or heating element, which is then applied to the workpiece.

INDUCTION HEATING

- It is the process of heating an electrically conducting object (usually a metal) by electromagnetic induction.
- It is a non-contact heating process.
- It uses high frequency electricity to heat materials that are electrically conductive.
- It is very efficient since the heat is actually generated inside the work piece.
- It is superior to their primitives' processes in terms of reliability, cost, efficacy, speed, accuracy, safety, and efficiency.

PRINCIPLE OF INDUCTION HEATING

- Induction heating is based on the principles of an electric transformer.
- Air is used as the coupling medium.
- High frequency (HF) current (1,000–100,000 Hz) is passed through the primary (coil) by connecting it to a suitable HF generator.
- A similar HF current is induced in the job, i.e., secondary. This current circulates and produces heat.
- The job thus gets heated by the induced current (Eddy Current).
- The heating is concentrated in a thin outer layer or skin of the work (Skin Effect).

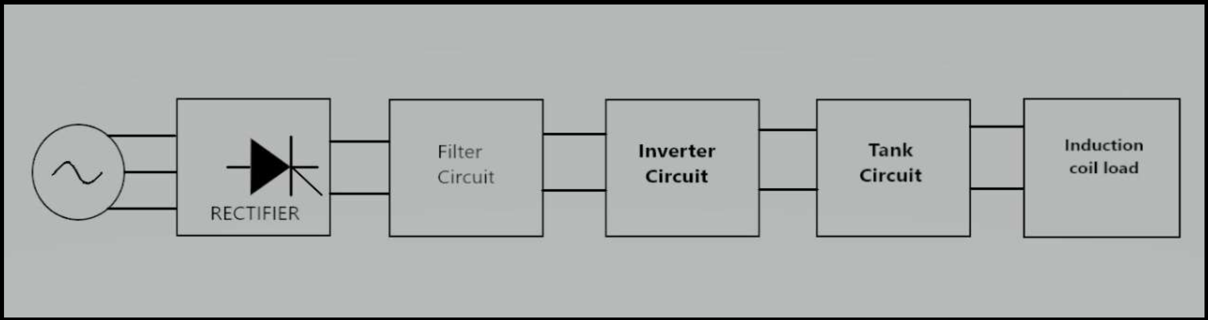
Factors on which heating effect depends

- Transformation of the electric energy into heat due to Joule effect (P=I2R).
- The depth *d* at which the current is 0.368 (= 1/e) of surface current is defined as the "depth of penetration".
- Depth of penetration is given by –

$$\delta = 5000\sqrt{\frac{\rho}{\mu_{\gamma} f}}\ \text{cm}$$

- Penetration decreases with increasing frequency.
- Resistivity *r* is directly proportional.

BLOCK SCHEMATIC OF INDUCTION HEATER



➢ Input to Rectifier is 50Hz, 3 Phase Supply which is rectified to the DC signal using an LC filter which is showed in second block here

➢ Here third block is the Inverter circuit which takes the DC output of rectifier as its input and output is the high frequency square wave

➢ Then comes the Tank Circuit.

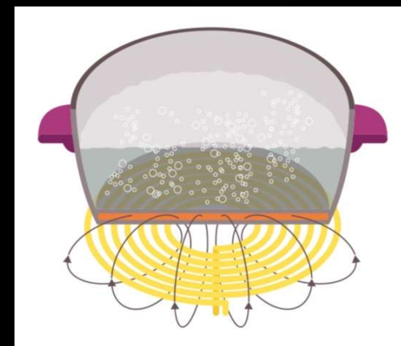
➢ It matches the load and generator impedances, corrects the power factor, and produces a resonant condition to derive maximum power.

➢Finally there is Induction Coil Load which we will design later.

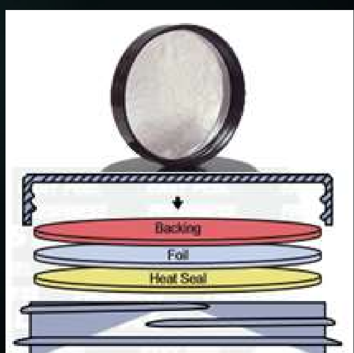
APPLICATION OF INDUCTION HEATING

Furnace

Welding



Cooking



Sealing

Heating to fit

Heat treatment

INDUCTION HEATING CONVERTER

Why AC to DC to AC type of converter?

- Induction heating requires variable frequency source.

  Penetration depth depends on the operating frequency.

  In the adjacent figure, A is fed with higher frequency than B.

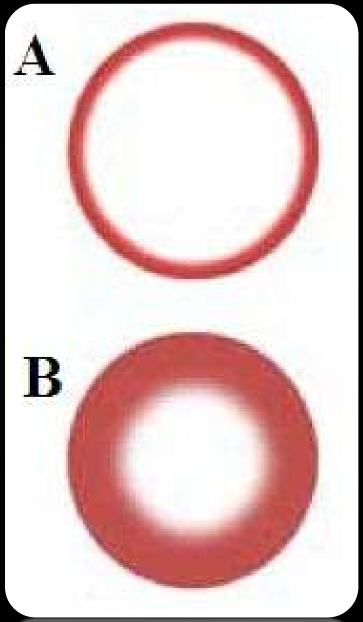
- Voltage should be controllable and oscillatory.
- Power required is determined by:

a) The type of material

b) The size od the work piece

c) The required temperature rise

d) The time to reach the temperature



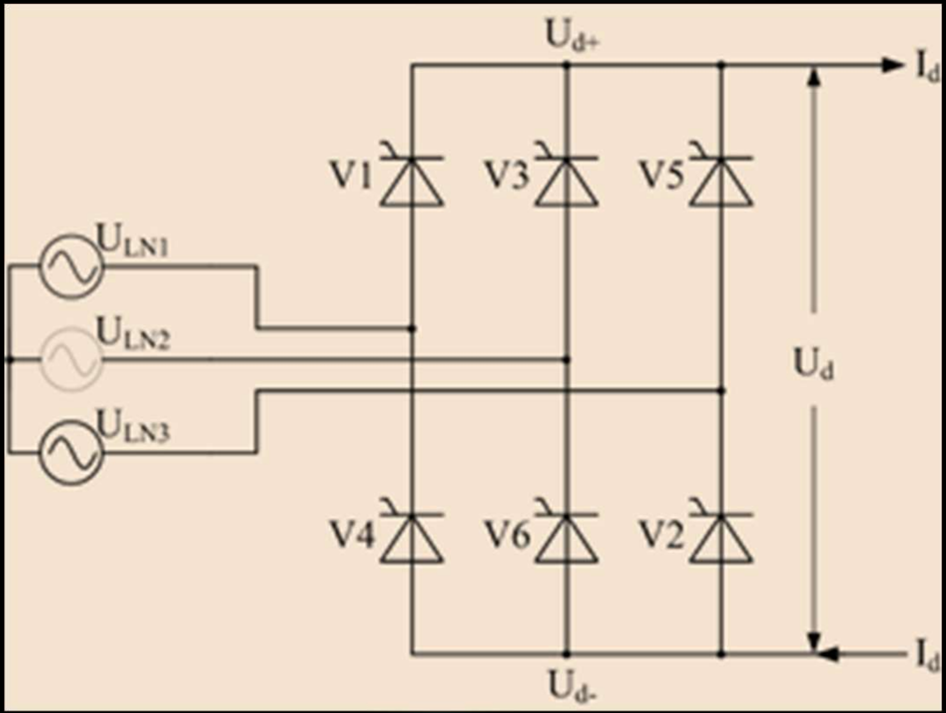
So, a natural choice is rectifier for converting from AC to DC and Inverter to convert it back to AC of variable frequency.

THREE-PHASE RECTIFIER

Here, we have used three-phase full wave SCR controlled rectifier.

- Provides two quadrant operation
- For the given numbering,

  Gate triggering sequence is 1-2, 2-3, 3-4, 4-5, 5-6, & 6-1
- Frequency of Ripple voltage is 6f.
- Small filter required compared to single phase rectifiers.



POWER CIRCUIT OF THE RECTIFIER

- Let's consider the line to neutral voltages at the input of the rectifier as:

$$v_{an} = V_m \sin \omega t$$

$$v_{bn} = V_m \sin(\omega t - 120°)$$

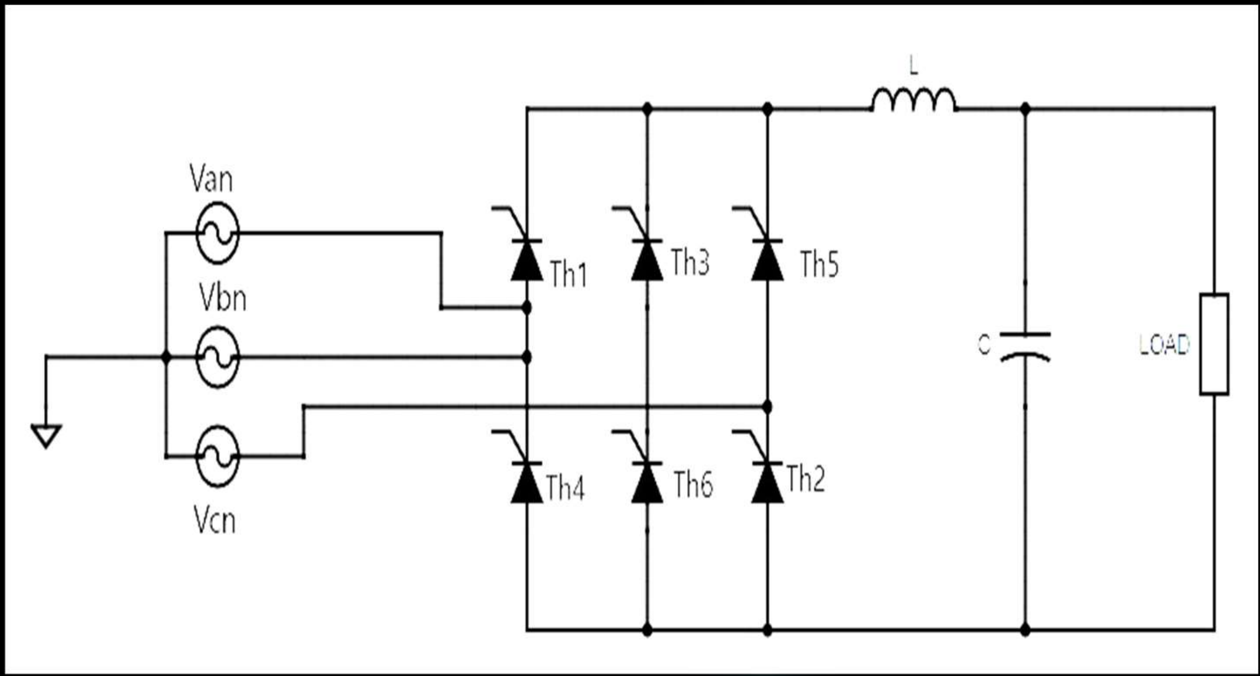
$$v_{cn} = V_m \sin(\omega t + 120°)$$

- For the above the average output voltage is given by:

$$v_{dc} = \frac{3\sqrt{3}V_m}{\pi} \cos\alpha$$

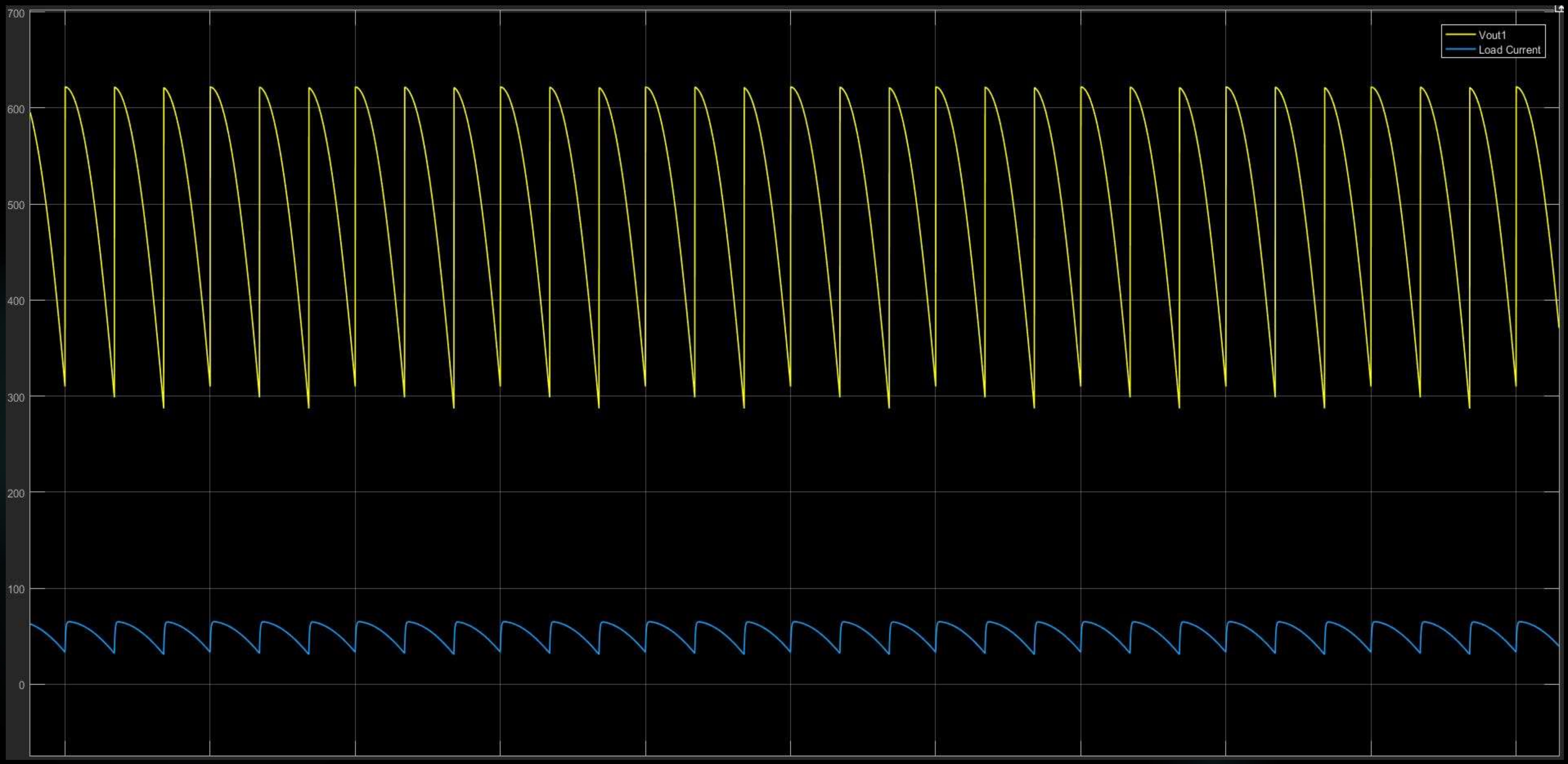
- And the rms output voltage is given as:

$$v_{rms} = \sqrt{3}V_m \left(\frac{1}{2} + \frac{3\sqrt{3}}{4\pi} \cos 2\alpha\right)^{1/2}$$



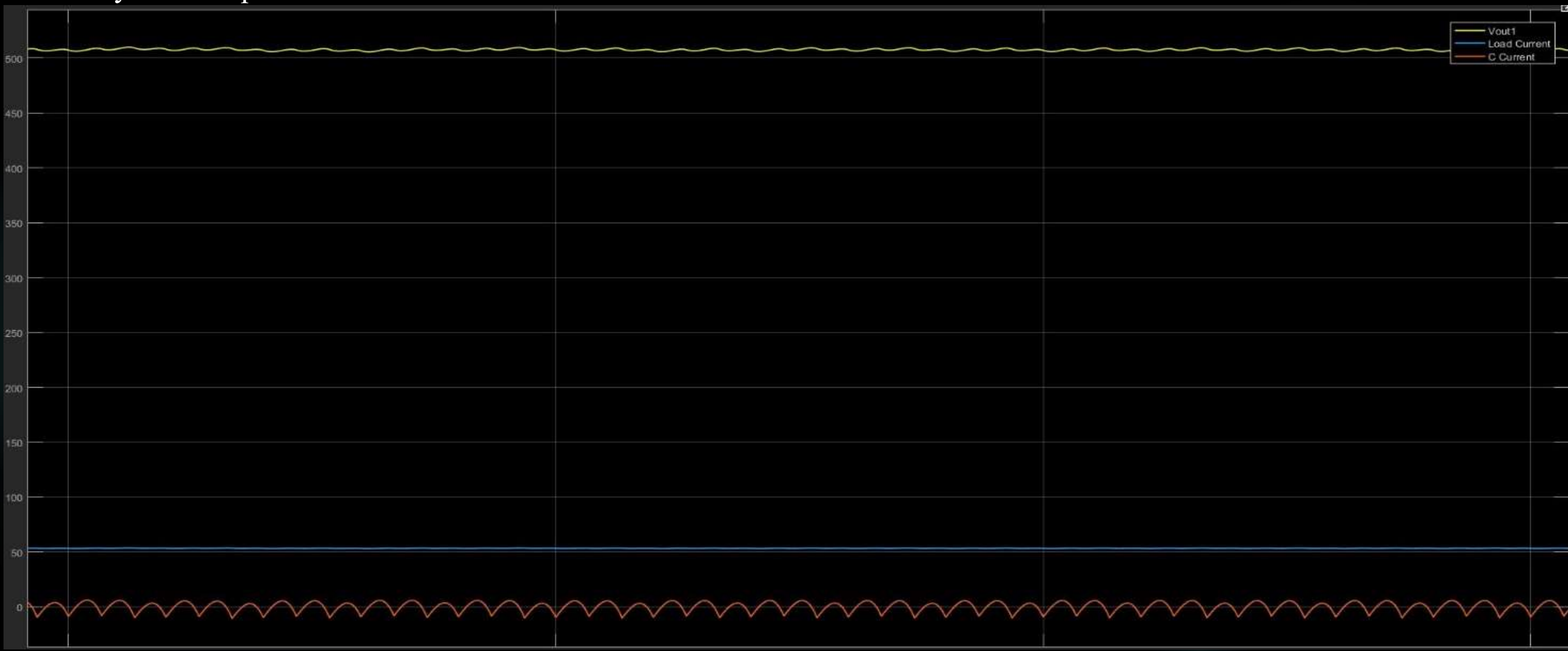
POWER CIRCUIT OF THE RECTIFIER:- SIMULATION RESULT

Rectifier output without using the LC filter at α=30º



POWER CIRCUIT OF THE RECTIFIER WITH LC FILTER:- SIMULATION RESULT

Steady state output of the rectifier for RL load with LC filter at $\alpha=30^{o}$



TRIGGERING CIRCUIT OF RECTIFIER

- The pulse circuit is required to trigger thyristor T1, T3, and T5 shifted by 120° and similarly T2, T4, and T6.
- Gating sequence: 1-2, 2-3, 3-4, 4-5, 5-6, & 6-1.
- Pulse train used as triggering signal.

■ The logic followed to generate each gate triggering pulse train is as follows:

a) Using a zero-crossing detector, generate a 180° pulse of uniform magnitude.

b) Pass it through an integrator to generate a ramp signal.

c) Compare it with a suitable voltage level control signal and generate a uniform magnitude signal for the duration it remains higher than the control signal.

d) And the signal with high frequency clock signal to generated the final output signal to be connected to the gate of the thyristor.

e) Reset the integrator before the next signal.

TRIGGERING CIRCUIT OF RECTIFIER: Simulation result for $\alpha=30^0$

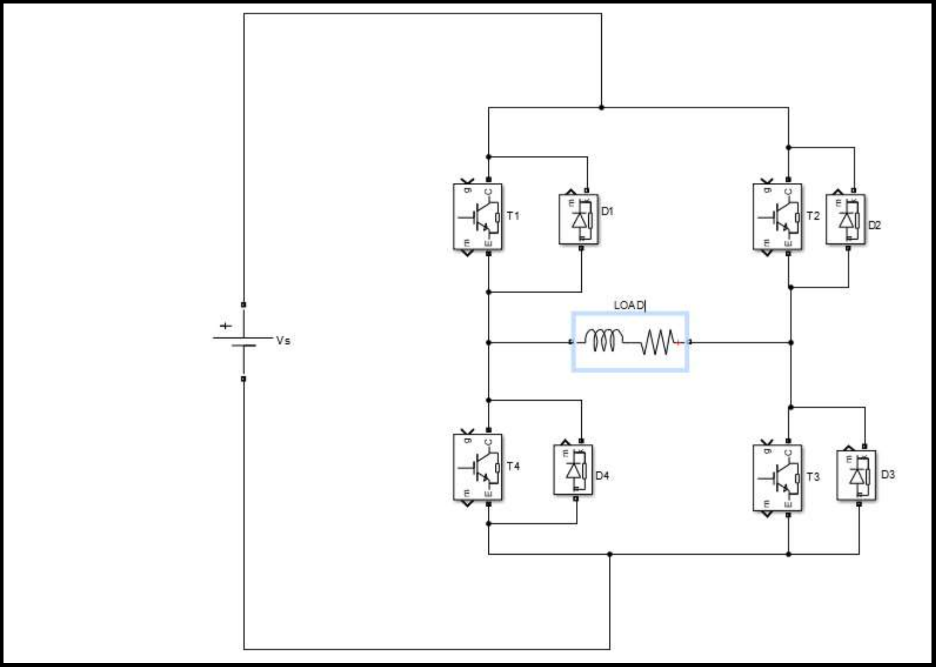
INVERTER

Points to be explained:

- Power circuit
- Control circuit and control strategy
- Future expansion plans

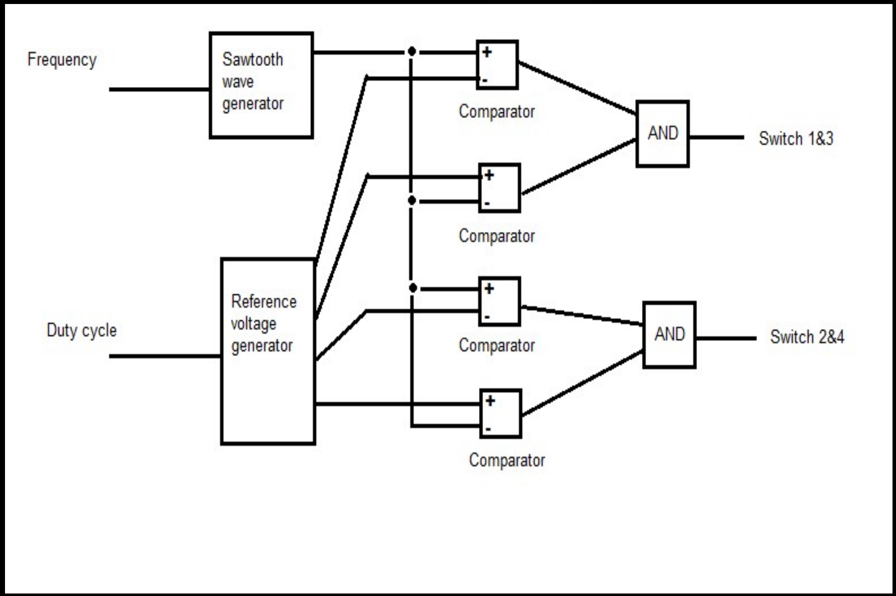
Power Circuit

- Here we are using 4 IGBTs as switches
- 4 antiparallel diodes connected with switches
- In order to design we used 500V DC voltage source. In next stage of the project output of rectifier would be connected as input to inverter.
- This inverter is rated for 50A and power factor of 0.7 and above.



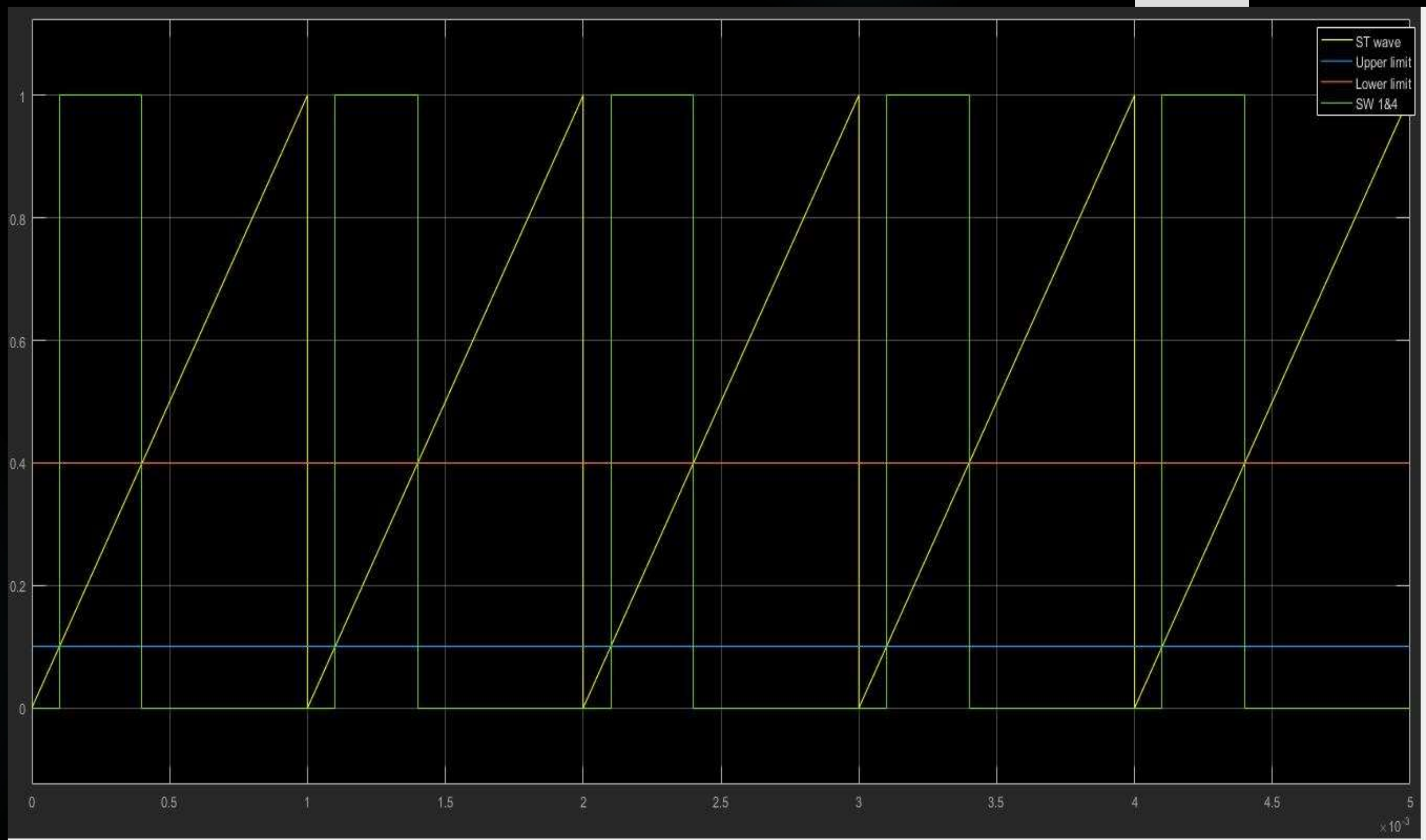
Control circuit

- In this attached figure basic workflow and logic is shown. Here our objective is to implement frequency control and rms voltage control by SPWM method.
- Sawtooth wave generator block is generating sawtooth wave of desired frequency(input) and max value 1.
- Reference voltage generator generates suitable reference voltages as bandwidth for desired duty cycle.
- Comparator and AND gate together are used for bandwidth comparison.



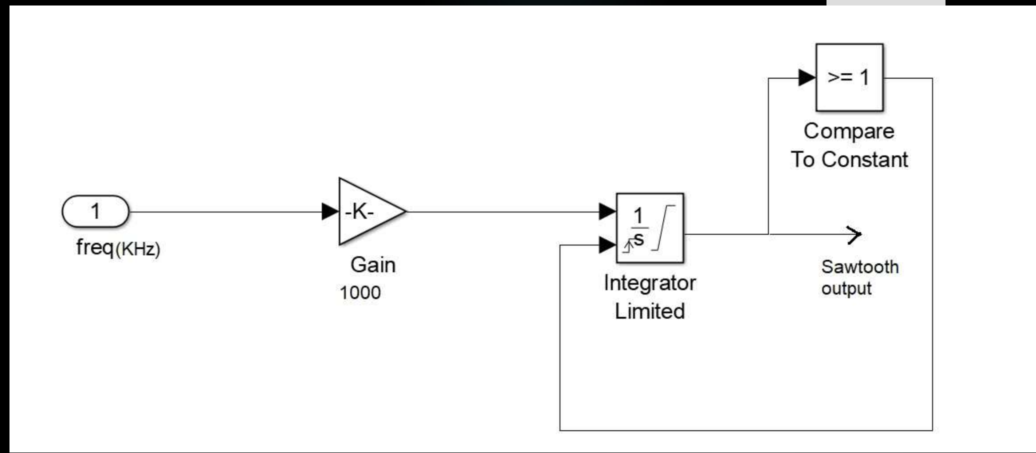
In this figure pulse generation topology is clearly shown. This example given is for pulse generation for switch 1 and 3 for frequency of 1KHz and duty cycle of 60%.

- Yellow line stands for ST wave.
- Blue and red lines are for lower and upper limit of bandwidth.
- Green line is pulse for switch 1



As logic and topology of pulse generation is already shown, now lets focus on detailed function of Sawtooth wave generator and reference voltage generator.

- In sawtooth wave generator an integrator is used with a gain of 1000 and it gets reset as its output reaches to 1.

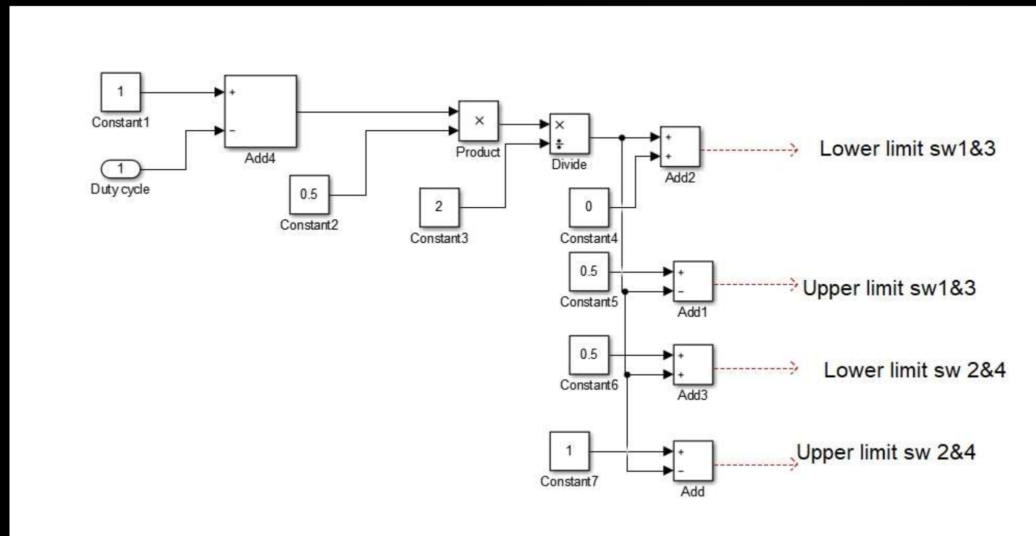


- In reference voltage generator logic of calculating reference voltage for corresponding duty cycle is implemented. The logic is if x is duty cycle(0<x<=1)

e=(1-x)/2 ; then the limits will be :

UL1,3=0.5-e; LL1,3=0+e

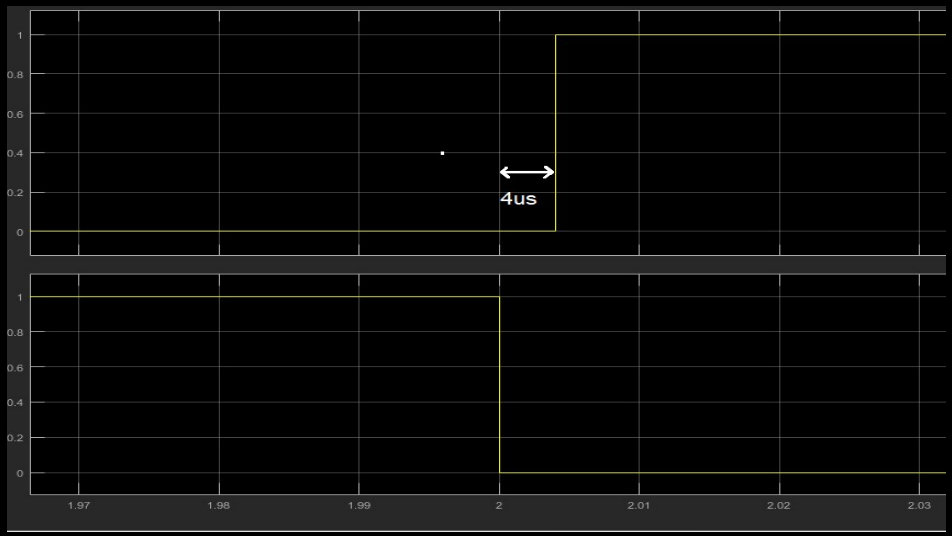
UL2,4=1-e; LL2,4=0.5+e



❖ Notes-

- Dead time: Dead is provided for safe switching of switches. Dead time provided is around 4us which is enough for switching off of typical IGBT.

- As we are dealing with inductive load, so during switching unwanted voltage spikes are coming . In order to reduce that spikes we are operating to switches at same leg (sw2&3) for desired duty cycle and other two switches (sw1&4) for entire half cycle(180’).

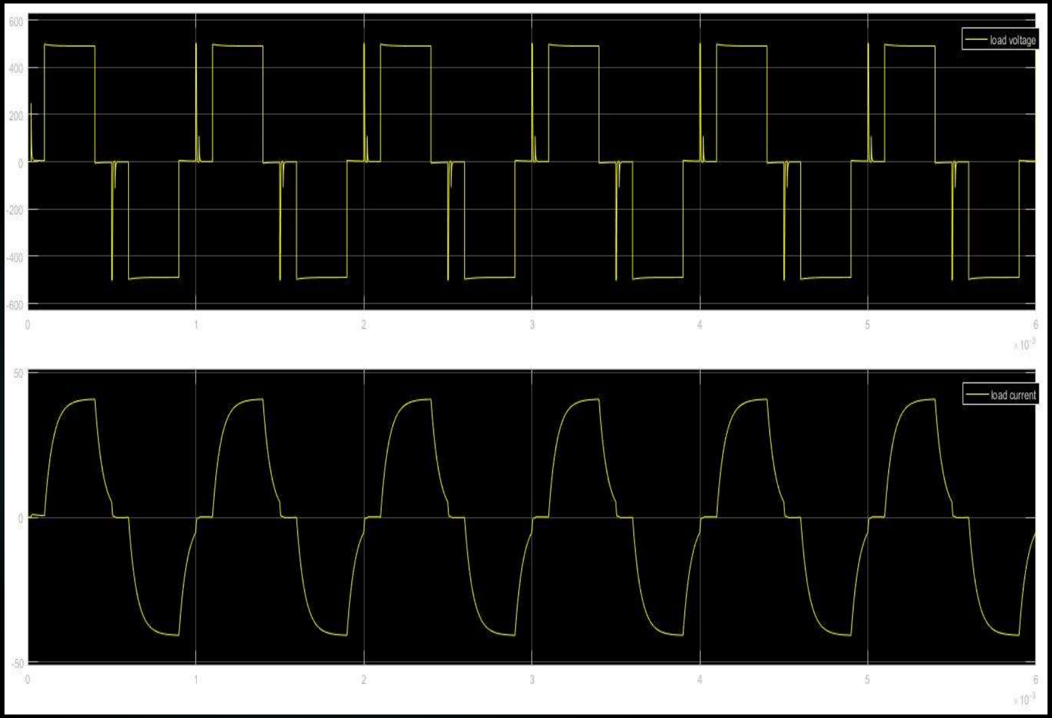


Dead time

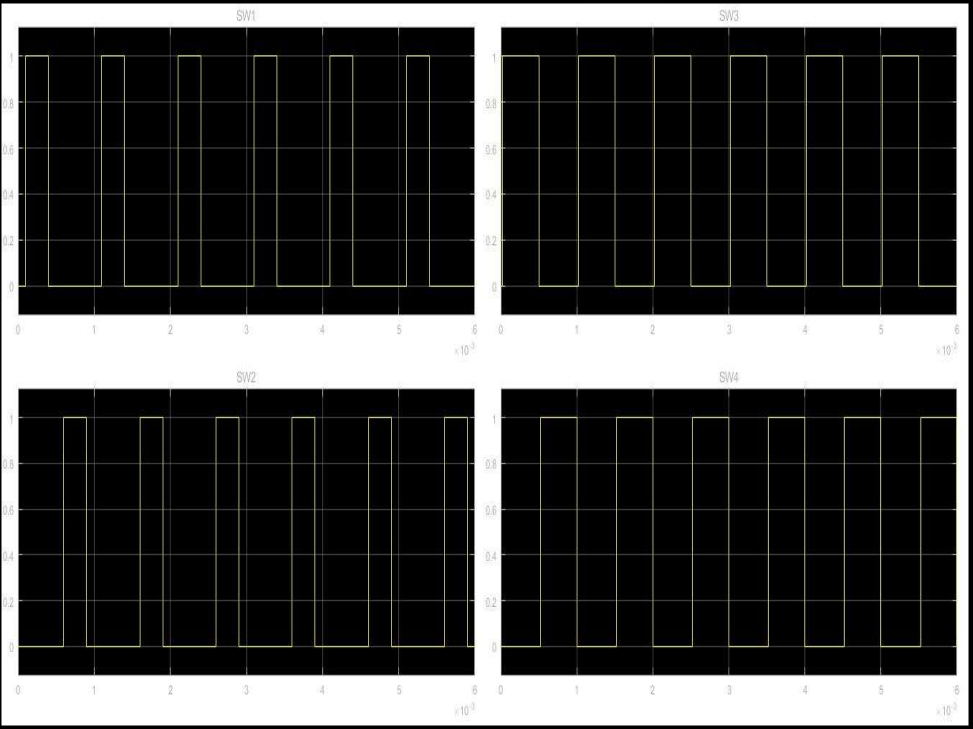
Some important waveforms:

Load voltage(rms)-387V
Frequency-1KHz

Load current(rms)-29A
P.F-0.8(lagging)



Load voltage and current



Pulses for 4 switches

OPEN LOOP CONTROL STRATEGY

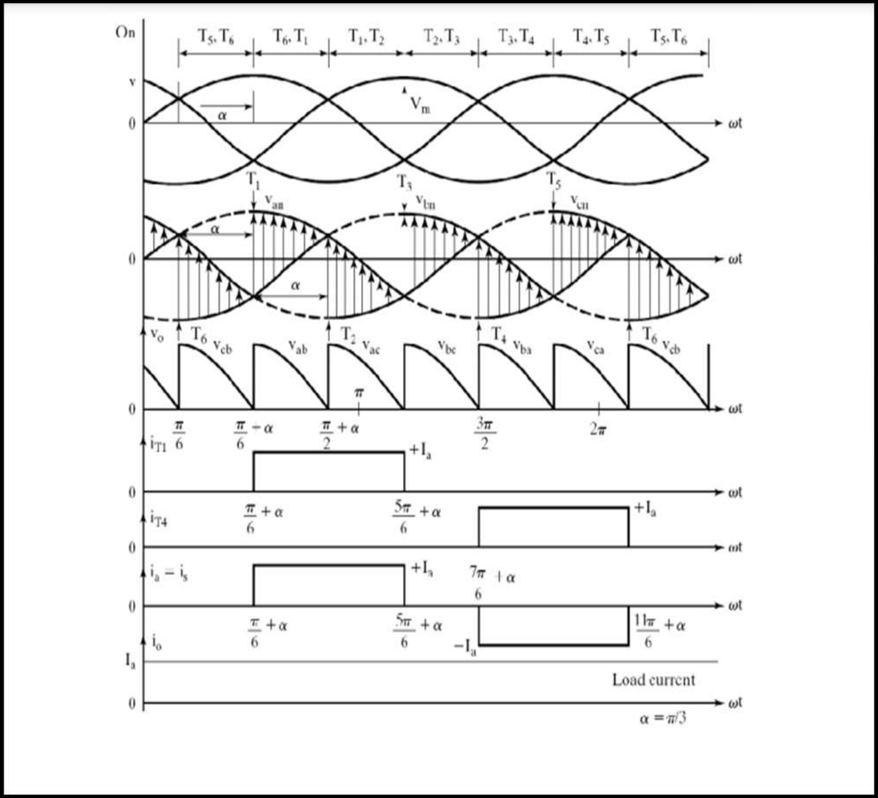
- Three Phase Controlled Rectifier Circuit

  Firing angle control

- Single Phase Inverter

  PWM control

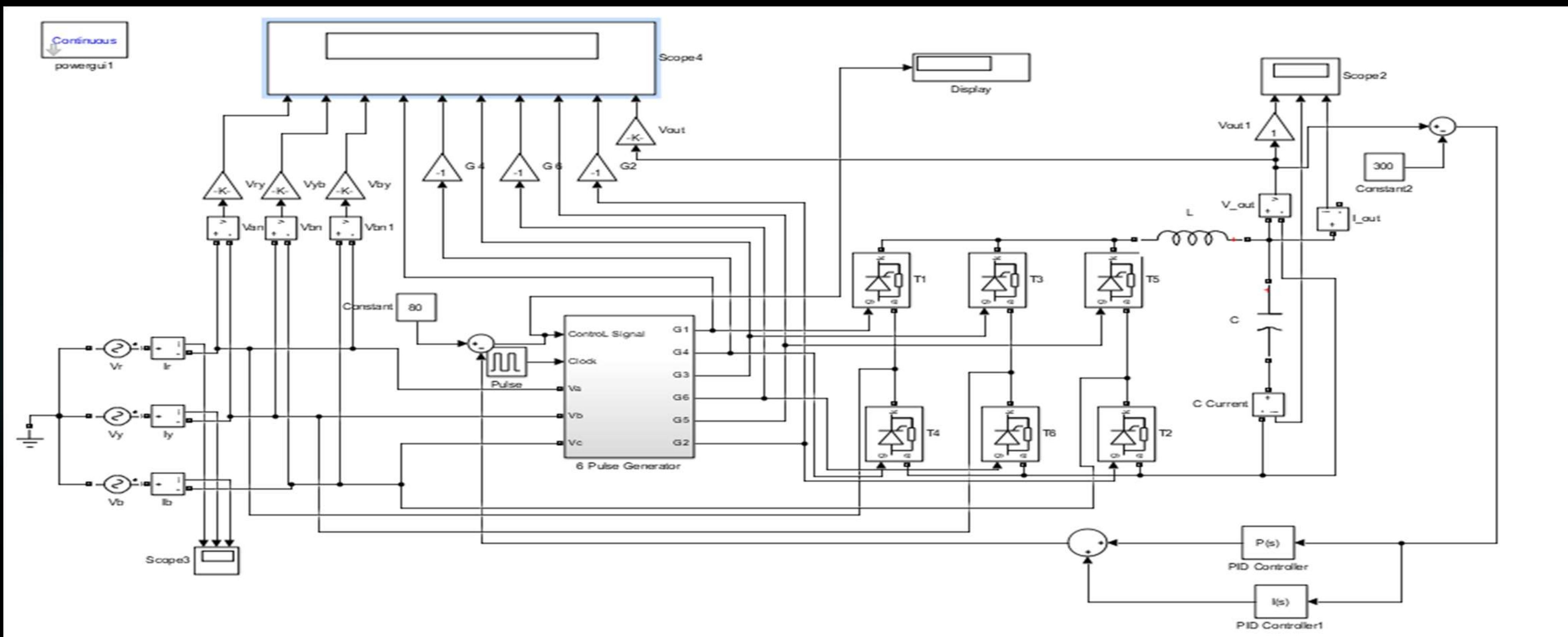
  Frequency control



CLOSED LOOP CONTROL STRATEGY

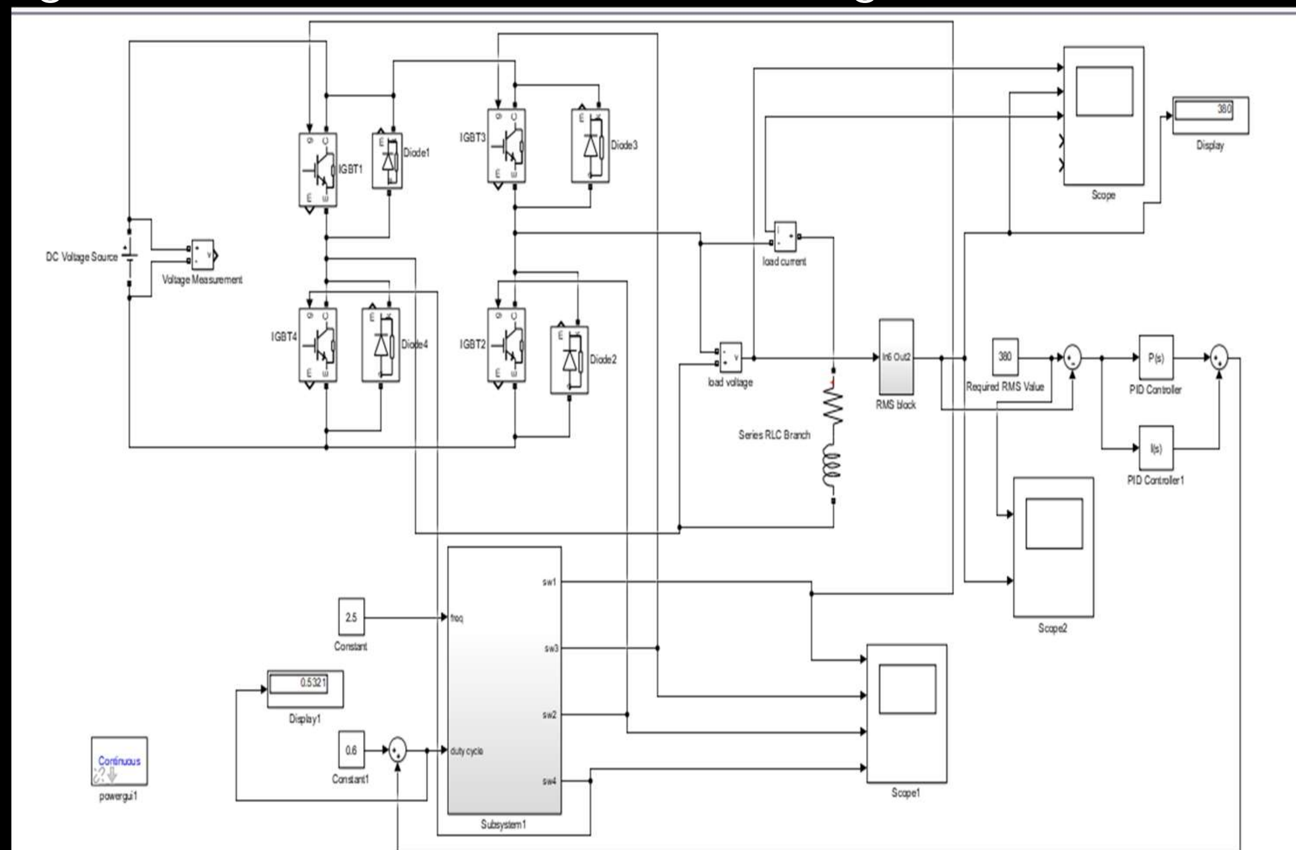
- Three Phase Controlled Rectifier Circuit

  Proportional-Integrator (PI) controller



- <u>Single Phase Inverter</u>

In this converter the required signal is the RMS value of output AC signal which is first compared to the inverter output signal's RMS value and then that error signal is fed back to the inverter circuit pulse duration



control signal using an adder. The feedback path contains a Proportional-Integrator (PI) controller which determines the transient and steady state response of the output signal.

Expansion of this section in next stage:

- Input of this circuit is going to be output of the rectifier we developed.
- Close loop control has already been implemented individually for both rectifier and inverter. A further algorithm has to be implemented to synchronise between this two control strategies.
- In order to achieve zero current switching is required so that's why a series resonance tank circuit is to be connected about which already discussed in report.
- Coil has to be designed for suitable rating and connected for heating purpose.


THANK YOU