DESIGN OF EXCITATION SYSTEM FOR SYNCHRONOUS GENERATOR USING DC-DC CONVERTER

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

WATER RESOURCES DEVELOPMENT

By

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CANDIDATE DECLARATION

I hereby certify that the work which is being presented in the dissertation titled "DESIGN OF EXCITATION SYSTEM FOR SYNCHRONOUS GENERATOR USING DC-DC CONVERTER" in the fulfillment of the requirements for the award of degree of Master of Technology in "Water Resource Development in Water Resources and Management Department of Indian Institute of Technology-Roorkee", is the evidence of my original work which is conducted during the period from May 2012 to June 2013 under the direction and supervision of Dr. D.D Das, Professor in Department of Water Resource Development and Management, and Dr. S.P Singh, Professor in Department of Electrical Engineering, "Indian Institute of Technology-Roorkee, India".

The work and the matter presented in the above mentioned dissertation has not been submitted for the award of any other degree by me.

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CERTIFICATE

This is to certify that the statement made by the student as mentioned above is appropriate and correct to the best of my information and knowledge.

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ABSTRACT

The dissertation titled as, "DESIGN OF EXCITATION SYSTEM FOR SYNCHRONOUS GENERATOR USING DC-DC CONVERTER", deals with the introduction of the basics of the excitation system, synchronous generator along with relevant power electronics, power converters and PWM technique. The basic aim of the dissertation is to design an excitation system for synchronous generator using power converter that is the application of DC – DC boost converter, which can control the terminal voltage under all kinds of operation conditions.

It includes the analysis of the boost converter along with its designing and simulation at different loads in open - loop and close - loop conditions. The methodology for the design and development of excitation system for synchronous generator by DC-DC converters using PWM technique, involves sensing of the terminal voltage of the synchronous generator compared to a constant value (which is the supposed value of the terminal voltage of the generator as per the design parameters).Thereafter the difference of the two is amplified and a pulse is generated by the pulse width modulator proportional to the difference, which is further given to the switch like IGBT or MOSFET which generates a pulse, which in turn changes the duty ratio and maintains the output again, so this forms a complete close loop system.

The whole system, that is synchronous generator integrated with the close – loop boost converter, is given different load conditions and the outputs are simulated in Simulink, which concludes that the terminal voltage of the synchronous generator is maintained same all-time.

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LIST OF SYMBOLS

C	Capacitance
D	Duty Ratio
F	Frequency in hertz
G	Generator
Ki	Integral Gain
Kp	Proportionality Gain
L	Series Inductor
N	Speed Of The Generator Rotor
P	No. Of Poles Of The Generator
Po	Output Power
Rg	Internal Resistance
R_L	Load Resistance
Toff	Switch Off Duration
Ton	Switch On Duration
Ts	Total Duration
Vc	Amplified Error Signal
Vg	Generator Open Circuit Voltage
Vi	Input Voltage
Vo	Output Voltage
Vst	Peak Of Saw Tooth Waveform

Chapter 1: THE INTRODUCTION

1.1 GENERAL INTRODUCTION

The consumption of electrical energy has been increasing at a rate higher than that witnessed during the previous century. Across the era of 2006 - 2030 authorized estimates indicate a total of 44 percent rise in power consumption of the globe [1].Due to the rise in the global electrical energy consumption it is the need of the hour to increase the overall power capacity but the deregulation of electrical power has been a main subject of concern, which has dropped the stocks in large power plants. A solution to this set back is to apply new electrical power sources in upcoming times, and in additional the production, distribution and transmission ought to be in such a manner that the custom of the power have to be technical competent and way to preserve power at the final -user ought to be made.

A method to fill the gap is by applying power electronics in the present systems. [2] It is one of the upcoming technologies in electrical engineering, being used in different applications [3]-[4].Important parameters of power delivered are frequency and voltage which were controlled by the large power generator units (synchronous generators).In new systems the power electronic interface is the one which regulate the voltage, frequency, and power which link the energy source to the grid. This leads to fast control of active power and reactive power, which are typically the key parameters to control the frequency and voltage of the system.

With the recent development in the power electronic devices, control conversion from one from to another form has become increasingly simpler. Three important problems which are achieved with the use of power converters are: efficiency, reliability and cost. [5]

Now with the application of these power converters[2]-[4] a new design of excitation system is proposed for the existing synchronous generators, with the help of Pulse width modulation [6] in the Dissertation, which tries to overcome the problems, faced in the traditional excitation systems.

1.2 EXCITATION SYSTEM

The process of generating a magnetic field in the synchronous machine by means of an electric current is called excitation. Its functions are to supply direct current to the generator field windings, improve the stability of the power system, control the reactive power flow between the generator and the grid, regulate the generator terminal voltage, and provide limiting and control functions to the generator when it works in association with the machines connected to the grid. [8]- [9] Figure No 1.2 shows a block diagram of the excitation system of synchronous generator.

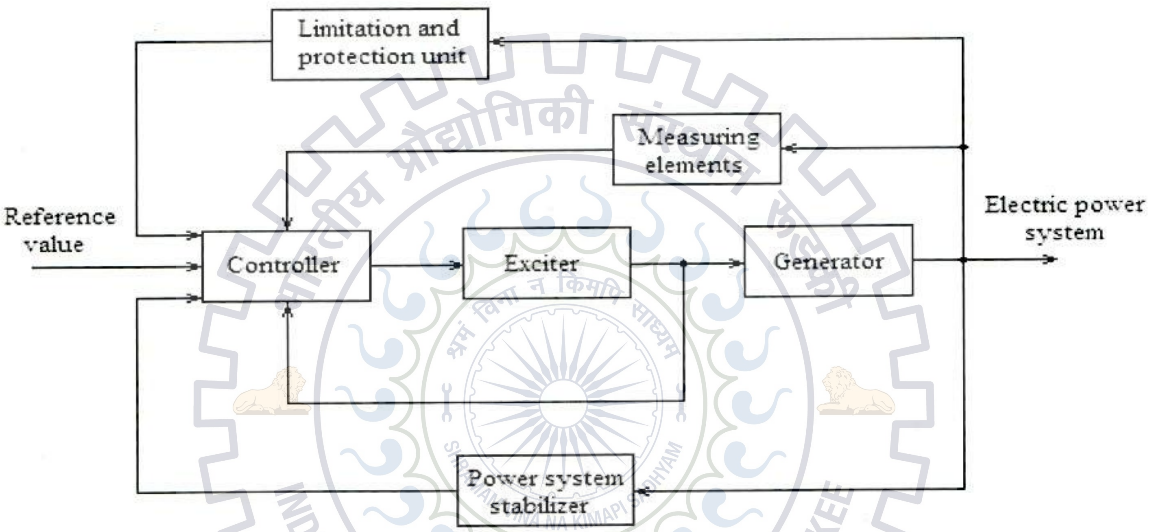


Figure 1.1 The Excitation System of Synchronous Generator

1.3 LITERATURE REVIEW

The effective control of the output of power system is an important method to overcome the upcoming energy crisis and its quality [5]. Since the regulation of the terminal voltage of the synchronous generator has been a major concern, over the years. Initially the linear regulators were used to control it, but had poor efficiency and output percentage was also less. [7] - [9]. Now, with the advent of power electronics, the power converters do the need full job with good performance index and efficiency. [1] So, as with the change in operation conditions or variation in the load the voltage remains constant, which has also been mentioned by M.P. Kazmierkowski and R. Krishnan. [2] In their paper.

F. Blaabjerg, Z. Chen and R. Teodorescu, [3] have introduced the role of power converters in various renewable energy sources, and there applications such as in wind, solar, hydro etc. They have also shown that the behavior and performance has improved, and they help in reducing energy cost. Mohan, N., Undeland, T. M., and Robbins, W. P [18] and M. H. Rashid [29] have displayed the various possibilities of use of power converters. Also how the working of converters can control the voltage and frequency of the system.

As, there are various kinds of generators Tesla, Nikola have mentioned about alternating electric current generators in detail .Shih-Jung Yang, Wai S. Leung, and John S. C. Htsui, have discussed about types of excitation system, there advantages, and there suitable application. [36]-[37]. Chan-Ki Kim, Byung-Mo Yang Bong-Eon Kho and Gil-Jo Jeong [38] have talked about Performance Analysis of Excitation System of Synchronous Machine.
With the implementation of PWM with the excitation the overall output response increases. Dr. Diya and Ali Al-Nimma, have mentioned about the parameters and how they are able to control step response/transfer function for a certain range for constructing a close loop converter with the application of PWM. After which RfanYazici have shown the real time implementation of system. [26]. A. Davoudi, J. Jatskevich and T. D. Rybel [14], have talked about the pulse width modulation technique which makes it faster for response to generate.

Though not much of work has been done in this field of using DC - DC converters as excitation system, as this is a new application of the converters, still S. Masri and P. W. Chan, [30] and Hong-Woo mew, SeUng-Ki SUI [37] have showed the results of controlling only the output of boost converter with variable input.

1.4 AIM OF DISSERTATION

The main objective of the dissertation is to design and develop an excitation system using DC - DC converter for regulating the terminal voltage of synchronous generator for variable load conditions.

So, that with the change in load, the output terminal voltage of the synchronous generator remains constant. The proposed system increases the reliability of the generator, and the overall performance. This system has fewer components compared to the conventional excitation system. During the decreased in input line voltage the field voltage is able to be stepped up to uphold or to rise the field current with the help of close loop boost converter.

This is achieved when, a Terminal voltage is sensed and compared with the reference voltage with a comparator. Thereafter the error is amplified and process through a PI controller to generate a pulse for switch, which enables to regulate the voltage given to excitation system of the generator. As, the error is positive, there is a drop in the terminal voltage and the pulse width increase. When the error is negative, there is gain in the terminal voltage and the pulse width decreases. PWM technique is used to control the output of converter, so the input for the converter is derived from the generator terminal and its output is controlled by a switch such as IGBT or MOSFET.

This aims to intensify or enhance the performance of the system and upholds the terminal voltage constant for variable load. Also the proposed excitation system aims to achieve lot of advantage which over the traditional system: It provides fast control of reactive power, improved steady-state response and transient response, also overall increased stability characteristics and most important it provides high efficiency.

1.5 DISSERTATION STRUCTURE

The Dissertation titled "Design of Excitation System for Synchronous Generator Using DC - DC Converters" has been divided into six chapters reflecting step by step approach.

Chapter 1: "THE INTRODUCTION", this chapter comprises of the basic concepts of synchronous generator, important parameters for working of synchronous generator, excitation system, power electronics, power converter, pulse width modulation, along with the literature survey, the aim of the Dissertation and it also includes the structure of Dissertation.

Chapter 2: "THE DC - DC CHOPPERS", this chapter includes the basic introduction, followed by the concept of linear voltage regulator and a basic switching converter, after that it introduces the types of converters and explains in detail the DC –DC buck converter and the DC - DC boost converter. Further the analysis of DC - DC boost converter is done, then the various open loop DC – DC boost converters are designed with different parameters and same is checked with different load conditions for respective outputs.

Chapter 3: This chapter titled as "THE CONTROL SYSTEM DESIGN OF THE DC –DC BOOST CONVERTERS" it includes the basics of pulse width modulation, PID controller, control flow chart which explains the complete working of the close loop converter. Next the modeling of a close loop dc–dc boost converter is done, and the final design and specifications of DC – DC close loop boost converter are specified, along with its structure in Simulink. Thereafter its output are obtained for different load conditions. In conclusion a comparison is done between chapter 2 and chapter 3 outputs i.e. same design parameters of boost converter but with and without PID controller.

Chapter 4: "THE DESIGN AND SPECIFICATIONS OF SYNCHRONOUS GENERATOR" This chapter includes the basic parameters for the design of synchronous generator for the above mentioned application and its Simulink models.

Chapter 5: "THE INTEGRATION OF THE DC - DC BOOST CONVERTER WITH THE SYNCHRONOUS GENERATOR", This chapter includes the particular designed synchronous generator from chapter 4 which is integrated with the final close loop DC –DC boost converter from chapter 3 and then the output is checked with different loads for the final working of the system.

Chapter 6: "MAIN CONCLUSION AND FUTURE SCOPE", this chapter comprises the conclusion of the entire Dissertation and also states the various advantages of choosing and designing the DC –DC boost converters as excitation system, along with the further scope of research and development of same concept in different applications.

Chapter 2: THE DC –DC CONVERTER SYSTEM

2.1 INTRODUCTION

The DC - DC converters are the power electronic circuits that change a DC voltage level to a different DC voltage level, providing a regulated output. The DC-DC converters are usually utilized in applications that need manipulated DC power (power), such as, television receivers, computers, contact mechanisms, health instrumentation, and battery chargers [17] - [18]. The DC-DC converters are additionally utilized to furnish a regulated variable DC voltage for the application of the DC motor speed power. The main purposes of the dc–dc converters are:

•To change a dc input voltage V_S into a wanted dc output voltage V_O

•To power the dc output voltage vs. load and the line variations

•To cut the ac voltage ripple on the output voltage below the needed level

•To furnish isolation between the load and the input source, though isolation is not always required

•To guard from electromagnetic interference (EMI), the supplied system and input source

•To fulfill different nationwide and global protection standards.

The DC-DC converters work in one of two manners reliant on the characteristics of "the output current" [17] [18] that are as following:

1. Continuous conduction
2. Discontinuous conduction

The continuous-conduction mode is explained as continuous output current present above the whole switching period that is larger than zero, and the discontinuous conduction mode is well-explained as discontinuous output present across each portion of the switching period that is equal to zero.

2.2 THE LINEAR VOLTAGE REGULATORS

A simple circuit is one method of changing a dc voltage to a lower dc voltages as shown in Figure No 2.1.The output voltage is where the load current is manipulated by the transistor [19]. The output voltage could be manipulated above a scope of 0 to roughly ebullient to input voltage Vs, by just regulating the transistor base current. The result of the output can be completed by base current adjustment. As the transistor operates in linear region, consequently this kind of circuit is known as "a linear DC -DC converter or a linear regulator".

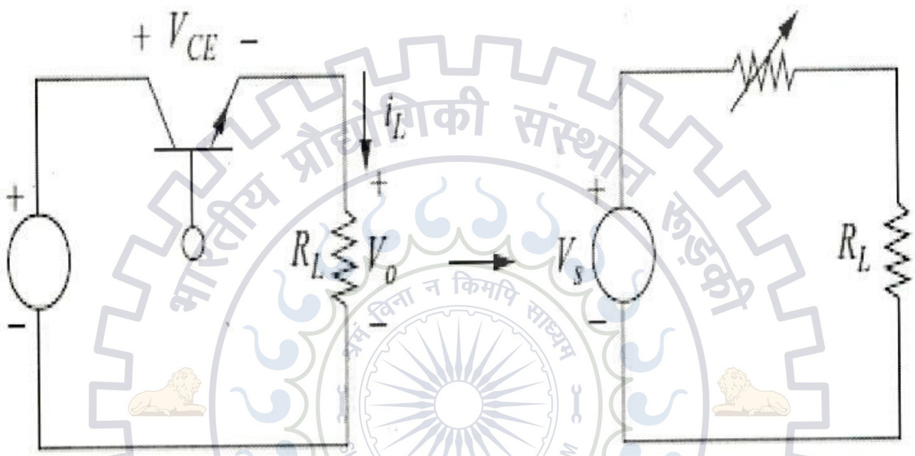


Figure 2.1 A Linear Dc –Dc Converter or Regulator

The transistor in result operates as a variable resistance. Nevertheless it could be an easy method of changing a dc supply voltage to a lower dc voltage and manipulating the output, but the low efficiency of this circuit is a main drawback for power system applications. Due to The power loss in the transistor, it makes the circuit inefficient, in case if the output voltage is (one-fourth) of the input voltage, the load resistor absorbs (one-fourth) of the source power that leads to an efficiency of twenty five percent. The transistor absorbs the supplementary seventy five percent of the power supplied by the source. Lower output voltages results in even lower efficiencies. Therefore, the linear voltage overseer is appropriate only for low-power applications

2.3 A BASIC SWITCHING CONVERTER

An alternative to the above mentioned regulator is the application of the switching converter. In a switching converter circuit, the transistor works as an electronic switch this circuit which is called as a dc chopper and an ideal switch is shown in Figure No 2-2. (a) When the switch is closed the output is alike as of input. Figure 2.2(b) shows when switch is open, the output is equal to zero. The output of switching equivalent of converter is shown in Figure No 2.2 (c) [19]

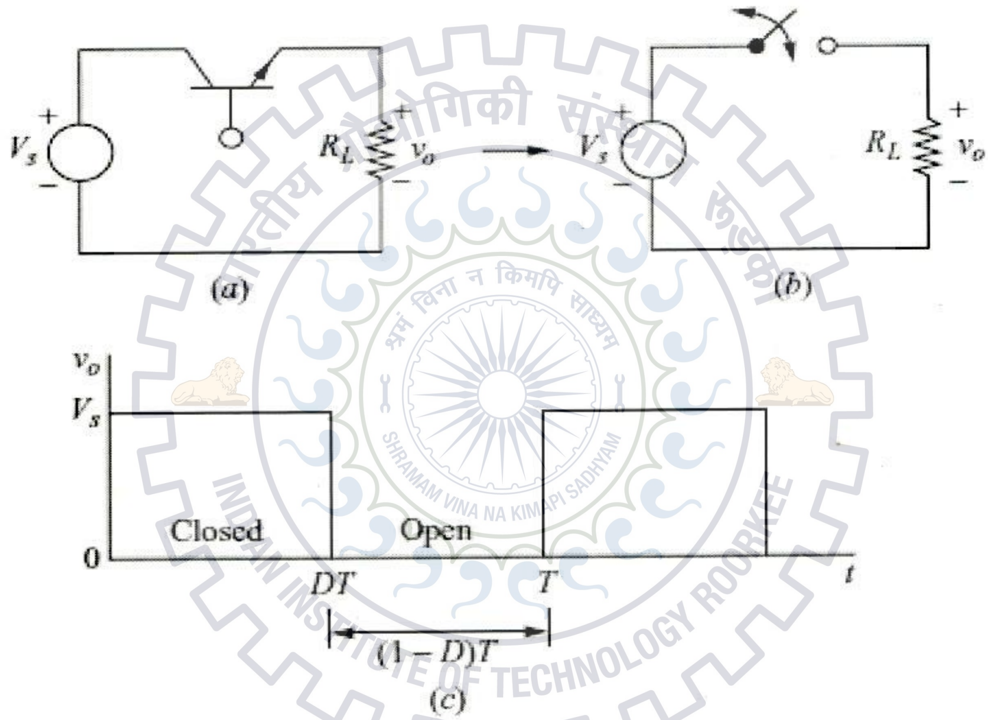


Figure 2.2 (a) A Dc-Dc Switching Converter (b) A Switching Equivalent of Converter (c) The Output Voltage of the Switch

The output voltage is in the form of a pulse which is formed from periodic opening and closing of the switch. The average value or the dc component of the output voltage is expressed as

$$V_o = \frac{1}{T}\int_0^T v_o(t)\,dt = \frac{1}{T}\int_0^{DT} V_s\,dt = V_s D \qquad (2.1)$$

The dc constituent of the output voltage is manipulated by adjusting the duty ratio D that is the fraction of the switching period to that the switch is closed whereas f is the switching frequency. Also the Figure No. 2.3 shows the relation of the duty cycle and the pulse width for various values.

$$D \equiv \frac{t_{on}}{t_{on} + t_{off}} = \frac{t_{on}}{T} = t_{on} f \qquad (2.2)$$

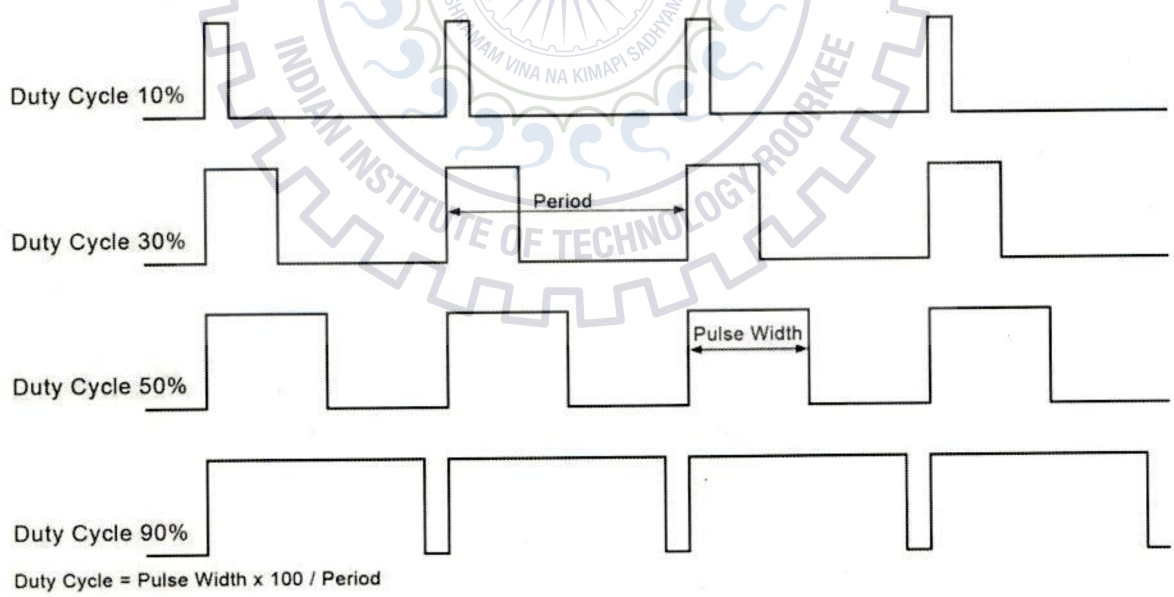


Figure 2.3 Duty Cycle Verses Pulse Width

2.4 TYPES OF DC – DC CONVERTERS

The target of a DC-DC converter is to supply a regulated DC output voltage. These converters are broadly classified into three categories namely: linear mode, hard-switching mode and soft switching mode. Further all these categories are divided into various parts as shown in the Figure No. 2.4. The dc- dc converters discussed in this Dissertation is from the hard – switching mode, non-isolated – boost converter.

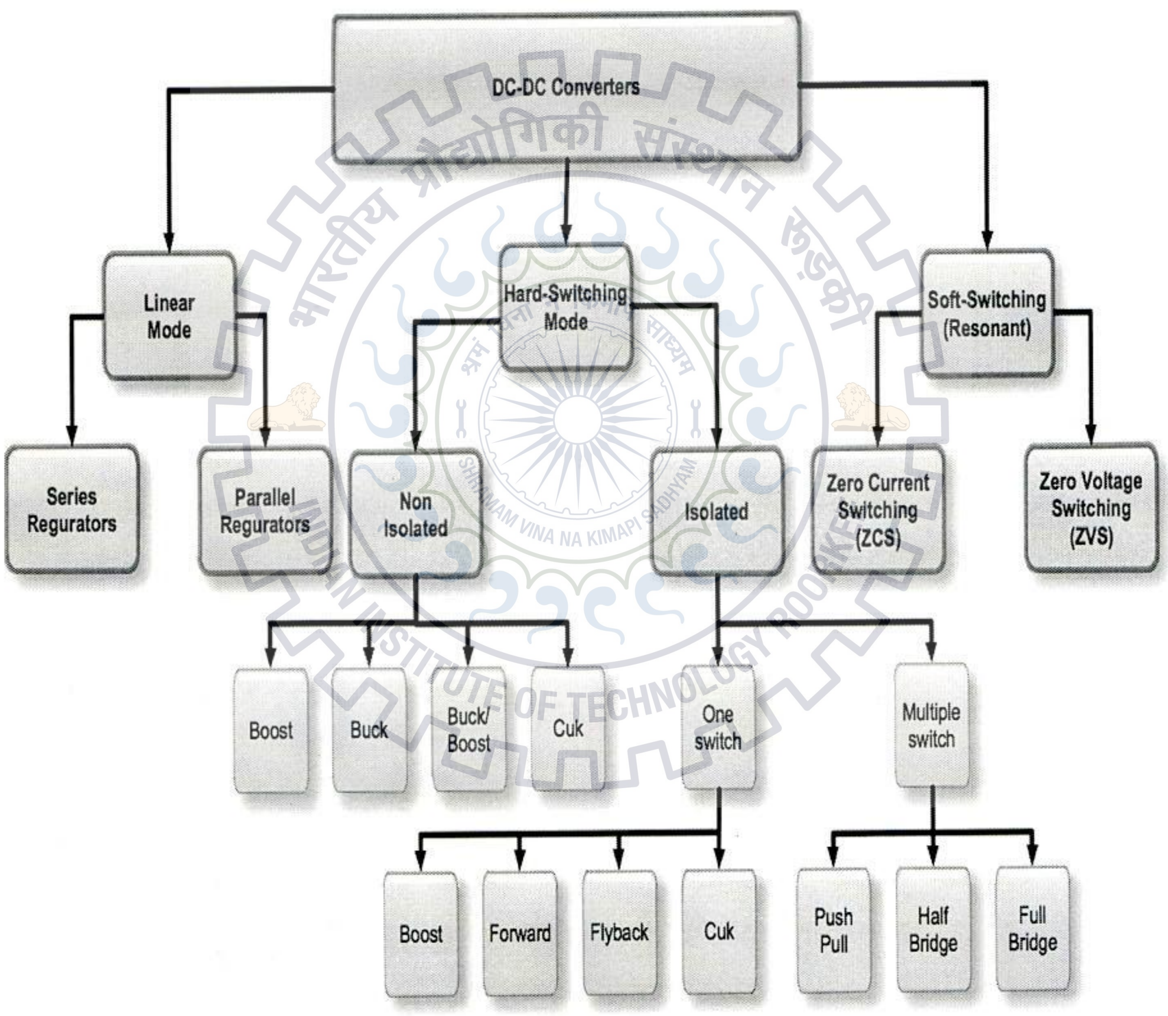


Figure 2.4The Classification of Dc –Dc Converter

There are two major kinds of converters which either decrease or increase the output and are discussed in detail below:

2.4.1 THE BUCK CONVERTER

The buck converter is also called as a step-down converter because the output voltage is less than the input. Figure 2.5 (a) shows an LC low-pass filter added to the converter. Diode provides trail for the inductor current. Figure No 2-3 (b) & (c) shows the equivalent circuits of the Buck converter for switch closed and for switch open respectively [19]. The output of the buck converter is:

$$\boxed{V_o = V_s D} \tag{2.3}$$

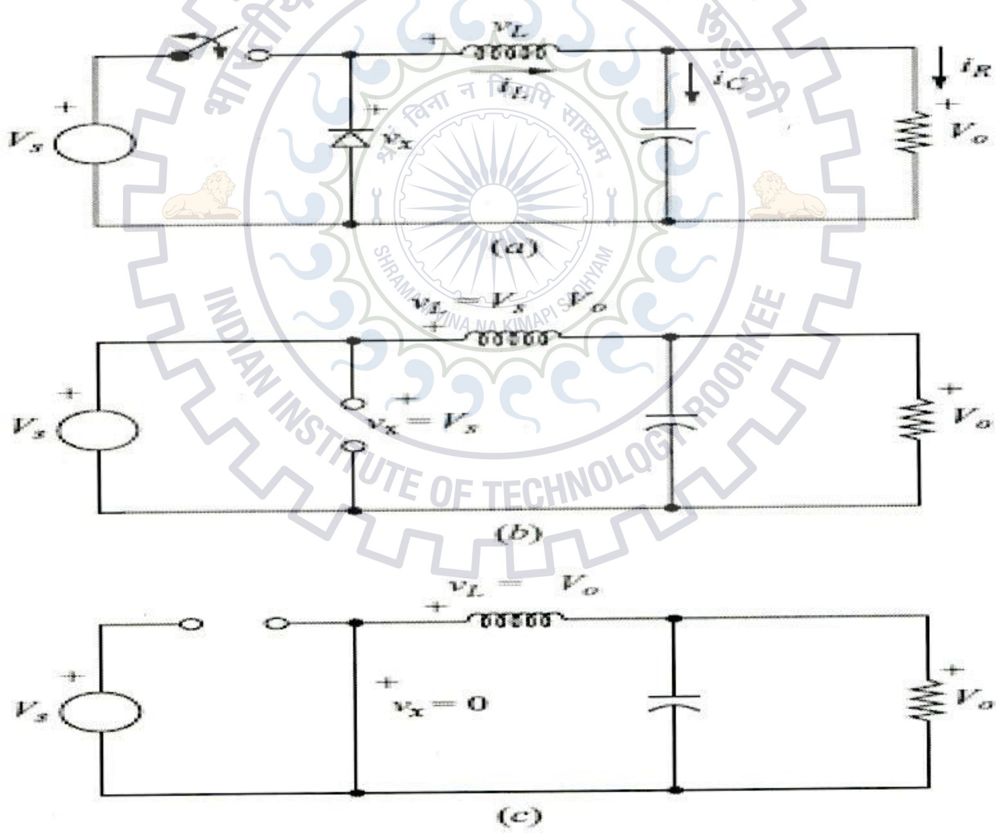


Figure 2.5 (a) The Dc –Dc Buck Converter (b) The Equivalent Circuit for the Switch Closed Converter (c) The Equivalent Circuit For the Switch Open Converter

The key to the analysis for the output Vo is to observe the current and voltage of inductor first for the switch closed and next for the switch open. The overall change in inductor present above one period have to be zero for stable state operation. Average inductor voltage is also equivalent to zero [20].Figure No. 2.6 displays the buck converter waveform (a) the inductor voltage waveform (b) the inductor current waveform (c) the capacitor current waveform.

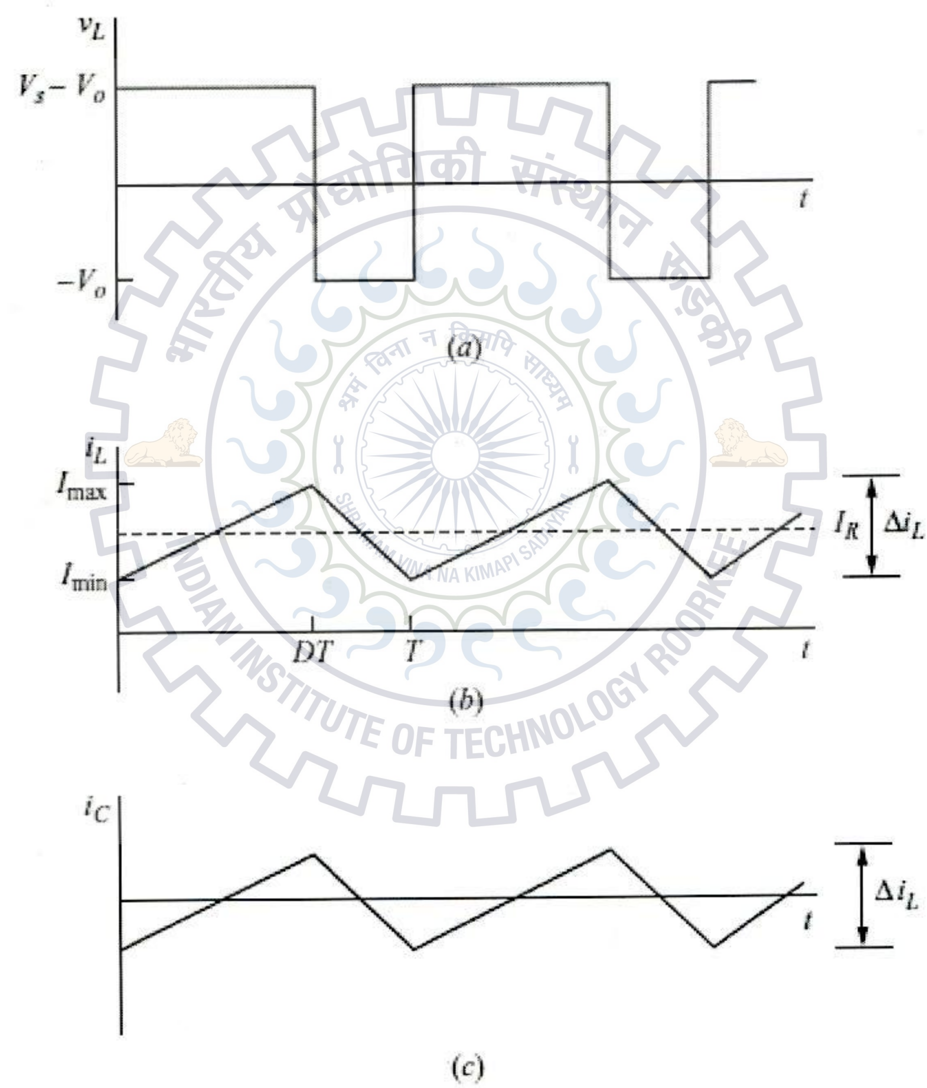


Figure 2.6 Waveforms - (a) Inductor Voltage Waveform (b) Inductor Current Waveform (c) Capacitor Current Waveform

2.4.2 THE BOOST CONVERTER

The boost converter is additionally known as a step-up converter because the output is more than the input. This switching converter operates by periodically opening and closing an electronic switch. Figure No. 2.7 displays the boost converter (a) the converter circuit (b) & (c) shows the equivalent circuits of the Boost converter for switch closed and for switch open respectively [19]. Output of boost converter is:

$$\boxed{V_o = \frac{V_s}{1 - D}} \tag{2.4}$$

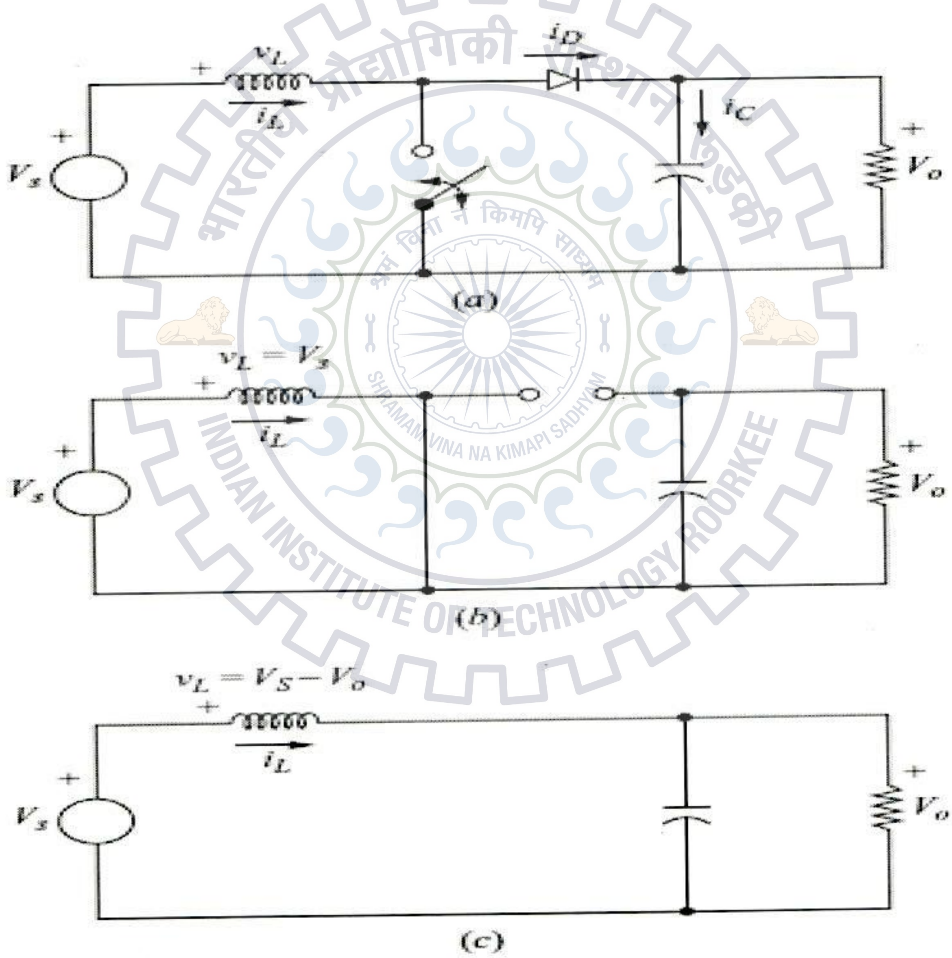


Figure 2.7 (a) Circuit of the Boost Converter (b) Equivalent Circuit For the Switch Closed Of the Converter (c) Equivalent Circuit for the Switch Open of the Converter

Average current in the inductor is computed by knowing that the average power supplied by the source have to be equal to the average power absorbed by the load resistor. [21]Figure No 2.8 Displays boost converter waveform (a) the inductor voltage waveform (b) the inductor current waveform (c) the capacitor current waveform (d) capacitor current waveform [19]

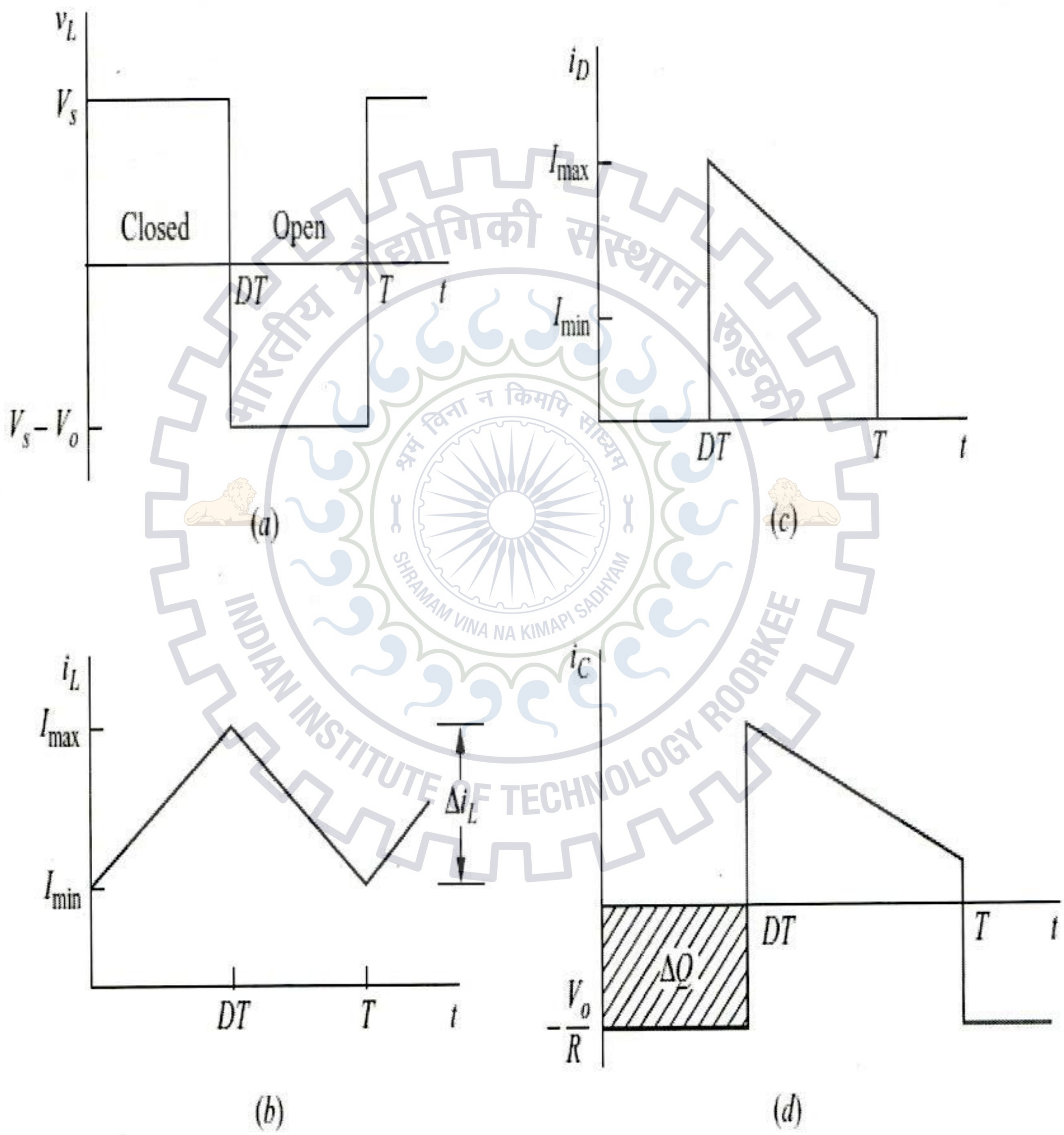


Figure 2.8 Waveforms- (a) Inductor Voltage Waveform (b) Inductor Current Waveform (c) Capacitor Current Waveform (d) Capacitor Current Waveform

2.5 ANALYSIS OF THE DC- DC BOOST CONVERTER

The simple "dc –dc boost converter" is displayed in Figure No. 2.9 [19]. It operates by periodically onset and closing an electronic switch. [25] It is known so because the output voltage is greater than the input. The analysis of the dc –dc boost converter in voltage and current relationship considers the following:

1. The Steady-state situation should exist.
2. The switching period is T, the switch is closed for period DT and open for period (1- D) T.
3. The inductor current, has to be continuously positive.
4. The output voltage is held steady at voltage Vo. And the capacitor is extremely large.
5. The constituents are ideal.

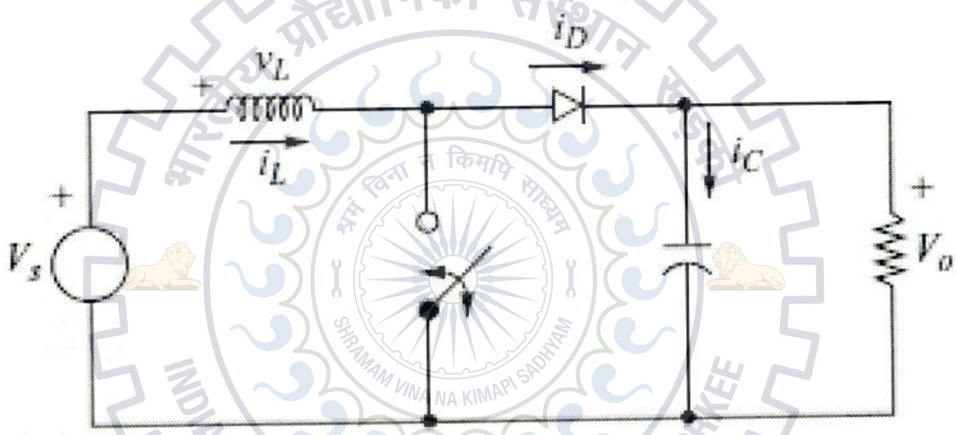


Figure 2.9 The Boost Converter Circuit

2.5.1 ANALYSIS FOR THE SWITCH CLOSED OF THE BOOST CONVERTER

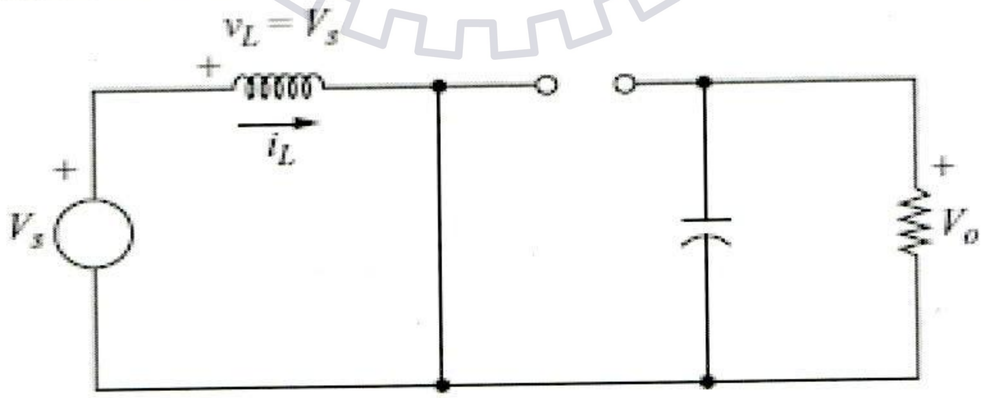


Figure 2.10 The Boost Converter with Switch Closed

As shown in the Figure No. 2.10 [19] when the switch is closed, the diode is reverse biased. Next Kirchhoff's voltage law in the trail encompassing the source, inductor, and closed switch is

$$v_L = V_s = L\frac{di_L}{dt} \qquad \text{or} \qquad \frac{di_L}{dt} = \frac{V_s}{L} \tag{2.5}$$

Inductor current (change) is computed from

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{DT} = \frac{V_s}{L} \tag{2.6}$$

Therefore for the switch closed

$$(\Delta i_L)_{\text{closed}} = \frac{V_s DT}{L} \tag{2.7}$$

2.5.2 ANALYSIS FOR THE SWITCH OPEN

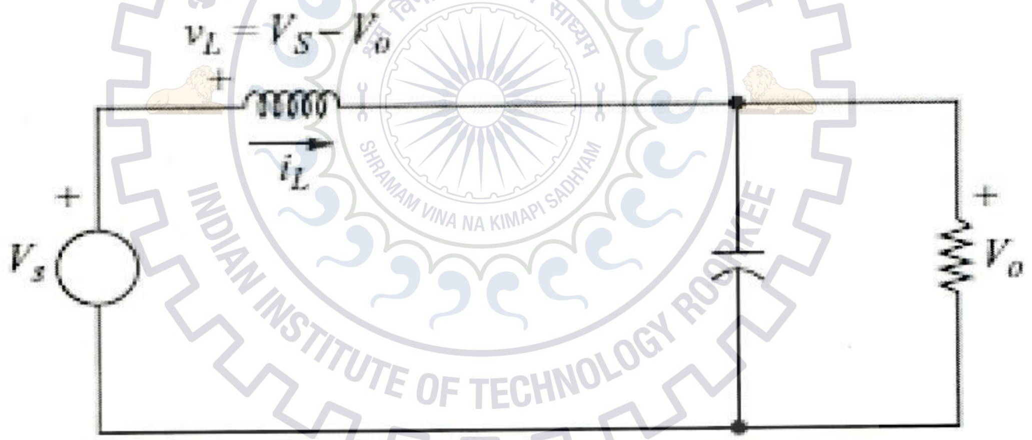


Figure 2.11 The Boost Converter with Switch Open

As shown in the Figure No. 2.11 [19], after the switch is opened, the current of inductor cannot change instantaneously. The diode becomes forward-biased to furnish a trail for inductor current. Presuming that the output voltage Vo is a steady, the voltage across the inductor is

$$v_L = V_s - V_o = L\frac{di_L}{dt} \tag{2.8}$$

$$\frac{di_L}{dt} = \frac{V_s - V_o}{L} \tag{2.9}$$

Inductor current (change) while the switch is open is

$$\frac{\Delta i_L}{\Delta t} = \frac{\Delta i_L}{(1-D)T} = \frac{V_s - V_o}{L} \tag{2.10}$$

$$(\Delta i_L)_{\text{open}} = \frac{(V_s - V_o)(1-D)T}{L} \tag{2.11}$$

As per the pre assumptions it should be steady-state operation. The overall change in inductor current must be zero.

$$(\Delta i_L)_{\text{closed}} + (\Delta i_L)_{\text{open}} = 0 \tag{2.12}$$

$$\frac{V_s DT}{L} + \frac{(V_s - V_o)(1-D)T}{L} = 0 \quad (2.13$$

Solving on behalf of Vo

$$V_s(D + 1 - D) - V_o(1-D) = 0 \tag{2.14}$$

$$\boxed{V_o = \frac{V_s}{1-D}} \tag{2.15}$$

The average value of inductor voltage must be zero for periodic operation.

$$V_L = V_s D + (V_s - V_o)(1-D) = 0 \tag{2.16}$$

Solving for Vo yields the same result as

$$\boxed{V_o = \frac{V_s}{1-D}} \tag{2.17}$$

The above mentioned equation demonstrations that if the switch is continuously open, Duty ratio D is zero, the voltage is equivalent to input. But as the duty ratio is greater than before, the denominator becomes lesser, resulting in a greater output voltage.so, the boost converter yields an output voltage that is larger than or equivalent to the input voltage. As in case of buck converter, the output can never be less than input for the boost converter.

Now, when the duty ratio D approaches 1, the output of the converter goes to infinity as per the equation mentioned above.

The Output power is

$$P_o = \frac{V_o^2}{R} = V_o I_o \tag{2.18}$$

Input power is

$$V_s I_s = V_s I_L \tag{2.19}$$

Equating both powers

$$V_s I_L = \frac{V_o^2}{R} = \frac{[V_s/(1-D)]^2}{R} = \frac{V_s^2}{(1-D)^2} R \tag{2.20}$$

Solving, it further

$$\boxed{I_L = \frac{V_s}{(1-D)^2 R} = \frac{V_o^2}{V_s R} = \frac{V_o I_o}{V_s}} \tag{2.21}$$

The average value is used for determining the Maximum and minimum inductor currents, which is as given below:

$$I_{max} = I_L + \frac{\Delta i_L}{2} = \frac{V_s}{(1-D)^2 R} + \frac{V_s DT}{2L} \tag{2.22}$$

$$I_{min} = I_L - \frac{\Delta i_L}{2} = \frac{V_s}{(1-D)^2 R} - \frac{V_s DT}{2L} \tag{2.23}$$

The borderline between continuous plus discontinuous inductor current is taken into account, assuming the inductor current to be always positive.

$$I_{min} = 0 = \frac{V_s}{(1-D)^2 R} - \frac{V_s DT}{2L} \tag{2.24}$$

$$\frac{V_s}{(1-D)^2 R} = \frac{V_s DT}{2L} = \frac{V_s D}{2Lf} \tag{2.25}$$

OR

The least possible combination of inductance plus switching frequency is

$$(Lf)_{\min} = \frac{D(1-D)^2 R}{2} \tag{2.26}$$

$$\boxed{L_{\min} = \frac{D(1-D)^2 R}{2f}} \tag{2.27}$$

For designing aspects, it is beneficial to precise L as following.

$$L = \frac{V_s DT}{\Delta i_L} = \frac{V_s D}{\Delta i_L f} \tag{2.28}$$

For The Output voltage ripple, the change within capacitor charge can be calculated from

$$|\Delta Q| = \left(\frac{V_o}{R}\right) DT = C\Delta V_o \tag{2.29}$$

An expression for ripple voltage is then

$$\Delta V_o = \frac{V_o DT}{RC} = \frac{V_o D}{RCf} \tag{2.30}$$

$$\boxed{\frac{\Delta V_o}{V_o} = \frac{D}{RCf}} \tag{2.31}$$

Capacitance in expressions of output voltage ripple yields

$$C = \frac{D}{R(\Delta V_o / V_o) f} \tag{2.32}$$

2.6 THE DESIGN OF OPEN LOOP DC- DC BOOST CONVERTER

For, using a boost converter for a specific output the boost converter given below is designed with specific specifications, because it voltage values are in corresponding to the required field voltage of synchronous generator used in the system. It has further been designed as close loop, with specific values of PI controller in Chapter 3.The open loop DC –DC Boost converter is given different load conditions to determine the output. Further the analysis of the output is done at the end of the chapter.

2.6.1 THE DESIGN SPECIFIC PARAMETERS OF THE BOOST CONVERTER

All the parameters set in the table below are calculated by the formulas mentioned in the section 2.5.The calculation starts with fixing the required output voltage value, and choosing the input value, (in this case it is chosen as per the required field voltage limits of the synchronous generator).These two basic and the most important values, help in calculating the duty ratio as per the formulae 2.4 mentioned in the section 2.4.2, thereafter the value of series inductance is set by the formulae 2.27 of section 2.5.2 and value of conductance is set by formulae 2.32 of the same section.

SYMBOL	PARAMETER	VALUE	UNIT
Vi	INPUT VOLTAGE	30	V
Vo	OUTPUT VOLTAGE	40	V
R	LOAD RESISTANCE	50	Ω
L	SERIES INDUCTANCE	570	μH
C	CAPACITANCE	660	μF
D	DUTY RATIO	0.25	
f	SWITCHING FREQUENCY	15	kHz

Figure 2.12 Parameters of Open Loop Boost Converter

2.6.2 THE SIMULINK MODEL OF THE BOOST CONVERTER

The Figure no.2.13 shown below is a Simulink model of the open loop DC –DC boost converter designed with the specific parameters mentioned in the previous page. The load resistance for it is 50 Ω

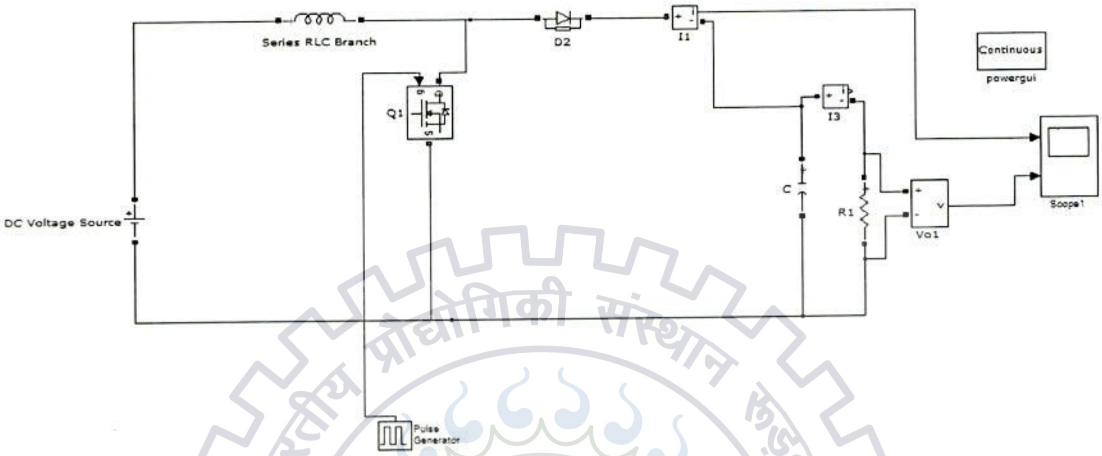


Figure 2.13 Simulink model of open loop boost converter

2.6.3 THE SIMULATION OUTPUT OF THE BOOST CONVERTER

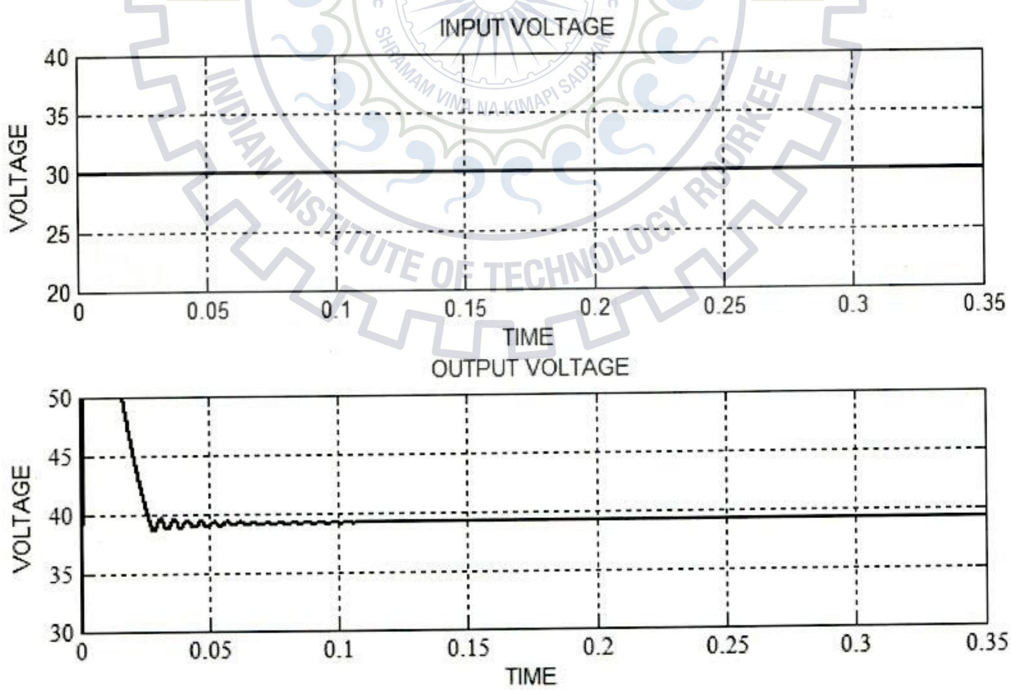


Figure 2.14 Simulation Output Of Open Loop Boost Converter

After designing the boost converter, to check the output, the system runs for a simulated time period, and then the output is achieved, the first graph is of the input voltage and the second one is of the output voltage, which is near about the calculated values but consist of ripples.

2.6.4 COMPARITIVE STUDY OF "OPEN LOOP DC – DC BOOST CONVERTER" WITH DIFFERNET LOAD CONDITIONS

Now to study the accuracy of the designing of the open -loop boost converter, it is important to check the same with different load conditions apart from the designing one.so, two different values are given in the variation of 5 Ω of the load resistance, and the output is compared.

2.6.4.1 CASE I

In this case I all of the designed parameters are kept the same, except the load resistance, which is made 45 Ω

THE DESIGN SPECIFIC PARAMETERS USED IN THE BOOST CONVERTER

SYMBOL	PARAMETER	VALUE	UNIT
Vi	INPUT VOLTAGE	30	V
Vo	OUTPUT VOLTAGE	40	V
R	LOAD RESISTANCE	45	Ω
L	SERIES INDUCTANCE	570	μH
C	CAPACITANCE	660	μF
D	DUTY RATIO	0.25	

Figure 2.15 Parameters of Open Loop Boost Converter

THE SIMULATIONOUTPUT OF THE BOOST CONVERTER CASE I

The first graph is of the input voltage and the second one is of the output voltage, this voltage has a little dip in the value which is near about the calculated values due to the change in current. But consist of ripples.

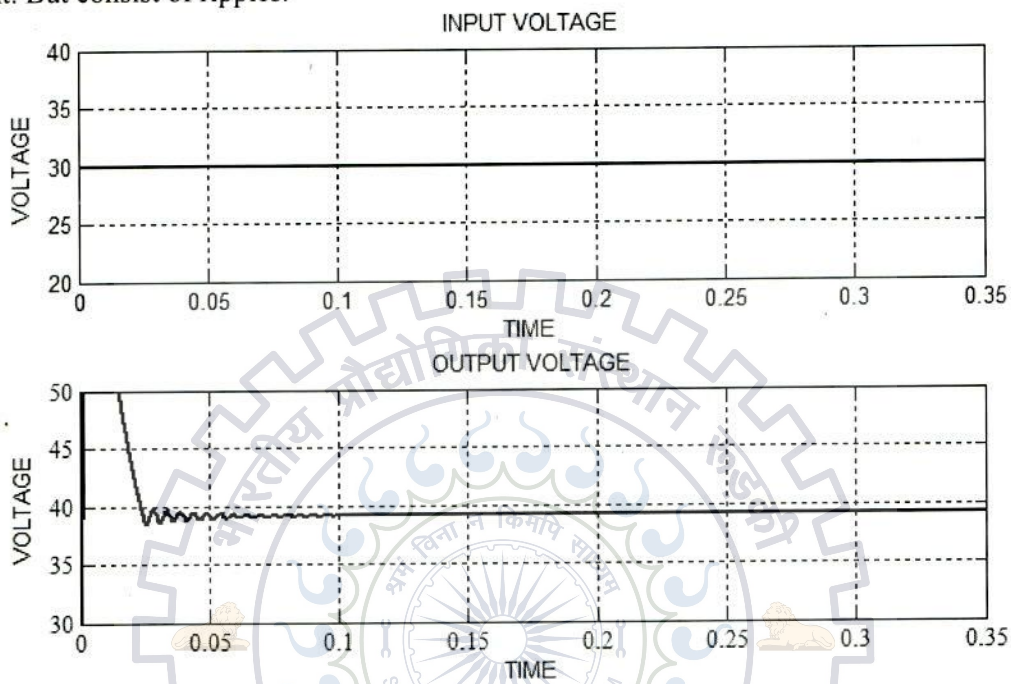


Figure 2.16 Simulation Output Of Open Loop Boost Converter

2.6.4.2 CASE II

In this case II all of the designed parameters are kept the same, except the load resistance, which is made 55 Ω

THE DESIGN SPECIFIC PARAMETERS USED IN THE BOOST CONVERTER ARE

SYMBOL	PARAMETER	VALUE	UNIT
Vi	INPUT VOLTAGE	30	V
Vo	OUTPUT VOLTAGE	40	V
R	LOAD RESISTANCE	55	Ω

L	SERIES INDUCTANCE	570	μH
C	CAPACITANCE	660	μF
D	DUTY RATIO	0.25	

Figure 2.17 Parameters of Open Loop Boost Converter

THE SIMULATION OUTPUT OF THE BOOST CONVERTER CASE II

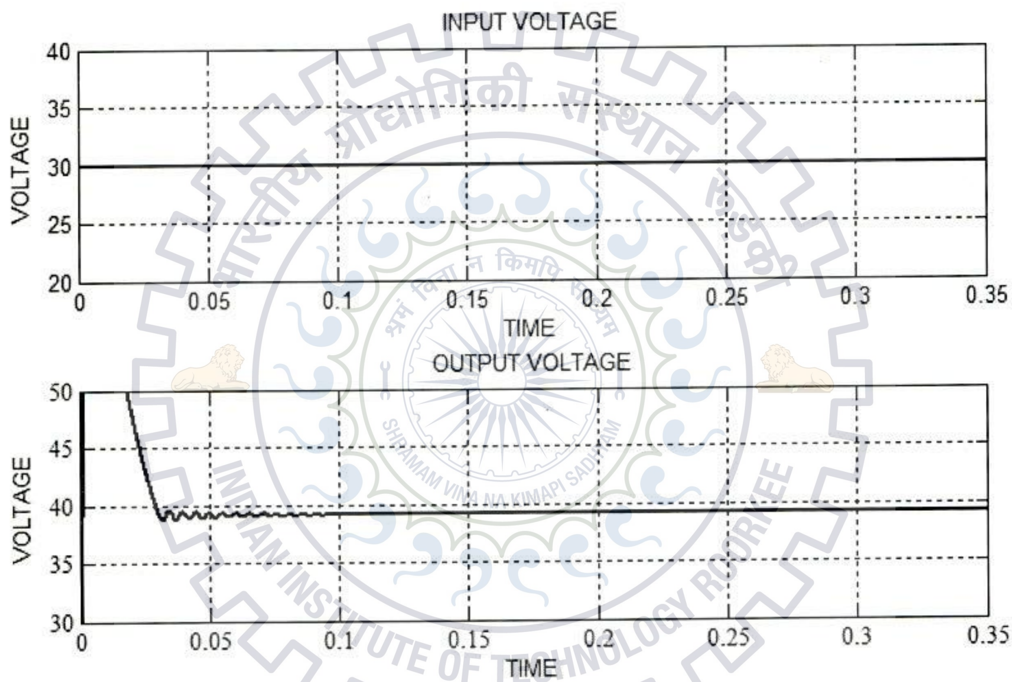


Figure 2.18 Simulation Output Of Open Loop Boost Converter

The first graph is of the input voltage and the second one is of the output voltage, this voltage has the value which is near about the calculated values due to the change in current due to increase in load, But consist of ripples.

2.7 CONCLUSION

After getting the outputs from different load conditions of the design of open loop boost converter, it can be seen and concluded by mathematical values as in section 2.7.1 or by graphical comparison shown in section 2.7.2. It can be noted that the output is not accurate or same for all the loads. Also the output consists of ripples as clearly visible in Figure 2.20 (a), (b) and (c). So, to improve the accuracy the close loop d –dc boost converter have been employed and there performance is reported and analyzed in chapter 3.

2.7.1 MATHEMATICAL VALUES

INPUT VOLTAGE	SERIES INDUCTANCE	CAPACITANCE	LOAD RESISTANCE	OUTPUT VOLTAGE
V	μH	μF	Ω	V
30	570	660	45	39.60
30	570	660	50	39.75
30	570	660	55	39.80

Figure 2.19 Mathematical Values of Different Loads of the Open Loop Boost Converter

2.7.2 GRAPHICAL COMPARISON

The input for all the cases has been the same of the converter, be it open loop or close loop.

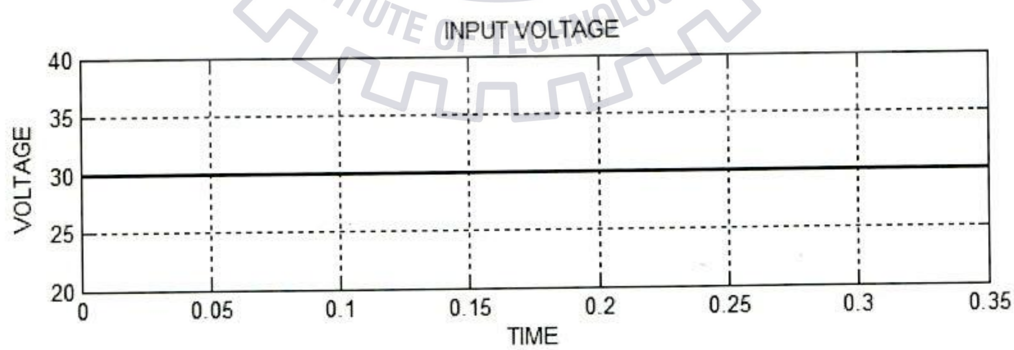
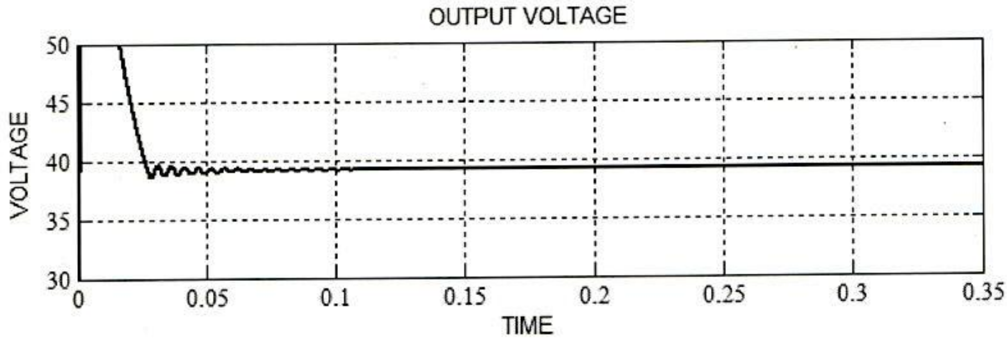


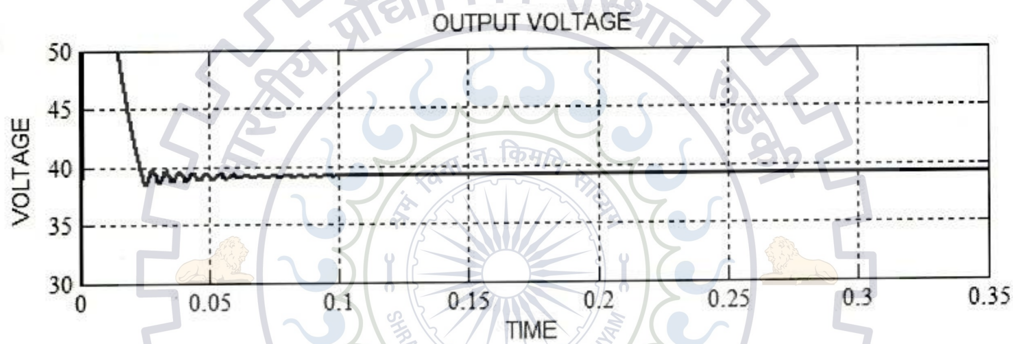
Figure 2.20 Shows the Input Graph for All Cases

ORIGINAL DESIGN: LOAD L =50 Ω



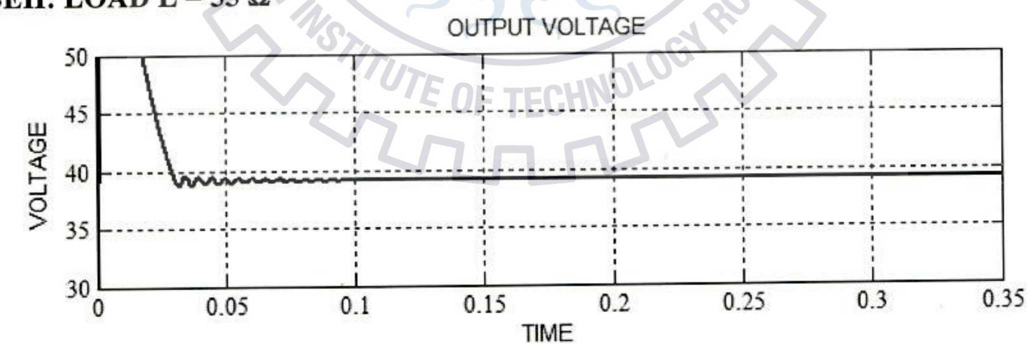
(a)

CASE I: LOAD L =45 Ω



(b)

CASEII: LOAD L = 55 Ω



(c)

Figure 2.21 Simulation Output of different loads of the Open Loop Boost Converter

Chapter 3: THE CONTROL SYSTEM DESIGNING OF THE DC – DC BOOST CONVERTER

3.1 PULSE WIDTH MODULATION (PWM)

In converters, the average output voltage should be to a desired equal level, irrespective of the fluctuations. In Switch mode, the dc- dc converter uses the switch to change a level to alternative level. Average result of the output is measured by controlling switch duration in converter. The Figure No 3.1[25] below show a basic dc – dc converter, switch –mode concept.

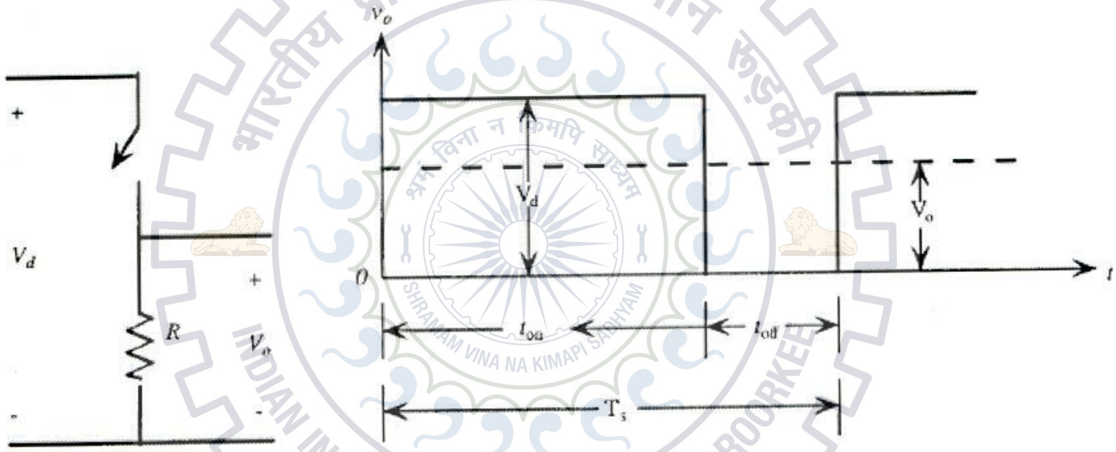


Figure 3.1 Switch – Mode Concept

The average output value of the voltage depends on t_{on} and t_{of}. The duty ratio is defined as the ratio of on duration to the total switching period. [26]

In PWM, switch control signal, are obtained from comparing an error signal, with a repetitive waveform as shown in Figure No 3.2. [25] When the difference between the actual output voltage and the desired value is amplified, the control signal is obtained.

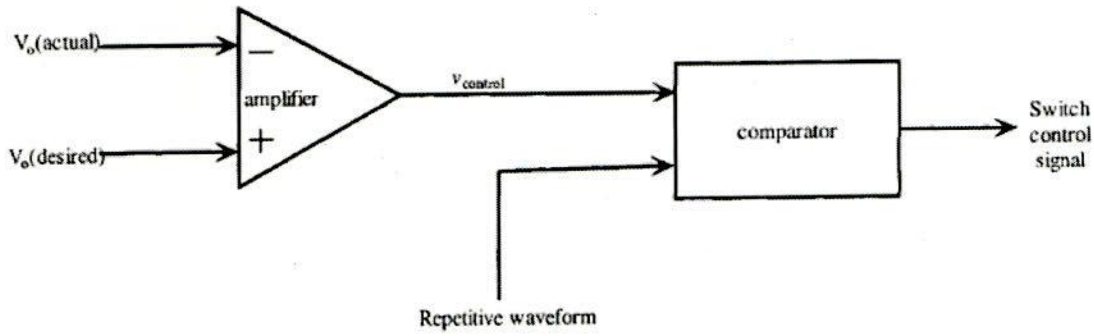
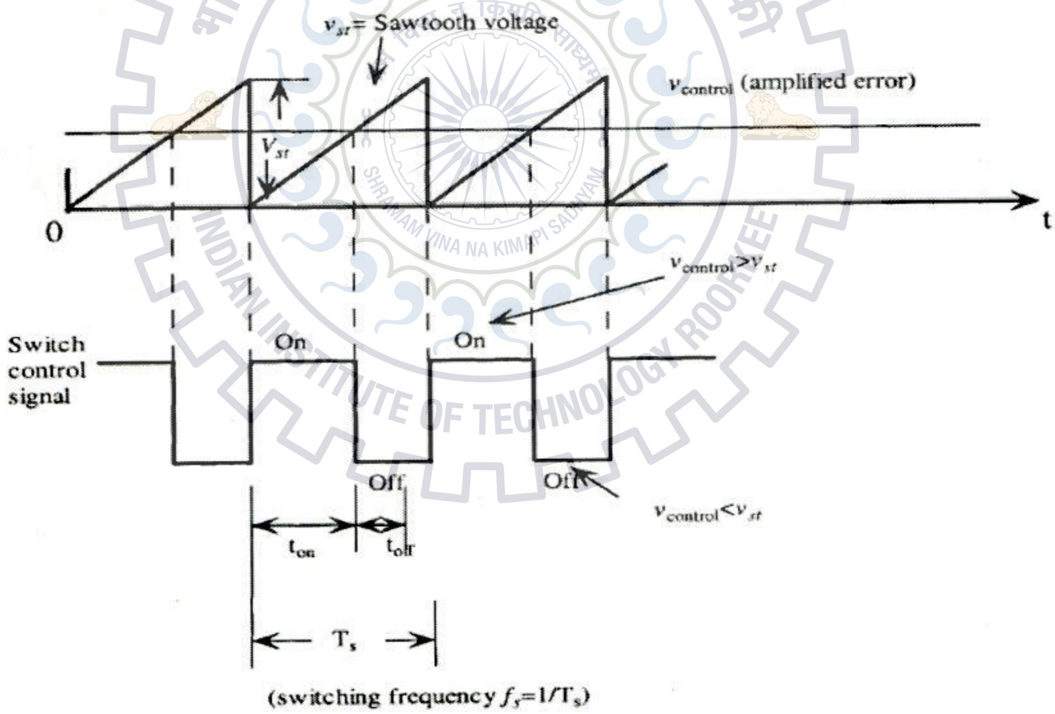


Figure 3.2 Block Diagram of PWM

If the switch control signal is high, when the error is greater than the saw tooth waveform which further causes the switch to turn on. As shown in Figure No 3.3 [25], [27].

The duty ratio is expressed as $$D = \frac{ton}{Ts} = \frac{Vcontrol}{Vst} \quad (3.1)$$



(b)

Figure 3.3 PWM Signal

3.2 PID CONTROLLER

PID means proportional-integral-derivative, it is a special type of feedback controller. The output is based on the error obtained between the desired values and measured variable. Figure No 3.4 displays the block diagram of the boost converter using PID controller. [28] Schematic diagram consists of a control circuit and the PWM modulator. The control circuit has a voltage divider, an amplifier and a PID controller, whereas the PWM modulator consists of a saw tooth voltage generator, a master clock, a comparator and an R-S flip-flop.

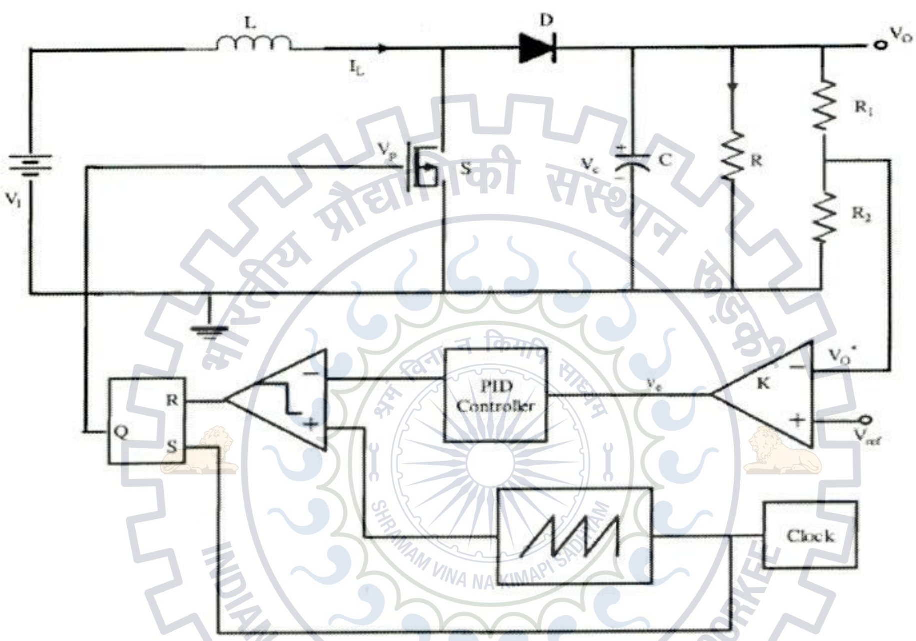


Figure 3.4 Diagram of the Boost Converter Using PID Controller

3.3 CONTROL FLOW CHART

This is a basic control flow chart of the working of the PID controller with the Pulse Width Modulator. This describes the basic functioning of the above mentioned .It initializes from taking the output of the system and feeding it to the pulse width modulator (PWM), it reads the feedback value, $V_{out.}$ Then it compares the feedback value to the desired input value. Now if the feedback value is equal to the desired value, then the normal working of the system is continued, but if the feedback value is not equal to the desired value, the duty cycle changes.in this case if the feedback value is greater than the desired value, it reduce the duty cycle and if the feedback value is less than the desired value than the duty cycle, the duty cycle is increased. Further as per the duty cycle the pulse width is changed by the pulse width modulator, and the new generated pulse is again feed to the system. This function is continuously carried for the whole operation period. [29]

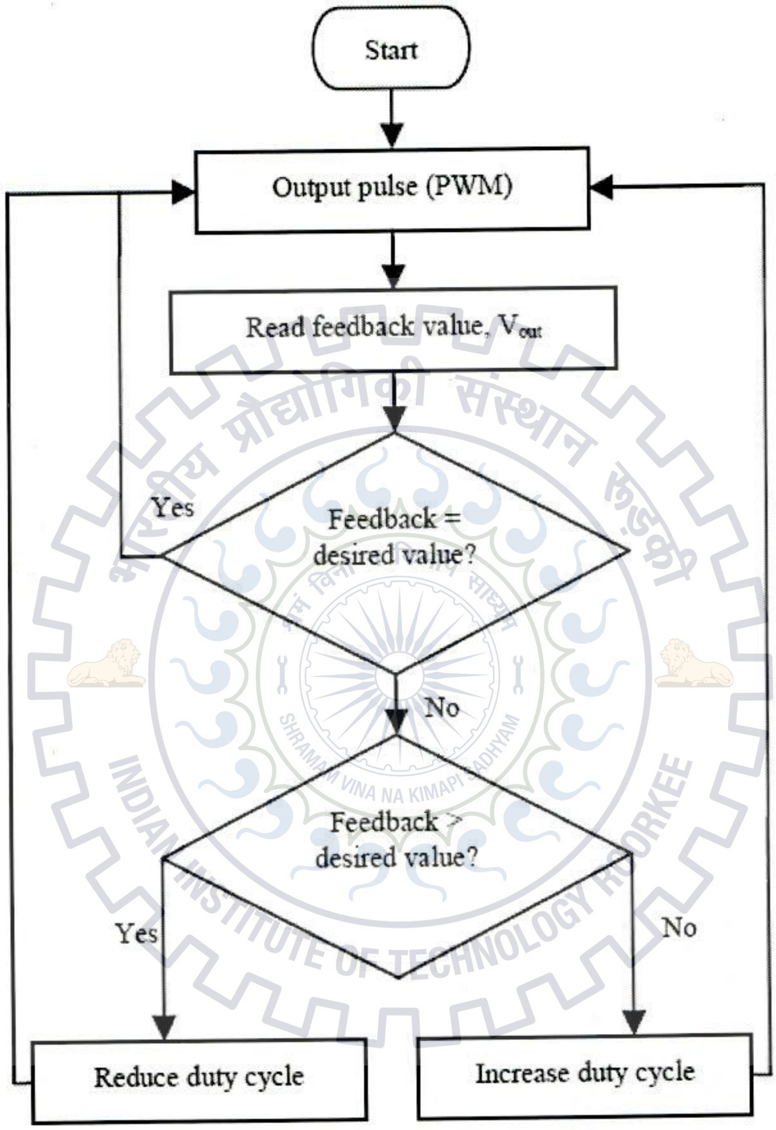


Figure 3.5 Control Flow Chart

3.4 MODELING OF BOOST CONVERTER

It is a useful method for developing the transfer function for the dc-dc converters [30]

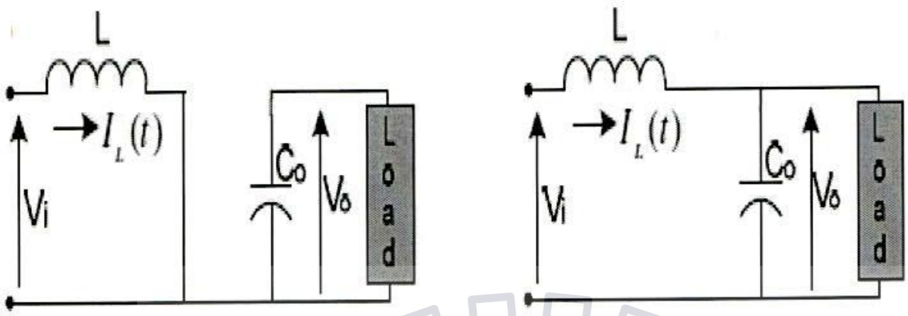


Figure 3.6 (a). Switch Is On (b) Switch Is Off of A Model of Boost Converter

SWITCH ON-

The equation are determined for the switch on state as shown in Figure 3.5 (a), which are mentioned below

$$\frac{dI_L(t)}{dt} = \frac{1}{L}\left(V_i - I_L(t)R_L - V_o\right) \tag{3.2}$$

$$\frac{dV_C(t)}{dt} = \frac{1}{C}\left(I_L(t) - \frac{V_o}{R_o}\right) \tag{3.3}$$

SWITCH OFF-

The equation are determined for the switch off state as shown in Figure 3.5 (b), which are mentioned below

$$\frac{dI_L(t)}{dt} = \frac{1}{L}\left(V_i - I_L(t)R_L\right) \tag{3.4}$$

$$\frac{dV_C(t)}{dt} = -\frac{V_o}{CR_o} \tag{3.5}$$

The transfer function of the boost converter is

$$G(s) = \frac{V_o(s)}{(1-d)} = \frac{V_i(s)}{sC(sL+R_L)} \tag{3.6}$$

The transfer function of the PID controller is:

$$G_{PI}(z) = K_p + K_i \frac{z}{z-1} = (K_p + K_i)\frac{z - \dfrac{K_p}{K_p + K_i}}{z-1} \tag{3.7}$$

With the help of discrete equation given below [30]

$$1 + G_{PI}(z)G(z) = 0 \tag{3.8}$$

Keeping the criteria as were settling time ts = 0.02s and damping ratio $\xi = 0.8$ the values calculated are-

PROPORTIONALITY GAIN, K_P=5.3

INTEGRAL GAIN, K_i =0.37

3.5 THE DESIGNS OF CLOSE LOOP DC- DC BOOST CONVERTER

For, using a boost converter for a specific output an open loop dc –dc boost converters is designed with specific specifications in chapter 2, as it voltage values are in corresponding to the required field voltage of synchronous generator used in the system. Now in this chapter it has been designed as close loop dc- dc boost converter, with specific values of PI controller calculated with the help of transfer function as mentioned in section 3.4.The dc –dc Boost converter deign is given different load conditions same as given in chapter 2 to read the outputs of each and compare with each other. Further the outputs of the open – loop dc – dc boost converter and close –loop boost converter with same parameters and load are compared by the end of the chapter.

3.5.1 THE DESIGN SPECIFIC PARAMETERS USED IN THE BOOST CONVERTER

SYMBOL	PARAMETER	VALUE	UNIT
Vi	INPUT VOLTAGE	30	V
Vo	OUTPUT VOLTAGE	40	V
R	LOAD RESISTANCE	50	Ω
L	SERIES INDUCTANCE	570	μH
C	CAPACITANCE	660	μF
D	DUTY RATIO	0.25	
K_p	PROPORTIONALITY GAIN	5.3	
K_i	INTEGRAL GAIN	0.37	
F	SWITCHING FREQUNECY	15	KHz
f	SAMPLING FREQUENCY	15	KHz

Figure 3.7 Parameters of close Loop Boost Converter

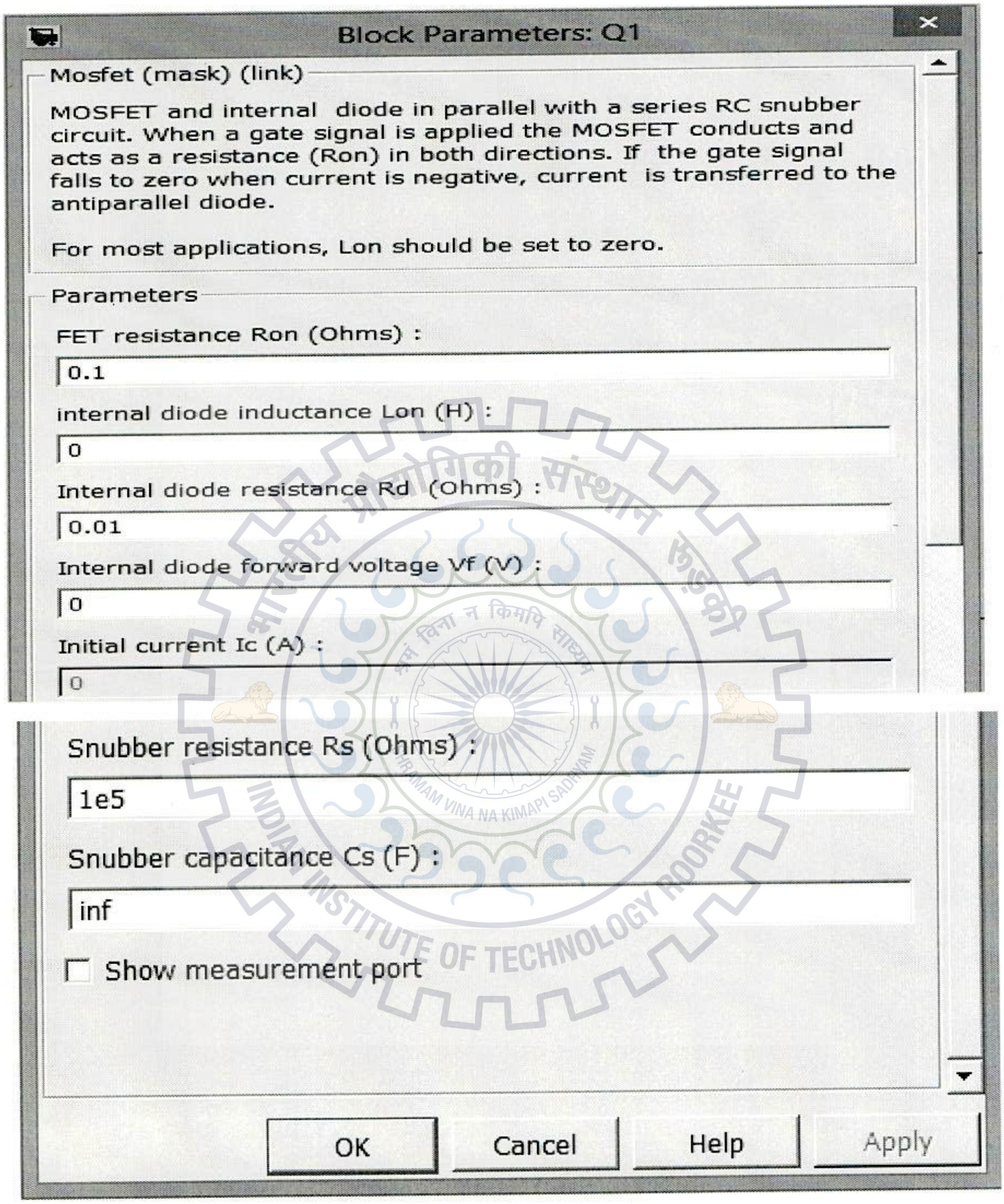


Figure 3.8 Parameters of the Switch Used In Close Loop Boost Converter

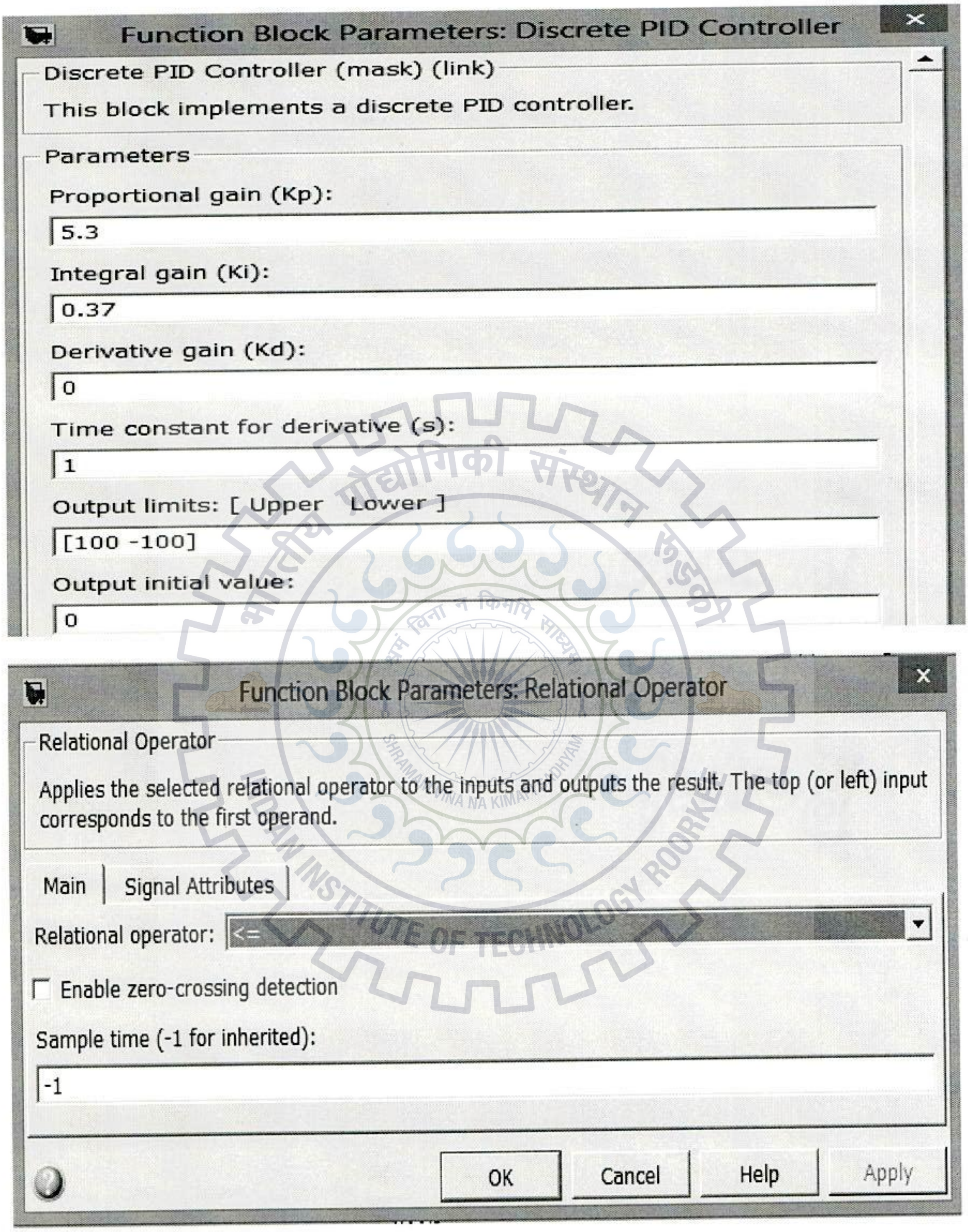
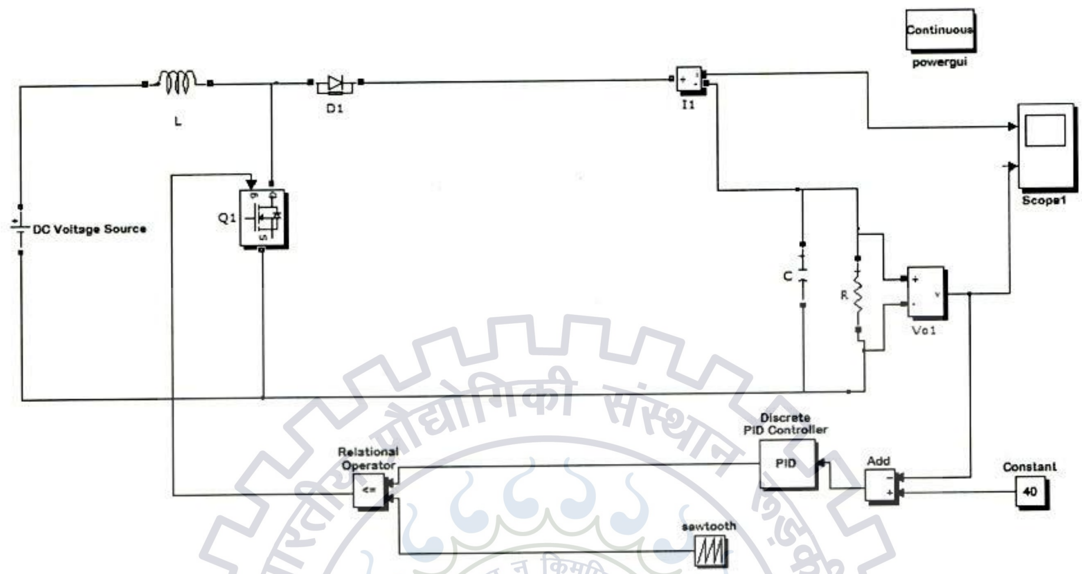
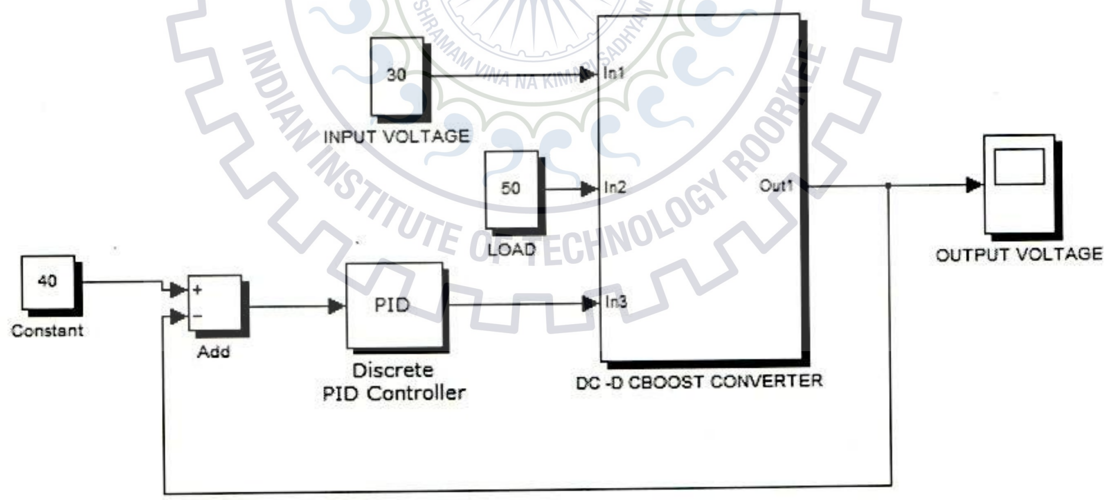


Figure 3.9 Parameters of the PID Controller and the Relation Operator Used In Close Loop Boost Converter

3.5.2 THE SIMULINK MODEL OF THE BOOST CONVERTER



(a)



(b)

Figure 3.10 (a) And (b) Shows the Simulink Model of Boost Converter

3.5.3 THE SIMULATION OUTPUT OF THE BOOST CONVERTER

After designing the boost converter, to check the output, the system runs for a simulated time period, and then the output is achieved, the first graph is of the input voltage and the second one is of the output voltage, which is same as the calculated values but does not consist of ripples.

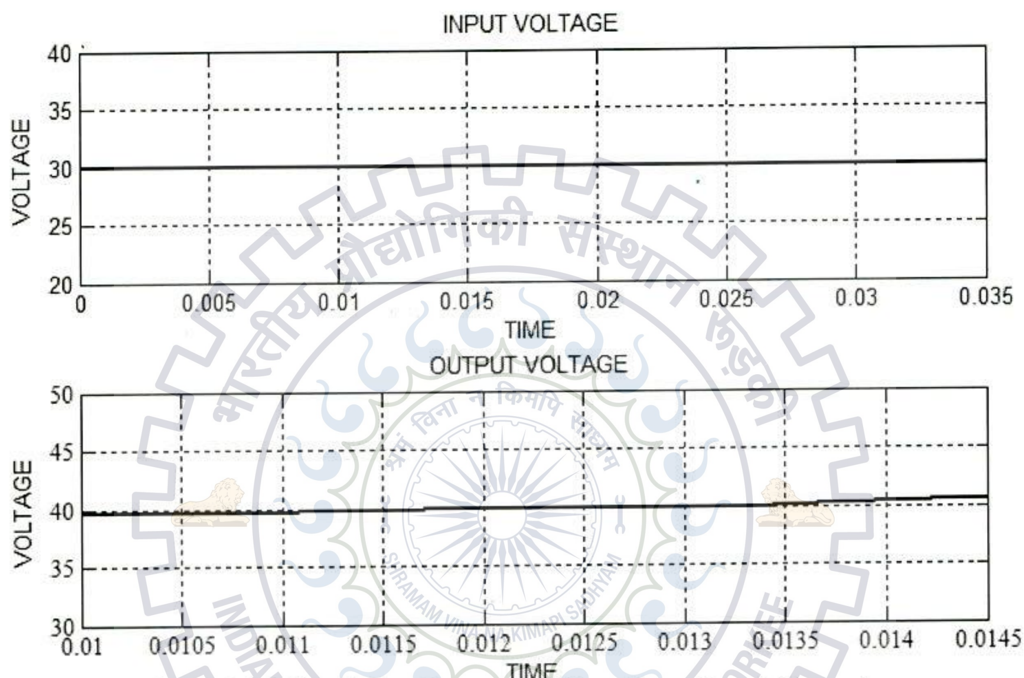


Figure 3.11 Simulation Output Of Close Loop Boost Converter

3.6 COMPARITIVE STUDY OF "CLOSE LOOP DC – DC BOOST CONVERTER "DIFFERNET LOAD CONDITIONS

Now to study the accuracy of the designing of the close -loop boost converter, it is important to check the same with different load conditions apart from the designing one.so, two different values are given in the variation of 5 Ω of the load resistance, and the output is compared.

3.6.1 CASE I

In this case I all of the designed parameters are kept the same, except the load resistance, which is made 45 Ω

THE DESIGN SPECIFIC PARAMETERS USED IN THE BOOST CONVERTER

SYMBOL	PARAMETER	VALUE	UNIT
Vi	INPUT VOLTAGE	30	V
Vo	OUTPUT VOLTAGE	40	V
R	LOAD RESISTANCE	45	Ω
L	SERIES INDUCTANCE	570	μH
C	CAPACITANCE	660	μF
D	DUTY RATIO	0.25	
K_p	PROPORTIONALITY GAIN	5.3	
K_i	INTEGRAL GAIN	0.37	
F	SWITCHING FREQUNECY	15	KHz
f	SAMPLING FREQUENCY	15	KHz

Figure 3.12 Parameters of close Loop Boost Converter

THE SIMULATION OUTPUT OF THE BOOST CONVERTER

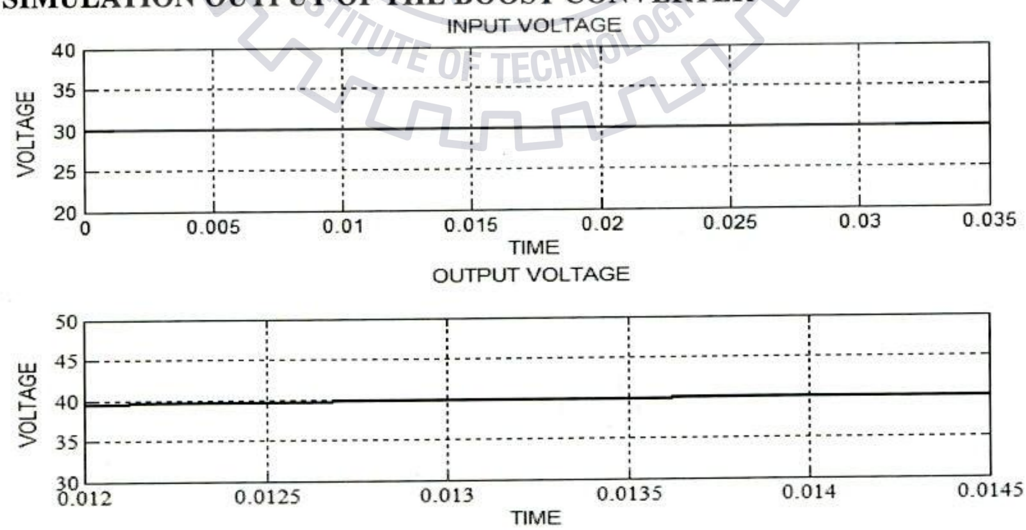


Figure 3.13 Simulation Output Of close Loop Boost Converter

The first graph is of the input voltage and the second one is of the output voltage, this voltage is same as the calculated voltage, irrespective of the load difference cause of the feedback provided in close loop systems.

3.6.2 CASE II

In this case I all of the designed parameters are kept the same, except the load resistance, which is made 55 Ω

THE DESIGN SPECIFIC PARAMETERS USED IN THE BOOST CONVERTER

SYMBOL	PARAMETER	VALUE	UNIT
Vi	INPUT VOLTAGE	30	V
Vo	OUTPUT VOLTAGE	40	V
R	LOAD RESISTANCE	55	Ω
L	SERIES INDUCTANCE	570	μH
C	CAPACITANCE	660	μF
D	DUTY RATIO	0.25	
Vi	INPUT VOLTAGE	30	V
Vo	OUTPUT VOLTAGE	40	V
K_p	PROPNALITITY GAIN	5.3	
K_i	INTEGRAL GAIN	0.37	
F	SWITCHING FREQUNECY	15	KHz
f	SAMPLING FREQUENCY	15	KHz

Figure 3.14 Parameters of close Loop Boost Converter

THE SIMULATION OUTPUT OF THE BOOST CONVERTER

The first graph is of the input voltage and the second one is of the output voltage, this voltage is same as the calculated voltage, irrespective of the load difference cause of the feedback provided in close loop systems.

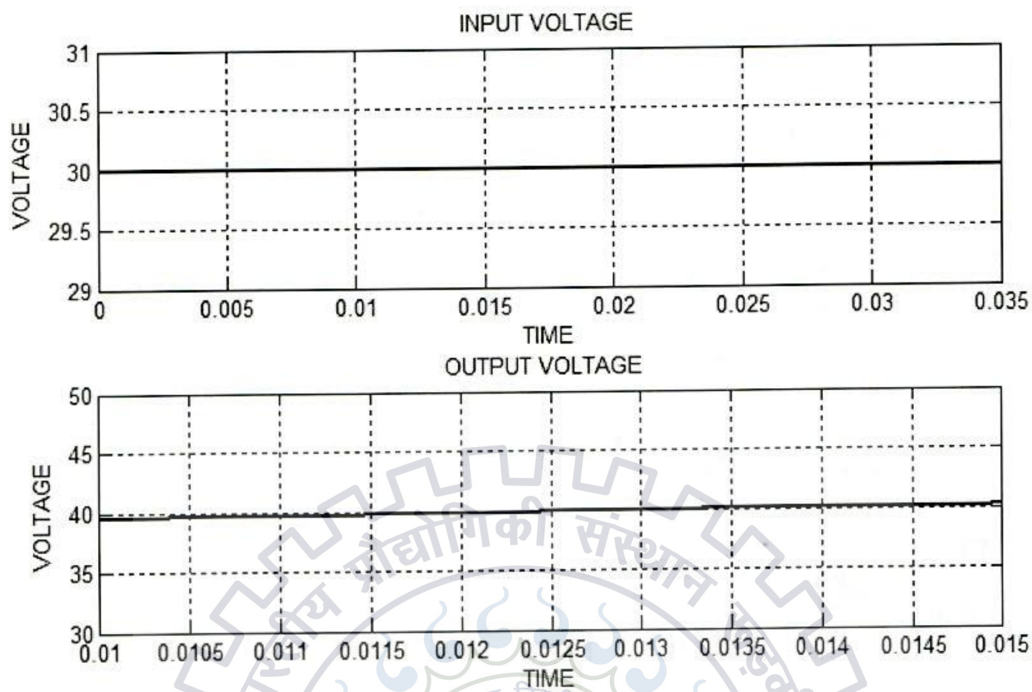


Figure 3.15 Simulation Output Of close Loop Boost Converter

3.7 CONCLUSION

After getting the outputs from chapter II and chapter III a comparative study can be done. It is concluded that the outputs from chapter II are not that accurate and also consists of good amount of ripples, whereas when the feedback system is introduced in chapter III that is the PID controller with properly defined values of proportionality gain and integral gain, the output attained is also accurate and ripple free. It can be seen by mathematical values as in section 3.6.1 or by graphical comparison in section 3.6.2

3.7.1 MATHEMATICAL VALUES

OUTPUT VOLTAGE WITHOUT PID CONTROLLER

INPUT VOLTAGE	SERIES INDUCTANCE	CAPACITANCE	LOAD RESISTANCE	OUTPUT VOLTAGE
V	μH	μF	Ω	V
30	570	660	45	39.60
30	570	660	50	39.75
30	570	660	55	39.80

OUTPUT VOLTAGE WITH PID CONTROLLER

INPUT VOLTAGE	SERIES INDUCTANCE	CAPACITANCE	LOAD RESISTANCE	OUTPUT VOLTAGE
V	μH	μF	Ω	V
30	570	660	45	40
30	570	660	50	40
30	570	660	55	40

Figure 3.16 Mathematical Values of Different Loads of the Close Loop Boost Converter

3.7.2 GRAPHICAL COMPARISON

The input for all the cases has been the same of the converter, be it open loop or close loop

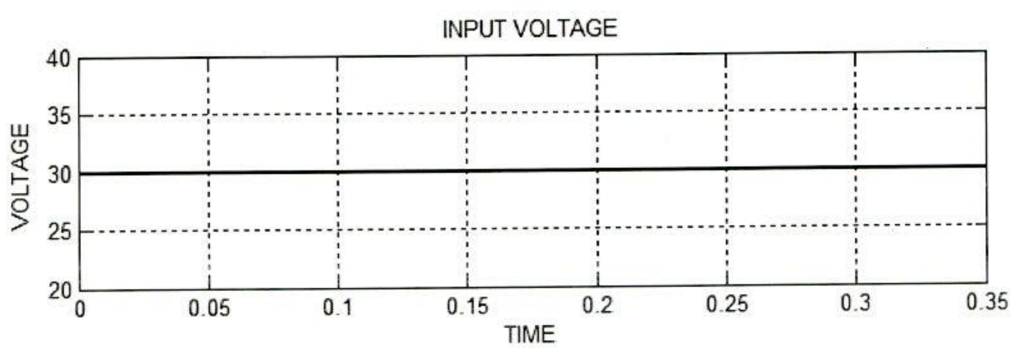


Figure 3.17 Shows the Input Graph for All Cases

3.7.2.1 ORIGINAL DESIGN: LOAD L=50 Ω

As it is seen, that output of the open loop converter that is without feedback is not accurate and consist of ripples, whereas the output for close loop is same as calculated and does not consist of the ripples.

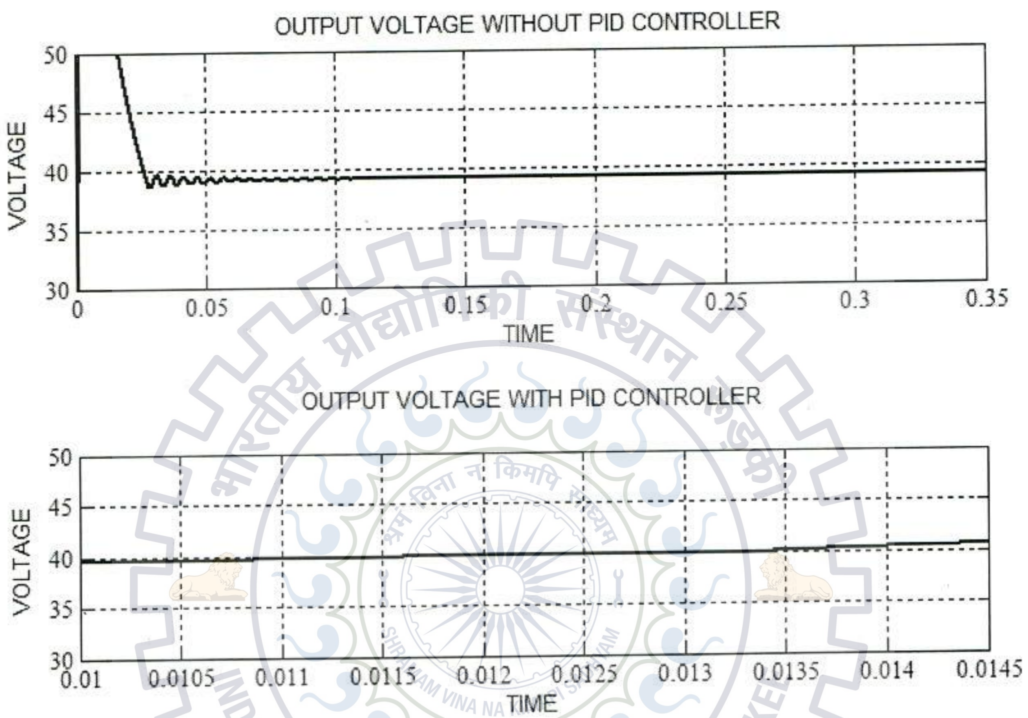


Figure 3.18 Simulation Output of the Open Loop and close loop Boost Converter

3.7.2.2 CASE I: LOAD L=45 Ω

As it is seen, that output of the open loop converter that is without feedback is not accurate and consist of ripples, whereas the output for close loop is same as calculated and does not consist of the ripples.

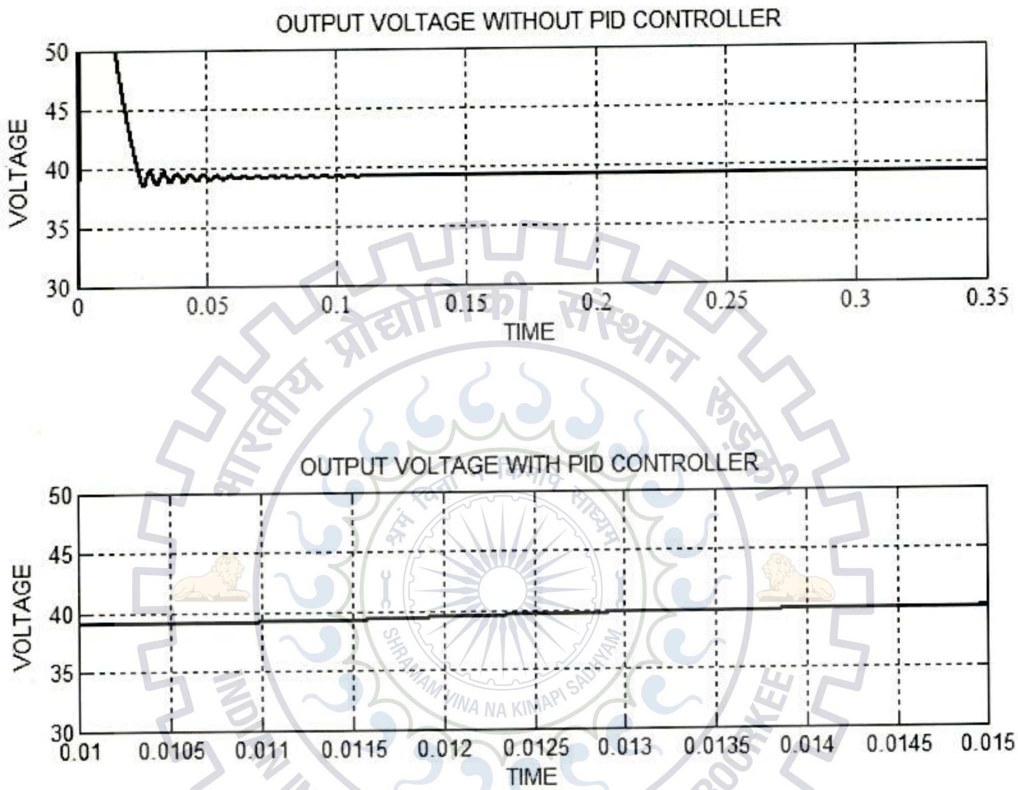


Figure 3.19 Simulation Output of the Open Loop and close loop Boost Converter

3.7.2.3 CASE II: LOAD L=55 Ω

As it is seen, that output of the open loop converter that is without feedback is not accurate and consist of ripples, whereas the output for close loop is same as calculated and does not consist of the ripples.

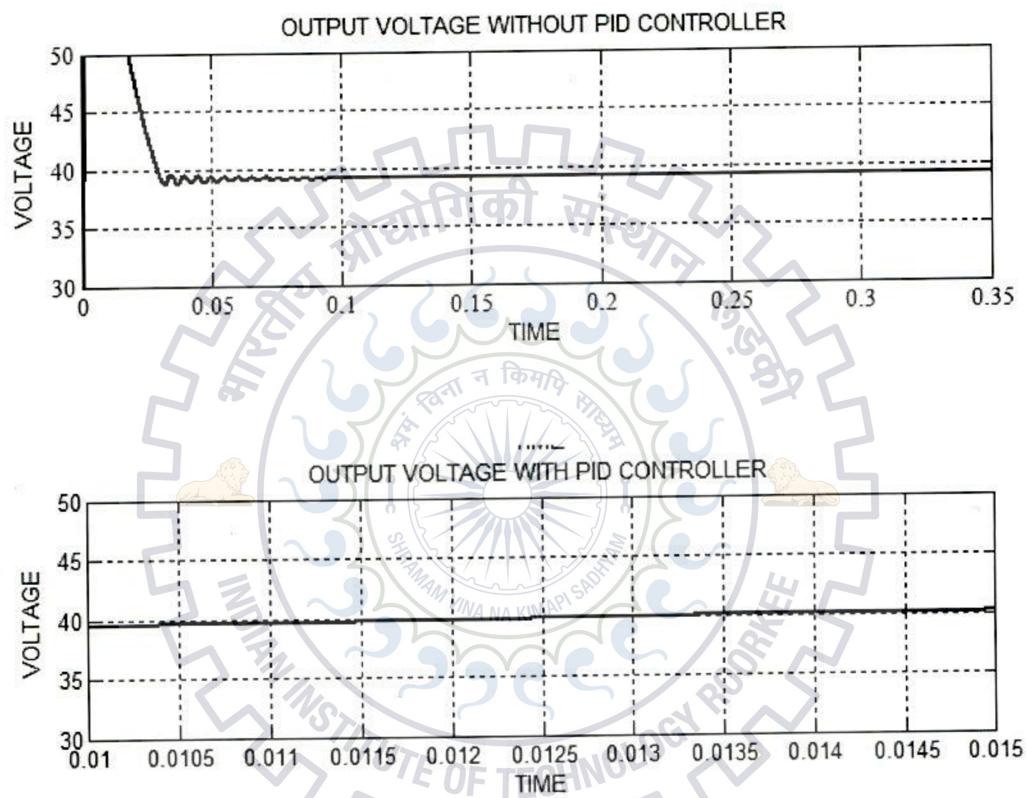


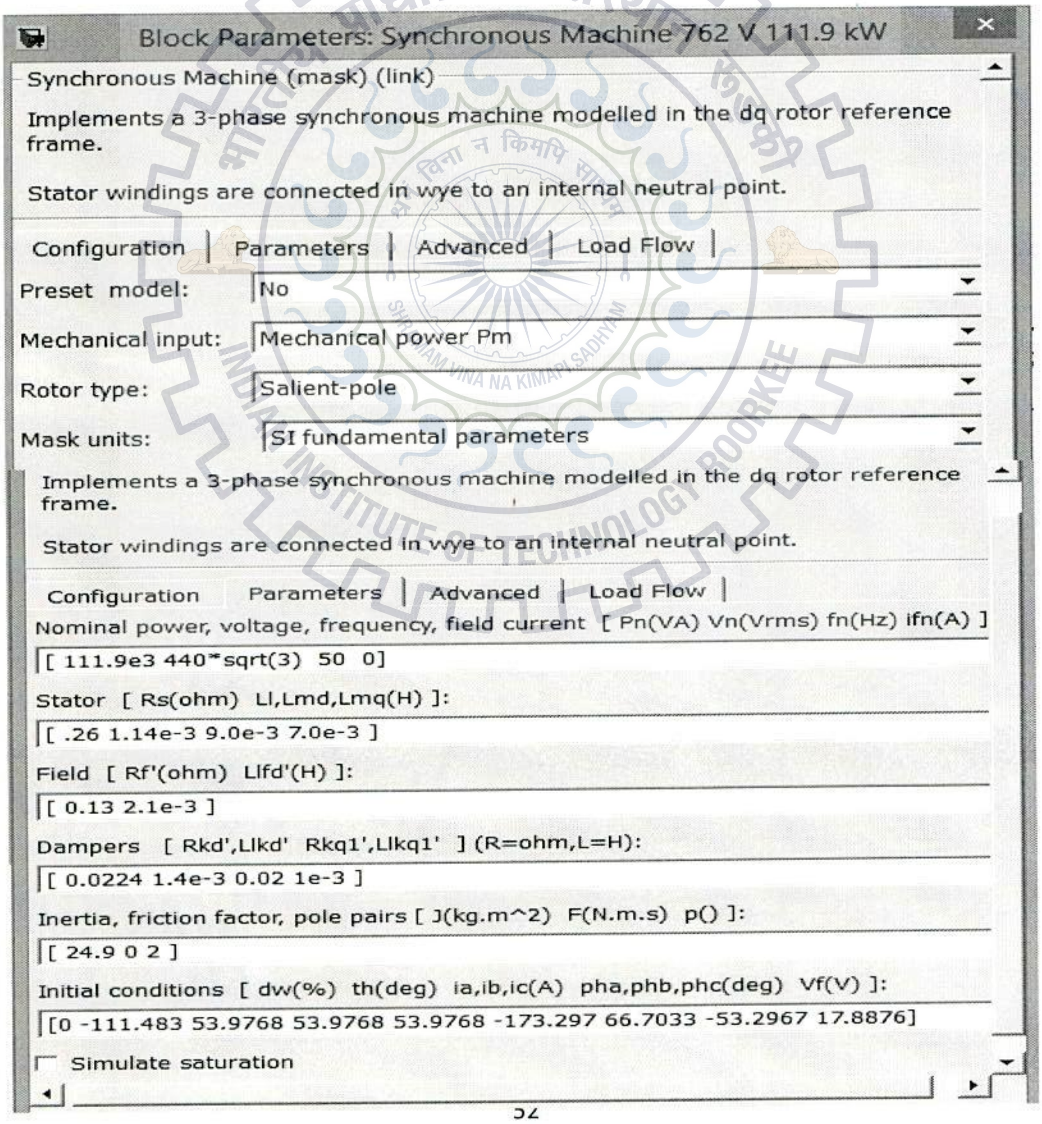
Figure 3.20 Simulation Output of the Open Loop and close loop Boost Converter

Chapter 4: INTRODUCTION TO SYNCHRONOUS GENERATOR

4.1 GENERAL

The devices employed for the generation are called the generators. Among the various types of generators, the one discussed in the Dissertation is synchronous generator. It is an electromechanical machine which produces alternating electricity, it is a kind of machine which converts mechanical energy into alternating electrical energy. It is also called as an alternator.

4.2 THE DESIGNS SPECIFICATIONS OF THE SYNCHRONOUS GENERATOR



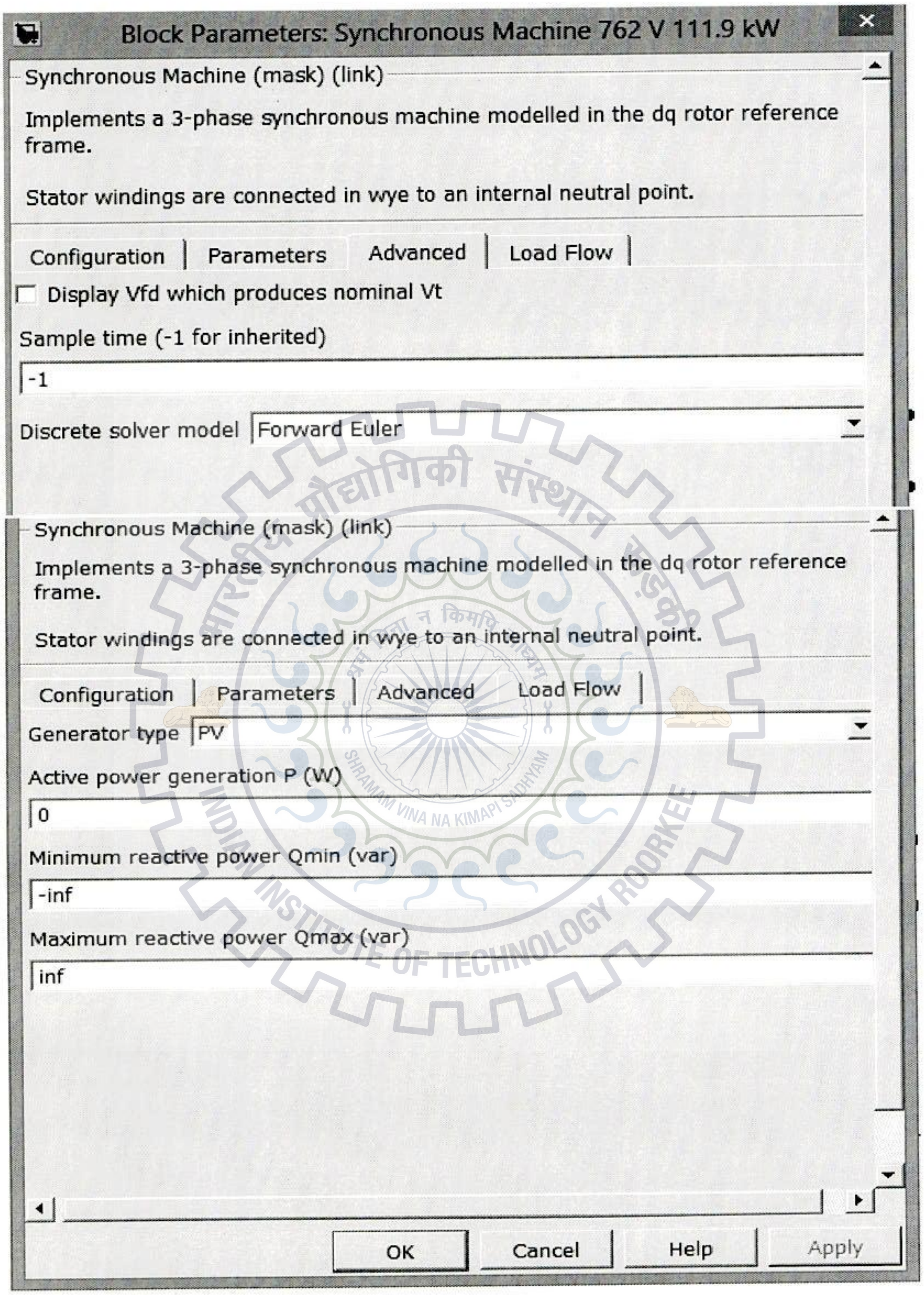


Figure 4.1 Parameters of the Synchronous Generator

4.2.1 THE 111.9KW SYNCHRONOUS GENERATOR CONSTRUCTED IN SIMULINK

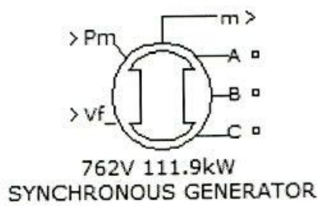


Figure 4.2 The Simulink model Synchronous Generator

The Figure No 4.3 shows the Simulink model of synchronous generator used for final design, the notation are as following:

Pm is the mechanical power

Vf is the field voltage

M is the measurement list

A, B, C is the three phase of terminal output

4.3 CONCLUSION

The 762 V 111.9Kw synchronous generator was particularly chosen for the system as it was suitable for the design. At different loads field voltage was calculated by verifying the output terminal voltage. The output terminal was supposed to be fixed for all loads that is 762 V.

The input and output voltage of the dc-dc boost converter were decided by the load conditions of the generator. The input voltage was decided at no load condition and the output voltage was decided by the full load condition, keeping the terminal voltage fixed.

FIELD VOLTAGE	LOAD	TERMINAL VOLTAGE
30	NO LOAD	762 V
40	FULL LOAD	762V

Chapter 5: INTEGRATION OF DC – DC BOOST CONVERTER WITH THE SYNCHRONOUS GENERATOR

5.1 INTRODUCTION

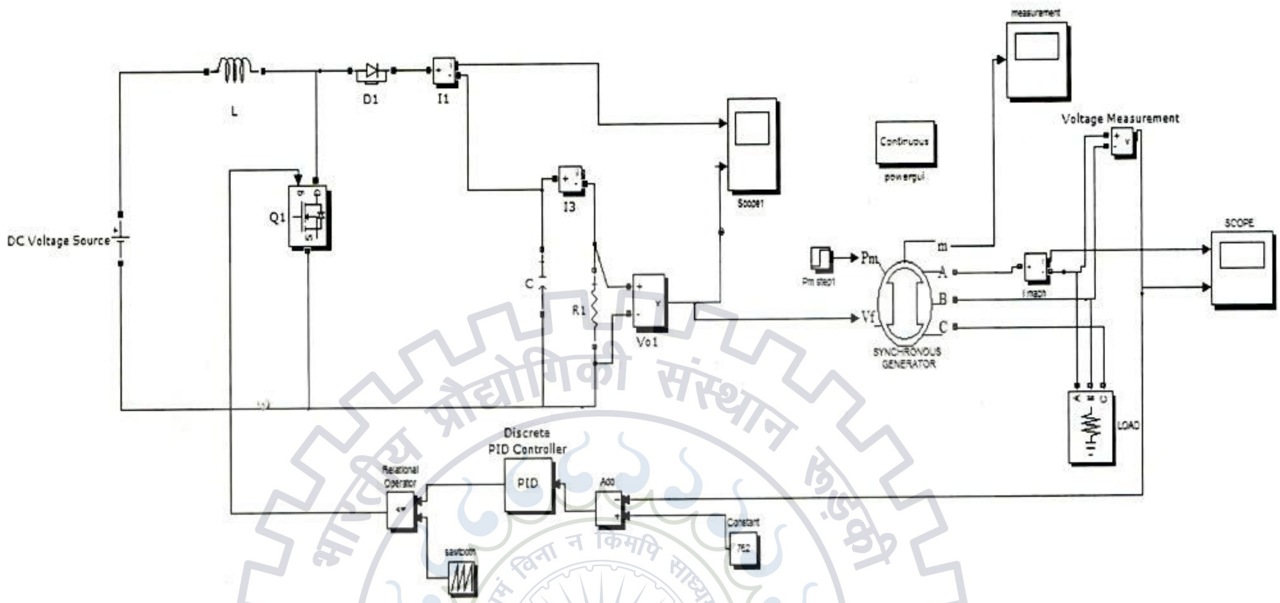
This is the most important part of the design of the excitation system for synchronous generator using DC – DC boost converter. In this chapter integration of dc –dc boost converter will be done with the 762V 111.9kW synchronous generator. We know, that the function of the excitation system is to maintain the terminal voltage of the system, so to verify this the whole system with be checked for different load conditions.

5.2 MAJOR SPECIFICATIONS OF THE COMPLETE SYSTEM

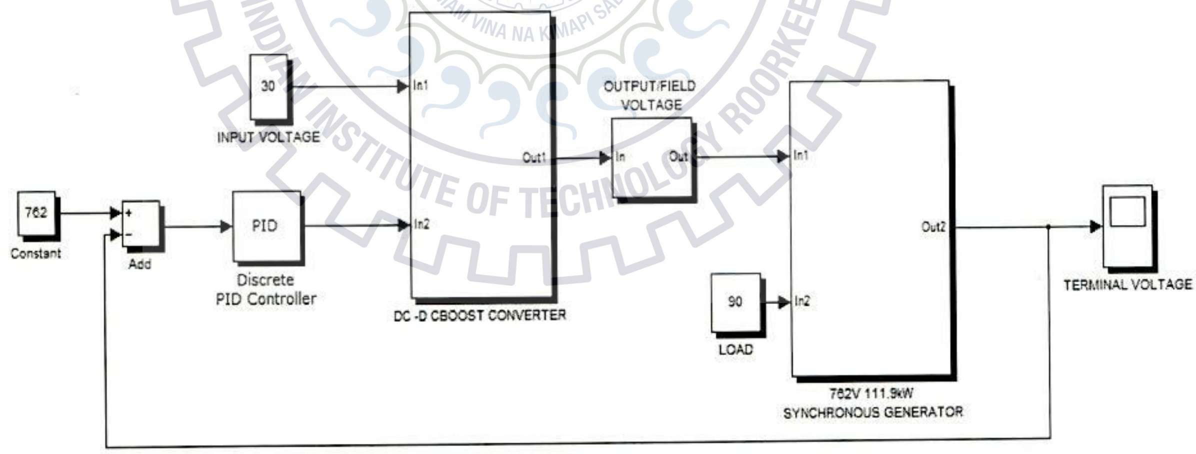
SYMBOL	PARAMETERS	VALUE	UNITS
Vi	INPUT CONVERTER VOLTAGE	30	V
Vo	OUTPUT CONVERTER VOLTAGE	40	V
Vf	OUTPUT TERMINAL VOLTAGE	762	V
F	SYSTEM FREQUENCY	50	Hz
K_p	PROPORTIONALITY GAIN	5.3	
K_i	INTEGRAL GAIN	0.37	

Figure 5.1 Major Specification of the complete system

5.3 THE DC –DC BOOST CONVERTER INTEGRATED WITH SYNCHRONOUS GENERATOR



(a)



(b)

Figure 5.2(a) and (b) Shows the Simulink Model of Synchronous Generator

5.4 SIMULATION OUTPUT OF THE WHOLE SYSTEM

Now to study and check the outputs of the whole working of the system, that is the close loop dc –dc boost converter integrated with the synchronous generator, the system is given different load conditions, as per the calculations and theoretical work, the system should be able to maintain the same terminal voltage in all conditions, though the output current will change as per the input load. The basic input of the boost converter is 30 V and the terminal voltage required all time is 762 V.

The following five cases are considered, and the output is shown below

5.4.1 CASE I: LOAD L = 50 kW

SIMULATION OUTPUT

In the Figure No 5.2 as shown below, the first graph is of the input voltage supplied by the boost converter, which is maintained as 30 V. The second graph is of the output terminal voltage of the synchronous generator, as it is visible that will the load L = 50 kW the output is maintained as 762 V, which help in achieving the main aim of the whole system.

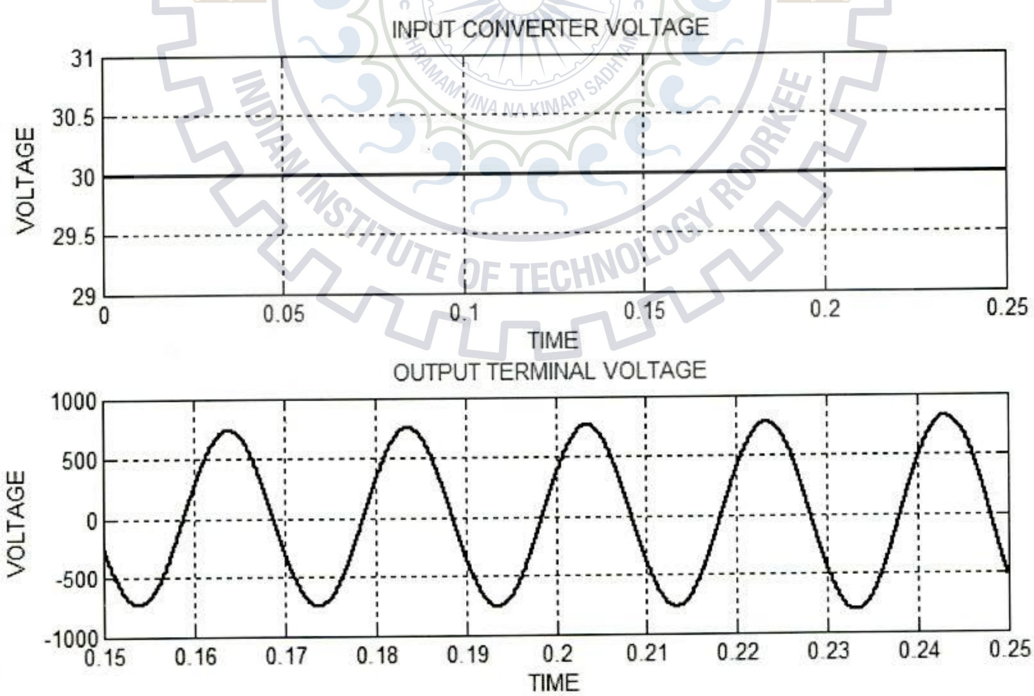


Figure 5.3 Simulation Output Of Load L = 50 kW

5.4.2 CASE II: LOAD L = 60 kW

SIMULATION OUTPUT

In the Figure No 5.3 as shown below, the first graph is of the input voltage supplied by the boost converter, which is maintained as 30 V. The second graph is of the output terminal voltage of the synchronous generator, as it is visible that will the load L = 60 kW the output is maintained as 762 V, which help in achieving the main aim of the whole system

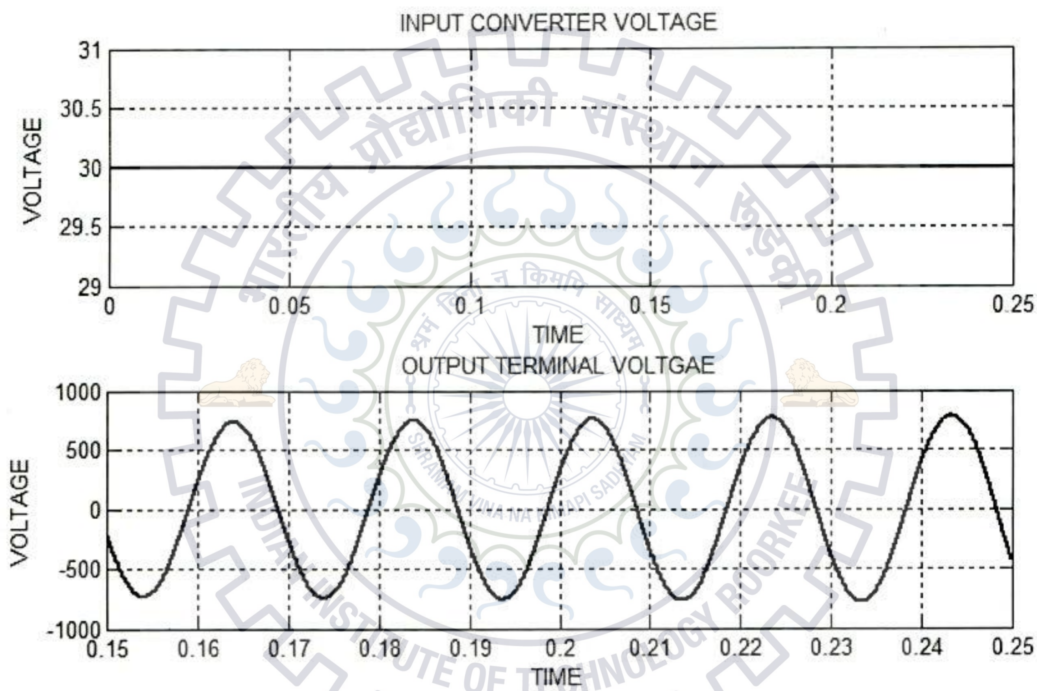


Figure 5.4 Simulation Output Of Load L = 60 Kw

5.4.3 CASE III: LOAD L = 70 kW

SIMULATION OUTPUT

In the Figure No 5.4 as shown below, the first graph is of the input voltage supplied by the boost converter, which is maintained as 30 V. The second graph is of the output terminal voltage of the synchronous generator, as it is visible that will the load L = 70 kW the output is maintained as 762 V, which help in achieving the main aim of the whole system

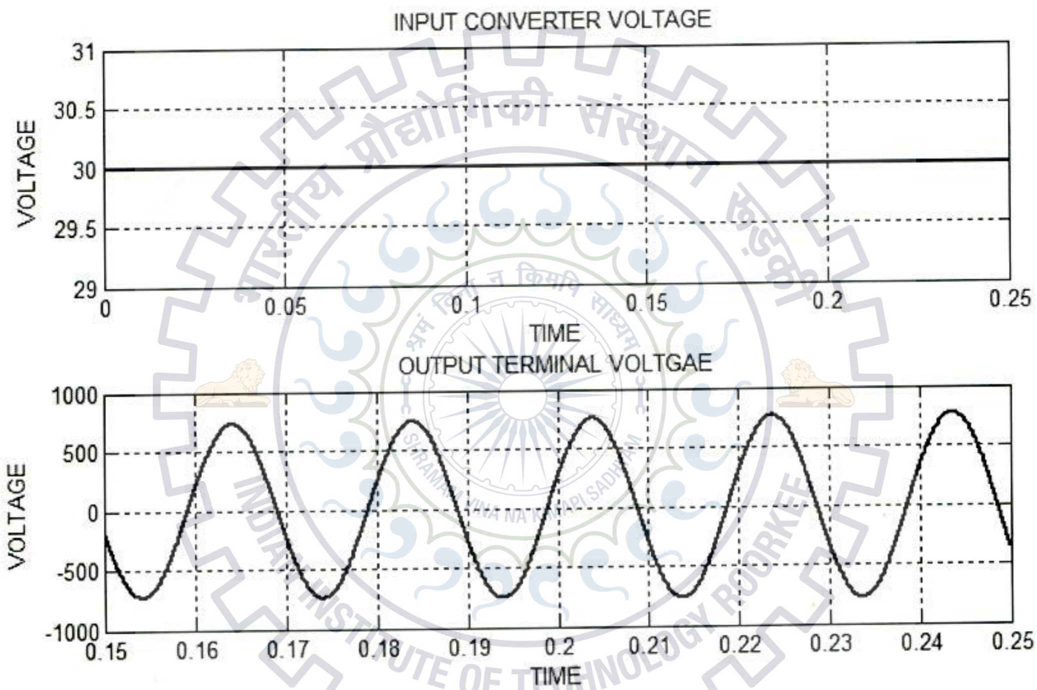


Figure 5.5 Simulation Output Of Load L = 70 kW

5.4.4 CASE IV: LOAD L = 80 kW

SIMULATION OUTPUT

In the Figure No 5.5 as shown below, the first graph is of the input voltage supplied by the boost converter, which is maintained as 30 V. The second graph is of the output terminal voltage of the synchronous generator, as it is visible that will the load L = 80 kW the output is maintained as 762 V, which help in achieving the main aim of the whole system

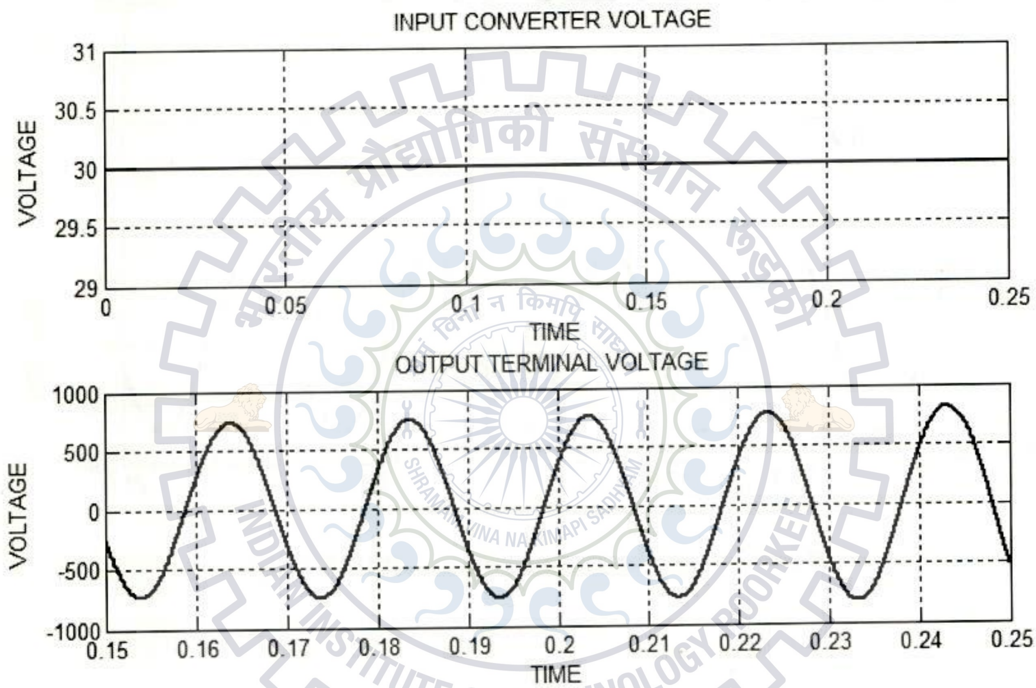


Figure 5.6 Simulation Output Of Load L = 80 kW

5.4.5 CASE V: LOAD L = 90 kW

SIMULATION OUTPUT

In the Figure No 5.6 as shown below, the first graph is of the input voltage supplied by the boost converter, which is maintained as 30 V. The second graph is of the output terminal voltage of the synchronous generator, as it is visible that will the load L = 90 kW the output is maintained as 762 V, which help in achieving the main aim of the whole system

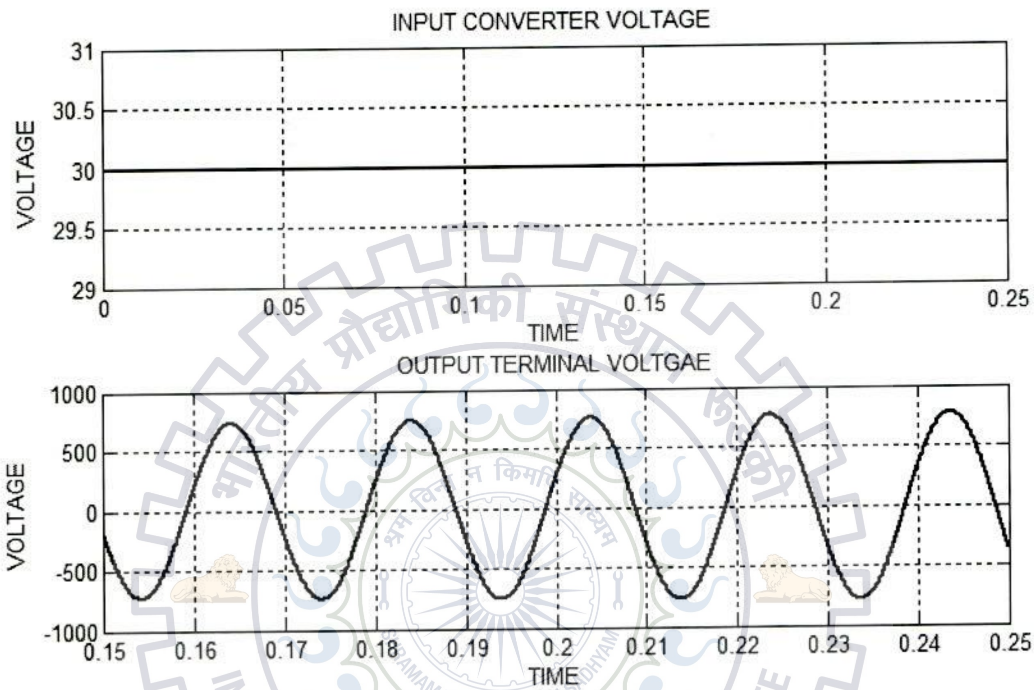


Figure 5.7 Simulation Output Of Load L = 90 kW

5.5 CONCLUSION

This chapter shows the results of the complete system that is "The DC –DC boost converters integrated with the synchronous generator". The close loop dc –dc boost converter act as the excitation system of the synchronous generator.

The whole designing process had stated from designing the open loop dc -dc boost converter, whose output was verified with various load conditions, but resulted in non-accurate output. To overcome this PID controller with specific parameters was integrated with open loop dc –dc boos converter, which became as close loop dc –dc boost converter.

The output of close loop dc –dc converter was verified with different load conditions, which resulted in accurate results, from there it is concluded that it is suitable to be integrated further with the synchronous generator.

After selecting the design parameters of the generator, it was integrated with the close loop d c-dc boost converter. Finally it is observed that with various load conditions the terminal voltage of the synchronous generator remains the same. Though with different loads the output current is changing, but with the help of PWM, the pulse generates and duty ratio chances, which maintain the terminal voltage constant.

This particular result is shown in the section 5.5.1with the help of the mathematical values. Finally it can be seen that the output terminal voltage of the generator remains constant, for different load conditions, hence the objective of the system designed has been achieved.

5.5.1 MATHEMATICAL VALUES

INPUT VOLTAGE OF DC –DC BOOST CONVERTER V	LOAD kW	TERMINAL VOLTAGE V	SYNCHRONOUS SPEED (RPM)
30	50	762	1500
30	60	762	1500
30	70	762	1500
30	80	762	1500
30	90	762	1500

Chapter 6: CONCLUSION AND FUTURE WORK POSSIBILITIES

6.1 THE CONCLUSION

In this Dissertation titled as "Design of Excitation System for Synchronous Generator Using Dc-Dc Converters", the regulation of the terminal voltage has been accomplished for variable load condition, so with the change of load the voltage remains constant. The proposed excitation system has lot of advantages over the presently employed system.

- Adjust the field current through increasing/boosting the field voltage for drop in line voltage.
- Fast control of reactive and active power.
- Improved steady-state response and transient response.
- Overall increased stability performance/characteristics
- Fast dynamic response
- Low output ripples
- Reduction in number of controlling devices
- Less power dissipation from chopper circuits
- Control and regulation of the complete output voltage achieved with the pulse width modulator
- Overall reduction in size of the system
- Overall reduction in the cost of the system
- Overall performance increased
- Provides high efficiency

Since the energy consumption is increasing, at a rate higher than that witnessed during the previous century, a method to fulfill the need and to intensify the overall efficiency of power system, Design of Excitation System for Synchronous Generator Using Dc-Dc Converters can be incorporated in various energy sources such as small hydro.

6.2 FUTURE SCOPE

The DC –DC boost converter can be replaced by the DC – DC buck - boost converter, for better performance in any kind of operating conditions. The buck converter controls the normal generator terminal voltage, under fault conditions the boost converter can increase the field voltage. Later a real time implementation can be done to verify the results even practically.

This can be implemented for sources like, wind, small hydropower plants, IC engines all this can be analyzed in future.

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