SWITCHED CAPACITOR VOLTAGE BOOST CONVERTER FOR HYBRID ELECTRIC DRIVES

Project Report

submitted in partial fulfillment for the award of the degree of

BACHELOR OF TECHNOLOGY

in

ELECTRICAL AND ELECTRONICS ENGINEERING

By

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CERTIFICATE

This is to certify that the project report entitled **"SWITCHED CAPACITOR VOLTAGE BOOST CONVERTER FOR HYBRID ELECTRIC DRIVES"** is the Bonafide record of project work carried out under my supervision by **V.SAI VAMSI (18L31A02A8), P.PURNA VIKAS (18L31A02C9), J.VENKATA KISHORE (19L35A0201), and B. MOHAN SAI(18L31A02H4)**, during the academic year 2021-2022, in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Electrical and Electronics Engineering The results embodied in this project report have not been submitted to any other University or Institute for the award of any Degree or Diploma.

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DECLARATION

We**, V. SAI VAMSI (18L31A02A8), P. PURNA VIKAS (18L31A02C9), J. VENKATA KISHORE (19L35A0201), B. MOHAN SAI (18L32A02H4)** hereby declare that this project report entitled "**SWITCHED CAPACITOR VOLTAGE BOOST CONVERTR FOR HYBRID ELECTRIC DRIVES**" is a record of the work done by us under the guidance of Mr. K Appala Naidu, Assistant Professor, Department of Electrical and Electronics Engineering, Vignan's Institution of Information Technology, Visakhapatnam and this work has not formed the basis for the award of any degree/diploma/associate ship/ fellowship or a similar award, to any candidate in any University, to the best of my knowledge.

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CONTENT

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ABSTRACT

This article presents a switched-capacitor (SC) voltage boost converter and its control methods for implementing dc-ac and ac-dc power conversion. The SC converter employs a switched-capacitor circuit augmented with the main converter circuit to the power source, thus providing unique features that cannot be attained by the traditional voltage-source inverter (VSI) or boost VSI. The additional features include doubling the area of the linear modulation region and eliminating both the large inductor in the boost dc-dc stage and the large filtering capacitor, which leads to a higher energy density and lower cost. The SC converter concept can be applied to all dc-ac, ac-dc, ac-ac, and dc-dc power conversions. To describe the operating principle and the control, we focus on one example: a bidirectional SC converter for dc-ac and ac-dc power conversion in electric and hybrid electric vehicles.

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND KNOWLEDGE

the authors concluded that a fast adaptation scenario for electric vehicles is likely to

happen. By 2042, around 93% (290 million) of all vehicles in the U.S. will be electric [1]. At that time, the internal combustion-based automakers that fail to transition to electric cars (EVs) will soon have a Kodak moment. In ideal world, the fast adaptation of EVs depends on how fast the EVs will outperform the internal combustion-based cars in mileage and price. The potential development of EV technology falls broadly into three categories: battery chemistry, autonomous driving, and the power electronic units. With regard to the last category, one of the most critical power conversion units is the drive train. The improvement of the drive train results in size reduction, fast speed/torque dynamic, and better utilization of battery power. Most of the existing EVs utilize a two-level voltage source inverter (VSI) with or without boost stage due to its reliability [2][3]. The opportunities to improve the EV power train can be addressed by exploring the limitations of VSIs. VSIs are inherently buck converters. Therefore, the dc-link voltage has to be higher than the dc or ac input voltage. For applications where the available dc voltage is limited, an additional dc-dc boost converter is needed to obtain the desirable ac voltage [4]. For the commercial traction electric drive system, two configurations are commonly used: the first one is a battery directly powering a two-level inverter; the second one is a battery connected to the inverter with an

intermediate dc-dc boost stage as shown in Fig. 1(a) [5]. The first configuration of a battery directly connected to the dc-bus offers minimum stress on the inverter side, but it requires an expensive battery with a large number of cells in series to achieve the necessary dc-link voltage [6]. The series connection of battery cells poses a challenge in terms of the slow charge equalization speed [7]. Furthermore, the isolation of one faulty cell in the series connection leads to a voltage drop in the overall series connection. In this case, the entire series row of batteries needs to be disconnected from the dc-link to avoid a short circuit with other non-faulty series rows of cells. The first configuration is seen only in extended-range electric vehicles (with large batteries) such as Tesla (75 to 100 kWh) [8]. The second configuration shown in Fig. 1(a) is used in

1.2 CIRCUIT DIAGRAMS

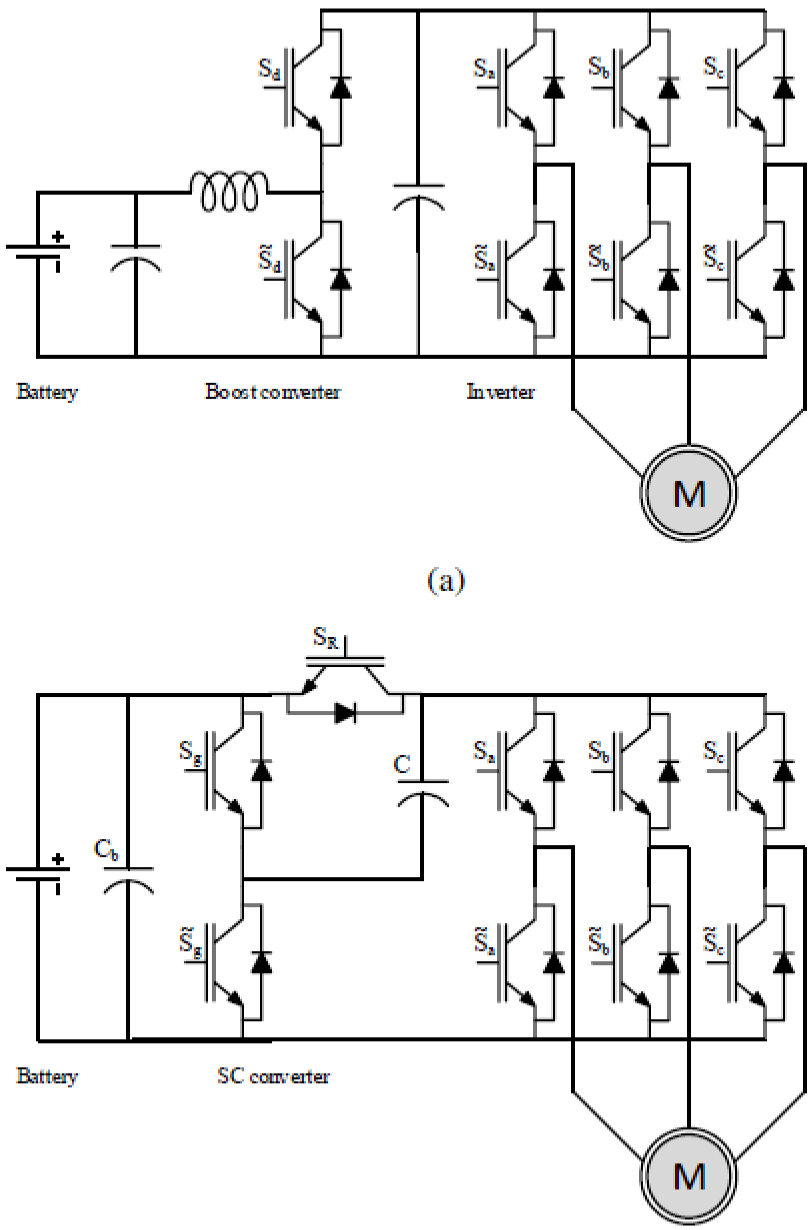


Fig. 1: The schematics of (a) the conventional inverter converter topology and of (b) the proposed switched-capacitor voltage boost converter

hybrid electric vehicles (HEVs) and plug-in HEVs (PHEVs) where the battery energy rating ranges from 5 to 50 kWh. While the current limit in the machine is dependent on its ability to dissipate the heat, the voltage limit is dependent on the dc-link voltage level. Therefore, using a dc-dc boost converter extends the constant torque region [9]. Owing to the superior current density characteristics of the Sic-MOSFET compared to the Si-IGBT, the current density of the 1200V Sic-MOSFET is similar to the current density of the lower voltage 600V Si-IGBT [10]. This advantage leads to a reduction in semiconductor die area by a factor of two, and this is accomplished by utilizing high-voltage motors and SiCMOSFETs [11]. Furthermore, the reduced current peak at a higher voltage leads to smaller peak losses by a factor of four [11]. Since power loss translates directly into cooling system capacity, a significant reduction in cooling system size and weight, as well as an improvement in EV range, can be achieved. The conventional boost stage depicted in Fig. 1(a) is not quite perfect. The power rating of the dc-dc converter must match the battery pack power, leading to a proportionally large inductor. The inductor is a heavy and costly component. Furthermore, the inductor copper and core losses increase proportionally with the size of the inductor. When boosted by a high-voltage ratio, the boost converter must operate with a high duty cycle where the efficiency is relatively low [12]. The partial power efficiency is also reduced, because the ac losses (switching loss and ac magnetic loss) depend on voltage but are nearly independent of current. At high duty cycles, the rms current applied to the bus capacitor is also quite high, which impacts the size and cost of the capacitor [11]. To overcome the above limitations of the traditional drive trains, this paper presents the switched-capacitor voltage boost (SC) converter and its control methods. Fig. 1(b) shows one version of the proposed SC converter. It employs a switched capacitor circuit with the inverter to form a unified circuit. The switched capacitor circuit is used to create a multi-leveled dc-link voltage. Therefore, the proposed switched-capacitor circuit differs from the conventional one by not having the reverse blocking diode at the load side or the large filtering capacitor. The regulation of the output current and voltage is realized by unified control of both the inverter and the switched-capacitor stages

1.3 THESIS WORK

Chapter 2 contains the Literature survey. It briefs about the different parameters on switched capacitor converters, controlling methodology, and about power electronic systems. Also briefing is done on the DC-DC converters

Chapter 3 deals with the different types of converters and their analysis and functioning process

Chapter 4 deals with the capacitor switching operations and slow switching limit impedance.

Chapter 5 explains briefly about the inverter types and their operations and their implementation

Chapter 6 gives through explanation about the BLDC motors and their control techniques and their speed torque characteristics and proposed modelling of PMBLDC

Chapter 7 deals with the MATLAB demonstration.

Chapter 8 deals with the MATLAB circuit and output waveforms.

Chapter 9 manages the future extent of the task and progression and conclusion.

1.4 CONCLUSION

Switched capacitor voltage boost converter for hybrid electric vehicles is useful to minimise the losses occurred in traditional converters. So, in this project SC voltage boot converted is proposed

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

For designing and analysis of the SC voltage converter different DC-DC converters are used such as BOOST, BOOST, BUCK-BOOST, CUK converters and control methodology for reliability.

2.2 LITERATUR SURVEY

2.2.1 “Riding the Energy Transition: Oil Beyond 2040

If the electric car were to take over road transportation, one would expect an increase in demand for electricity to be quite substantial. Fossil fuels could still play a major role in electricity generation, as does coal today. However, renewables are growing rapidly enough to provide the increasing demand for electricity and potentially replace existing fossil energy sources. Examining the potential increase in demand for electricity because of a significant rise in electric vehicles, we note it would have been only a fraction of electricity consumption in an advanced economy in 2015. Moreover, switching all motor vehicles in the US (about 253 million vehicles) to electric vehicles and generating all the electricity needed to power them (an increase of about 30% in demand for electricity) from oil alone would still result in a decline in oil demand by 3.6 million barrels a day in 2015 (out of nine million barrels a day used to produce gasoline.

2.2.2 “Evaluation Methodology and Control Strategies for Improving Reliability

he reliability prediction of hybrid electric vehicles (HEVs) is of paramount importance for planning, design, control, and operation management of vehicles, since it can provide an objective criterion for comparative evaluation of various configurations and topologies and can be used as an effective tool to improve the design and control of the overall system. This paper presents a mission-profile-dependent simulation model based on MATLAB for quantitatively assessing the reliability of the electric drivetrain of HEVs. This model takes into consideration the variable driving scenarios, dormant mode, electrical stresses, and thermal stresses. Therefore, more reliable and accurate prediction of system reliability has been achieved. The methodology is explained in detail, and the results of reliability assessment based on a series HEV are presented. Based on reliability analysis, two control strategies are proposed to increase the mean time to failure of HEV powertrains: 1) variable dc-link voltage control and 2) hybrid discontinuous pulse width modulation scheme. These novel control schemes reduce the power losses and thermal stresses of power converters, and consequently, enhance system reliability. Numerical simulation results verify the benefits of two proposed control strategies in terms of power losses and reliability.

2.2.3 wide-spread application of power electronic systems

across many different industries, their reliability is being studied extensively. This paper presents a comprehensive review of reliability assessment and improvement of power electronic systems from three levels: 1) metrics and methodologies of reliability assessment of existing system; 2) reliability improvement of existing system by means of algorithmic solutions without change of the hardware; and 3) reliability-oriented design solutions that are based on fault-tolerant operation of the overall systems. The intent of this review is to provide a clear picture of the landscape of reliability research in power electronics. The limitations of the current research have been identified and the direction for future research is suggested.

CHAPTER 3

CONVERTERS

3.1 INTRODUCTION DC to DC CONVERTER

In electronics engineering, a DC-to-DC converter is a circuit which converts a source of direct current from one voltage to another. It is a class of power converter.

DC to DC converters are important in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries. Such electronic devices often contain several sub-circuits with each sub-circuit requiring a unique voltage level different than that supplied by the battery (sometimes higher or lower than the battery voltage, and possibly even negative voltage). Additionally, the battery voltage declines as its stored power is drained. DC to DC converters offer a method of generating multiple controlled voltages from a single variable battery voltage, thereby saving space instead of using multiple batteries to supply different parts of the device.

3.2 CONVERSION METHODS

Linear

A simple method of converting one voltage to another is a circuit known as a voltage divider. This technique uses resistors in series with the voltage supply to provide a lower voltage. However, this method suffers serious drawbacks:

- Provides no voltage regulation
- Requires knowledge of the resistance of the load
- Poor efficiency, which also leads to excess heat dissipation
- Impossible to generate voltages higher than the supply voltage
- Impossible to generate negative voltages, unless the system ground is defined by a node in the resistor network.

Any kind of voltage regulator solves the first two problems, however, linear regulators still have the last three problems.

3.2.1 Switched-mode conversion

Electronic switch-mode DC to DC converters are available to convert one DC voltage level to another. These circuits, very similar to a switched-mode power supply, generally perform the conversion by applying a DC voltage across an inductor or transformer for a period of time (usually in the 100 kHz to 5 MHz range) which causes current to flow through it and store energy magnetically, then switching this voltage off and causing the stored energy to be transferred to the voltage output in a controlled manner. By adjusting the ratio of on/off time, the output voltage can be regulated even as the current demand changes. This conversion method is more power efficient (often 80% to 95%) than linear voltage conversion which must dissipate unwanted power. This efficiency is beneficial to increasing the running time of battery operated devices. A drawback to switching converters is the electronic noise they generate at high frequencies, which must sometimes be filtered.

Isolated DC-DC converters convert a DC input power source to a DC output power while maintaining isolation between the input and the output, generally allowing differences in the input-output ground potentials in the range of hundreds or thousands of volts. They can be an exception to the definition of DC-DC converters in that their output voltage is often (but not always) the same as the input voltage.

A current-output DC-DC converter accepts a DC power input, and produces as its output a constant current, while the output voltage depends on the impedance of the load. The various topologies of the DC to DC converter can generate voltages higher, lower, higher and lower or negative of the input voltage; their names are:

- Buck
- Boost
- Buck-boost
- Ćuk

In general, the term "DC to DC converter" almost always refers to one of these switching converters.

Switching DC to DC converters are available in a wide variety of input and fixed or adjustable output voltages.

DC to DC converters are now available as integrated circuits needing minimal extra components to build a complete converter. DC to DC converters are also available as complete hybrid circuits, ready for use within an electronic device.

DC-DC CONVERTER BASICS

A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc. This is a summary of some of the popular DC-to-DC converter topologies:

3.3 BUCK CONVERTER STEP-DOWN CONVERTER

In this circuit the transistor turning ON will put voltage Vin on one end of the inductor. This voltage will tend to cause the inductor current to rise. When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode. We initially assume that the current through the inductor does not reach zero, thus the voltage at Vx will now be only the voltage across the conducting diode during the full OFF time. The average voltage at Vx will depend on the average ON time of the transistor provided the inductor current is continuous.

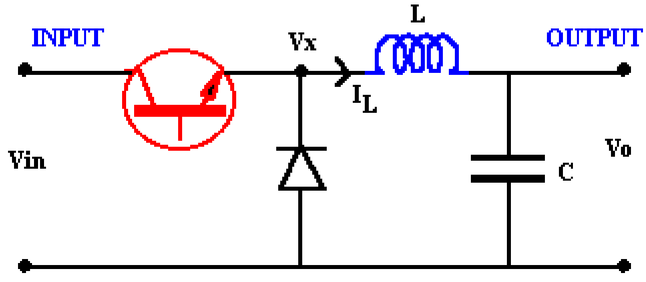
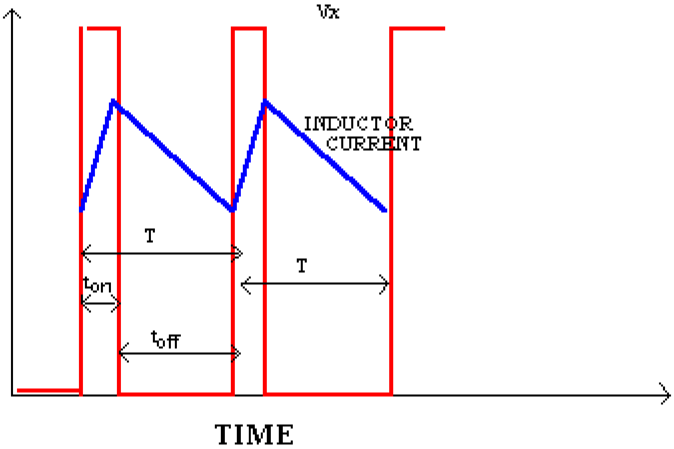


Fig 3.2 buck converter



Buck Converter

Fig 3.3 Voltage and current changes

To analyze the voltages of this circuit let us consider the changes in the inductor current over one cycle. From the relation

$$V_x - V_o = L\frac{di}{dt}$$

the change of current satisfies

$$di = \int_{ON} (V_x - V_o)dt + \int_{OFF} (V_x - V_o)dt$$

For steady state operation the current at the start and end of a period T will not change. To get a simple relation between voltages we assume no voltage drop across transistor or diode while ON and a perfect switch change. Thus during the ON time V_x=V_{in} and in the OFF V_x=0. Thus

$$0 = di = \int_0^{t_{on}} (Vin - Vo)dt + \int_{t_{on}}^{t_{on}+t_{off}} (-Vo)dt$$

which simplifies to

$$(Vin - Vo)t_{on} - Vo\ t_{off} = 0$$

or

$$\frac{Vo}{Vin} = \frac{t_{on}}{T}$$ and defining "duty ratio" as $$D = \frac{t_{on}}{T}$$ the voltage relationship becomes Vo=D Vin Since the circuit is lossless and the input and output powers must match on the average V_o* I_o = V_{in}* I_{in}. Thus the average input and output current must satisfy I_{in} =D I_o These relations are based on the assumption that the inductor current does not reach zero.

Transition between continuous and discontinuous

When the current in the inductor L remains always positive then either the transistor T1 or the diode D1 must be conducting. For continuous conduction the voltage V_x is either V_{in} or 0. If the inductor current ever goes to zero then the output voltage will not be forced to either of these conditions. At this transition point the current just reaches zero as seen in Figure 3. During the ON time V_{in}-V_{out} is across the inductor thus

$$I_L(peak) = (Vin - Vout) \cdot \frac{t_{ON}}{L}$$

The average current which must match the output current satisfies

$$I_L(average\ at\ transition) = \frac{I_L(peak)}{2} = (Vin - Vout)\frac{dT}{2L} = Iout(transition)$$

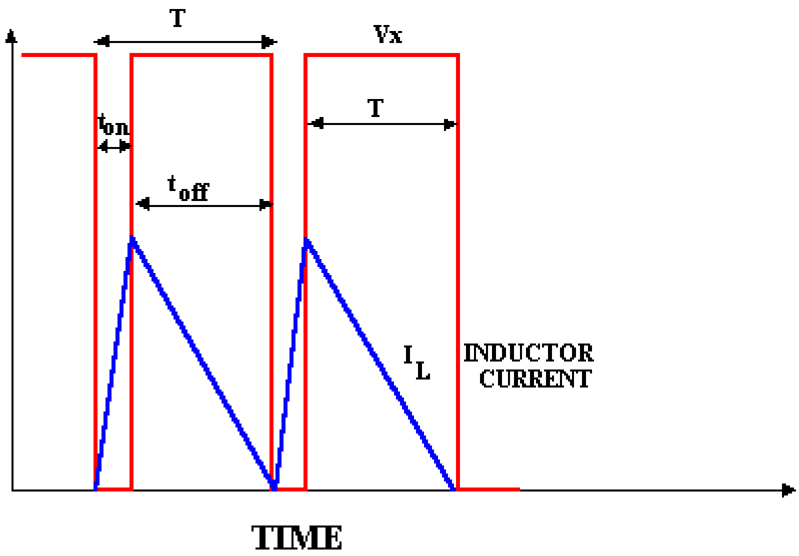


Fig 3.4 Buck Converter at Boundary

If the input voltage is constant the output current at the transition point satisfies

$$Iout(transition) = Vin\frac{(1-d)d}{2L}T$$

Voltage Ratio of Buck Converter (Discontinuous Mode)

As for the continuous conduction analysis we use the fact that the integral of voltage across the inductor is zero over a cycle of switching T. The transistor OFF time is now divided into segments of diode conduction d_dT and zero conduction d_oT. The inductor average voltage thus gives

$(V_{in} - V_o)\ DT + (-V_o)\ d_dT = 0$

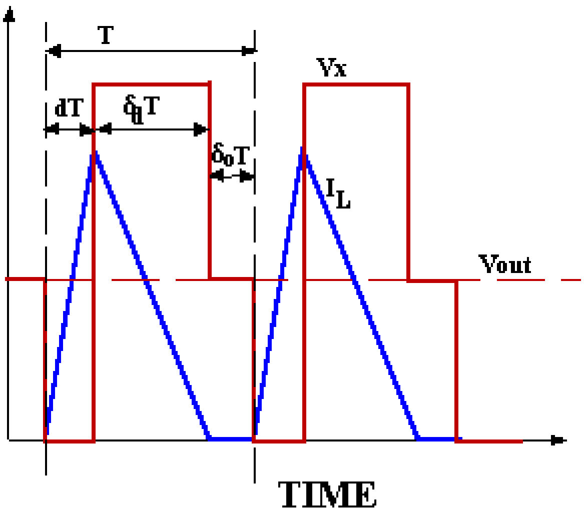


Fig 3.4 Buck Converter - Discontinuous Conduction

$$\therefore \frac{Vout}{Vin} = \frac{d}{d + \delta_d}$$

for the case $d + \delta_d < 1$. To resolve the value of δ_d consider the output current which is half the peak when averaged over the conduction times $d + \delta_d$

$$Iout = \frac{I_L(peak)}{2} d + \delta_d$$

Considering the change of current during the diode conduction time

$$I_L(peak) = \frac{V_0(\delta_d T)}{L}$$

Thus from (6) and (7) we can get

$$I_{out} = \frac{V_0 \delta_d T \cdot (d + \delta_d)}{2L}$$

using the relationship in (5)

$$Iout = \frac{Vin\, d\ \delta_d T}{2L}$$

and solving for the diode conduction

$$\delta_d = \frac{2\,L\;Iout}{Vin\;d\;T}$$

The output voltage is thus given as

$$\frac{Vout}{Vin} = \frac{d^2}{d^2 + (\frac{2\,L\;Iout}{Vin\;T})}$$

defining k* = 2L/(V_{in} T), we can see the effect of discontinuous current on the voltage ratio of the converter.

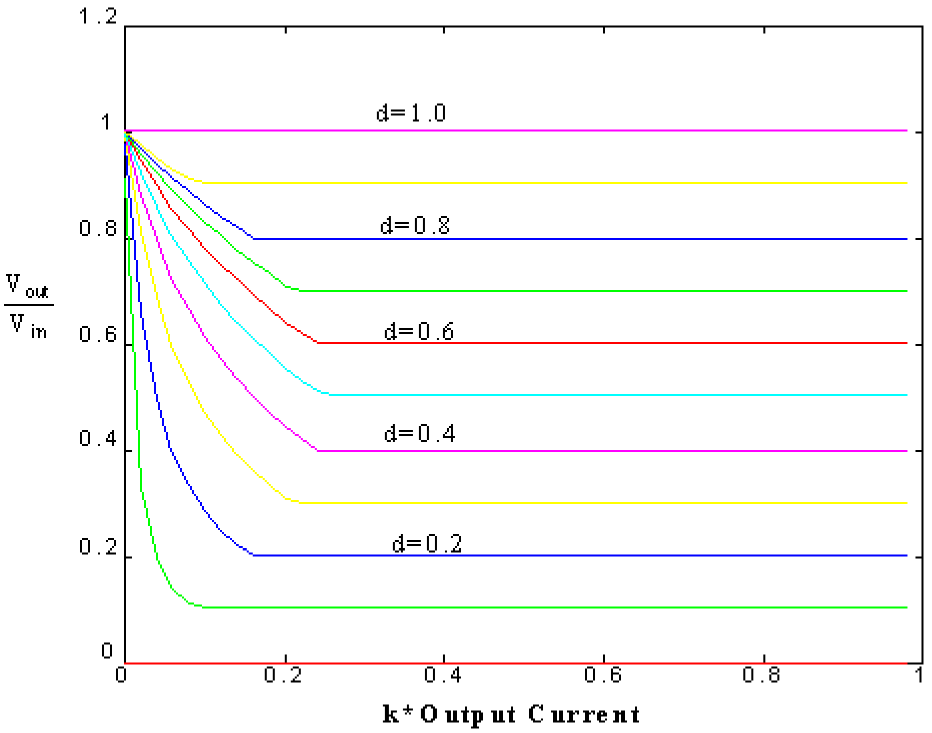


Fig 3.5 Output Voltage vs Current

As seen in the figure, once the output current is high enough, the voltage ratio depends only on the duty ratio "d". At low currents the discontinuous operation tends to increase the output voltage of the converter towards V_{in}.

3.4 BOOST CONVERTER STEP-UP CONVERTER

The schematic in Fig. 6 shows the basic boost converter. This circuit is used when a higher output voltage than input is required.

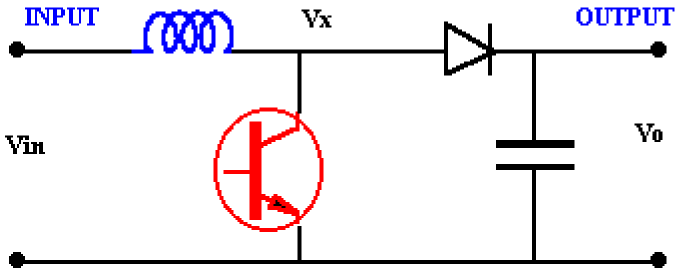


Fig 3.6 Boost Converter Circuit

While the transistor is ON $V_x = V_{in}$, and the OFF state the inductor current flows through the diode giving $V_x = V_o$. For this analysis it is assumed that the inductor current always remains flowing (continuous conduction). The voltage across the inductor and the average must be zero for the average current to remain in steady state

$$Vin\, t_{on} + (Vin - Vo)t_{off} = 0$$

This can be rearranged as

$$\frac{Vo}{Vin} = \frac{T}{t_{off}} = \frac{1}{(1-D)}$$

and for a lossless circuit the power balance ensures

$$\frac{Io}{Iin} = (1-D)$$

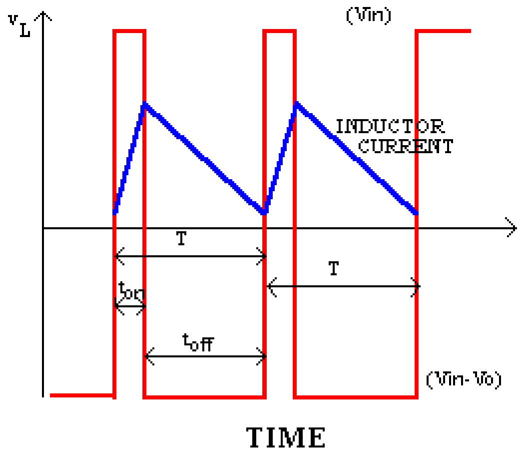
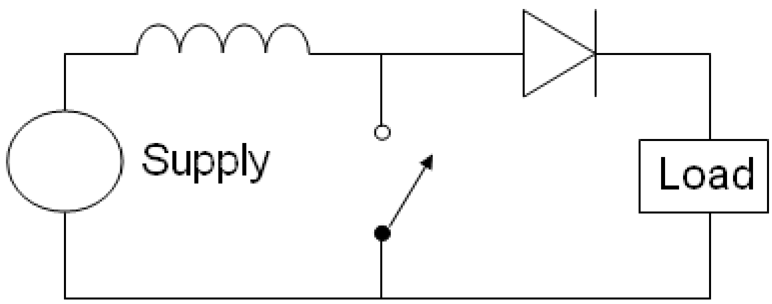


Fig 3.7 Voltage and current waveforms (Boost Converter)

Since the duty ratio "D" is between 0 and 1 the output voltage must always be higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

A **boost converter** (**step-up converter**) is a power converter with an output DC voltage greater than its input DC voltage. It is a class of switching-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.



3.4.1 Overview

Power can also come from DC sources such as batteries, solar panels, rectifiers and DC generators. A process that changes one DC voltage to a different DC voltage is called DC to DC conversion. A boost converter is a DC to DC converter with an output voltage greater than the source voltage. A boost converter is sometimes called a step-up converter since it “steps up” the source voltage. Since power (P = VI) must be conserved, the output current is lower than the source current.

A boost converter may also be referred to as a 'Joule thief'. This term is usually used only with very low power battery applications, and is aimed at the ability of a boost converter to 'steal' the remaining energy in a battery. This energy would otherwise be wasted since a normal load wouldn't be able to handle the battery's low voltage.

3.4.2 History

For high efficiency, the SMPS switch must turn on and off quickly and have low losses. The advent of a commercial semiconductor switch in the 1950’s represented a major milestone that made SMPSs such as the boost converter possible. Semiconductor switches turned on and off more quickly and lasted longer than other switches such as vacuum tubes and electromechanical relays. The major DC to DC converters were developed in the early 1960s when semiconductor switches had become available. The aerospace industry's need for small, lightweight, and efficient power converters led to the converter's rapid development.

Switched systems such as SMPS are a challenge to design since its model depends on whether a switch is opened or closed. R.D. Middlebrook from Caltech in 1977 published the models for DC to DC converters used today. Middlebrook averaged the circuit configurations for each switch state in a technique called state-space averaging. This simplification reduced two systems into one. The new model led to insightful design equations which helped SMPS growth.

3.4.3 Applications

Battery powered systems often stack cells in series to achieve higher voltage. However, sufficient stacking of cells is not possible in many high voltage applications due to lack of space. Boost converters can increase the voltage and reduce the number of cells. Two battery-powered applications that use boost converters are hybrid electric vehicles (HEV) and lighting systems.

The Toyota Prius HEV uses a 500 V motor. Without a boost converter, the Prius would need nearly 417 cells to power the motor. However, a Prius actually uses only 168 cells and boosts the battery voltage from 202 V to 500 V. Boost converters also power devices at smaller scale applications, such as portable lighting systems. A white LED typically requires 3.3 V to emit light, and a boost converter can step up the voltage from a single 1.5 V alkaline cell to power the lamp. Boost converters can also produce higher voltages to operate cold cathode fluorescent tubes (CCFL) in devices such as LCD backlights and some flashlights.

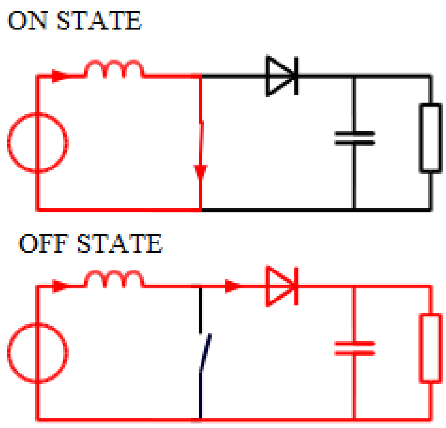
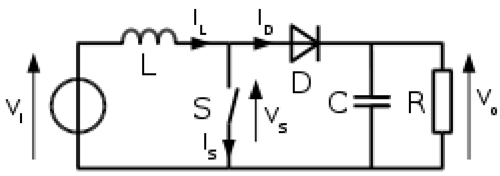


Fig 3.8 Ton. fig 3.9 Toff

3.4.4 Circuit analysis   Operating principle

The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged it acts as a load and absorbs energy (somewhat like a resistor), when being discharged, it acts as an energy source (somewhat like a battery). The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages.



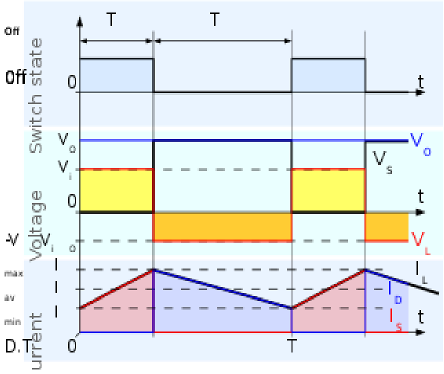
Boost converter schematic

The two configurations of a boost converter, depending on the state of the switch S.

The basic principle of a Boost converter consists of 2 distinct states (see figure 2):

- In the On-state, the switch S (see figure 1) is closed, resulting in an increase in the inductor current;
- In the Off-state, the switch is open and the only path offered to inductor current is through the flyback diode D, the capacitor C and the load R. This results in transferring the energy accumulated during the On-state into the capacitor.
- The input current is the same as the inductor current as can be seen in figure 2. So it is not discontinuous as in the buck converter and the requirements on the input filter are relaxed compared to a buck converter.

Continuous mode



Waveforms of current and voltage in a boost converter operating in continuous mode.

When a boost converter operates in continuous mode, the current through the inductor (I_L) never falls to zero. shows the typical waveforms of currents and voltages in a converter operating in this mode. The output voltage can be calculated as follows, in the case of an ideal converter (i.e. using components with an ideal behavior) operating in steady conditions:

During the On-state, the switch S is closed, which makes the input voltage (V_i) appear across the inductor, which causes a change in current (I_L) flowing through the inductor during a time period (t) by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L}$$

At the end of the On-state, the increase of I_L is therefore:

$$\Delta I_{L_{On}} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is On. Therefore, D ranges between 0 (S is never on) and 1 (S is always on).

During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of I_L is:

$V_i - V_o = L\frac{dI_L}{dt}$ Therefore, the variation of I_L during the Off-period is:

$\Delta I_{L_{Off}} = \int_0^{(1-D)T} \frac{(V_i - V_o)\,dt}{L} = \frac{(V_i - V_o)(1-D)T}{L}$ As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by:

$E = \frac{1}{2}LI_L^2$ So, the inductor current has to be the same at the start and end of the commutation cycle. This means the overall change in the current (the sum of the changes) is zero:

This can be written as:

$$\frac{V_o}{V_i} = \frac{1}{1-D}$$

Which in turns reveals the duty cycle to be:

$$D = 1 - \frac{V_i}{V_o}$$

From the above expression it can be seen that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a step-up converter.

Discontinuous mode

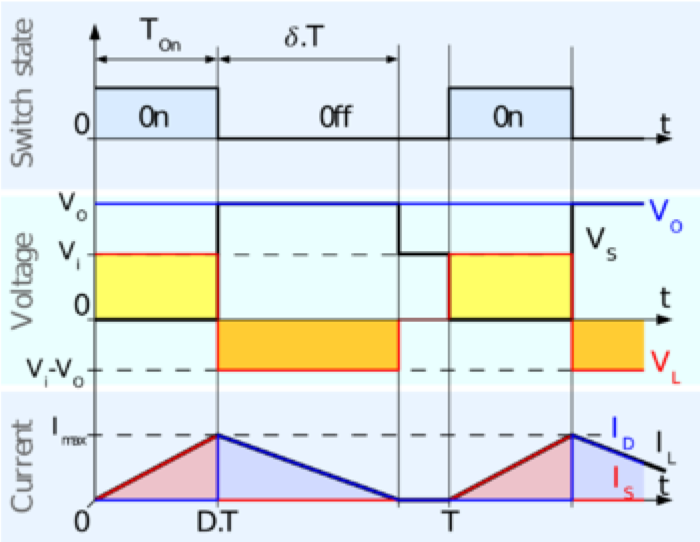


Fig 3.11 Waveforms of current and voltage in a boost converter operating in discontinuous mode.

In some cases, the amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle (see waveforms in figure 4). Although slight, the difference has a strong effect on the output voltage equation. It can be calculated as follows:

As the inductor current at the beginning of the cycle is zero, its maximum value (at t = DT) is

$$I_{L_{Max}} = \frac{V_i DT}{L}$$

During the off-period, I_L falls to zero after δT:

$$I_{L_{Max}} + \frac{(V_i - V_o)\,\delta T}{L} = 0$$

Using the two previous equations, δ is:

$$\delta = \frac{V_i D}{V_o - V_i}$$

The load current I_o is equal to the average diode current (I_D). As can be seen on figure 4, the diode current is equal to the inductor current during the off-state. Therefore the output current can be written as:

$$I_o = \bar{I_D} = \frac{I_{L_{max}}}{2}\delta$$

Replacing Imax and δ by their respective expression's yields:

$$I_o = \frac{V_i DT}{2L} \cdot \frac{V_i D}{V_o - V_i} = \frac{V_i^2 D^2 T}{2L\left(V_o - V_i\right)}$$

Therefore, the output voltage gain can be written as flow:

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2LI_o}$$

Compared to the expression of the output voltage for the continuous mode, this expression is much more complicated. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current.

3.5 BUCK-BOOST CONVERTER

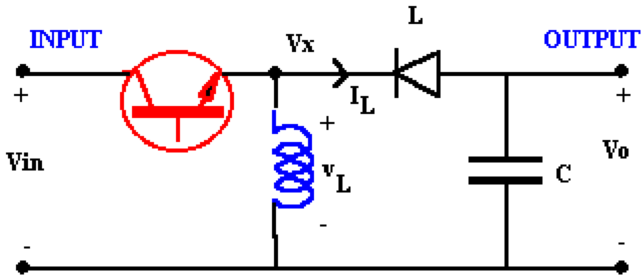


Fig 3.13 schematic for buck-boost converter

With continuous conduction for the Buck-Boost converter $V_x = V_{in}$ when the transistor is ON and $V_x = V_o$ when the transistor is OFF. For zero net current change over a period the average voltage across the inductor is zero

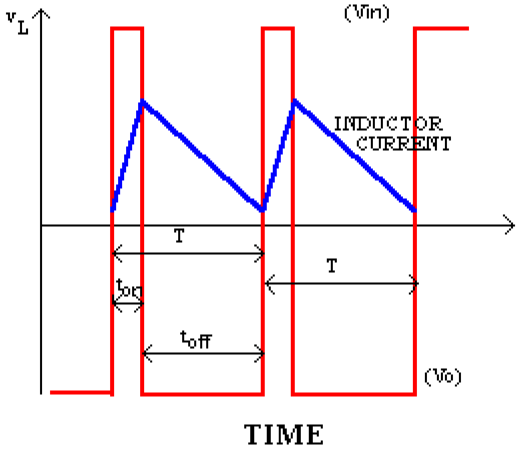


Fig 3.14 Waveforms for buck-boost converter

$$Vin\,t_{ON} + Vo\,t_{OFF} = 0$$

which gives the voltage ratio

$$\frac{Vo}{Vin} = -\frac{D}{(1-D)}$$

and the corresponding current

$$\frac{Io}{Iin} = -\frac{(1-D)}{D}$$

Since the duty ratio "D" is between 0 and 1 the output voltage can vary between lower or higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

3.6 CUK CONVERTER

The buck, boost and buck-boost converters all transferred energy between input and output using the inductor, analysis is based of voltage balance across the inductor. The CUK converter uses capacitive energy trans fer and analysis is based on current balance of the capacitor. The circuit i is derived from DUALITY principle on the buck-boost converter.

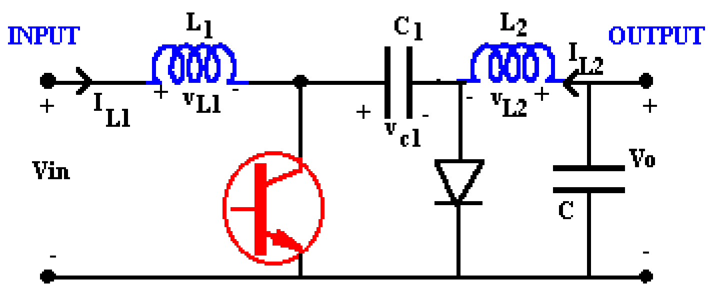


Fig 3.15

CUK Converter

If we assume that the current through the inductors is essentially ripple free we can examine the charge balance for the capacitor C1. For the transistor ON the circuit becomes

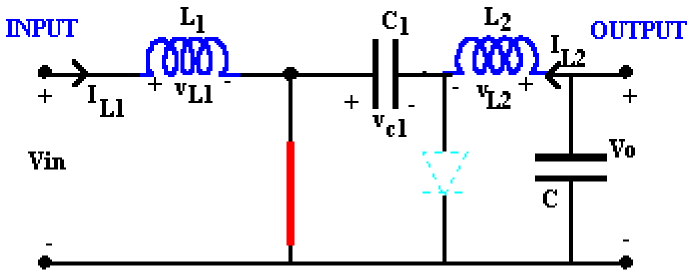


Fig 3.16

CUK "ON-STATE"

and the current in C1 is I_{L1}. When the transistor is OFF, the diode conducts and the current in C1 becomes I_{L2}.

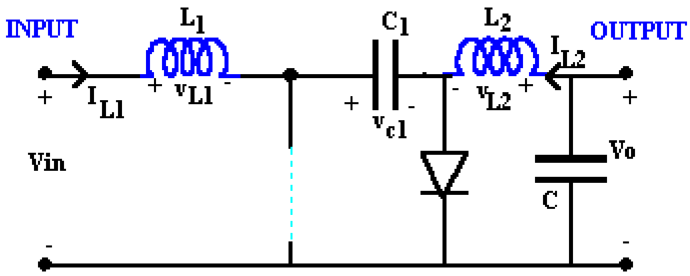


Fig 3.17

CUK "OFF-STATE"

Since the steady state assumes no net capacitor voltage rise, the net current is zero

$$I_{L1} t_{ON} + (-I_{L2}) t_{OFF} = 0$$

which implies

$$\frac{I_{L2}}{I_{L1}} = \frac{(1-D)}{D}$$

The inductor currents match the input and output currents, thus using the power conservation rule

$$\frac{Vo}{Vin} = -\frac{D}{(1-D)}$$

Thus the voltage ratio is the same as the buck-boost converter. The advantage of the CUK converter is that the input and output inductors create a smooth current at both sides of the converter while the buck, boost and buck-boost have at least one side with pulsed current.

CHAPTER 4

CAPACITOR SWITCHING

4.1 CAPACITOR SWITCHING DC-DC

Output Resistance and Efficiency With a non-zero load at the output of an SC converter, the steady-state output voltage (in absolute value) is lower than the ideal unloaded value V, = M, V, this is because all capacitors in the converter are periodically charged and discharged in order to supply the output current to the load. As a result, capacitor voltages now have an ac ripple component. Energy is lost on the capacitor and the switch on-resistances during each charge transfer to or from a capacitor. The energy loss is smaller if the ac components in capacitor voltages are smaller. In general, precise knowledge of all network parasitic is necessary in order to estimate the converter power losses and efficiency. Depending on the values of network "parasitic" time constants r, with respect to the switching period T,, we can distinguish three different cases, and identify three possible analysis methods. If r, >> T,, the capacitor voltage ripples are approximately linear, and the method of state-space averaging can be ap plied to determine the converter steady-state and dynamic responses. As r, becomes closer to T,, the ripple nonlinearity can no longer be neglected. The method of modified state-space averaging can be used. Finally, if r, << T, the charge discharge transients are completed within each clock cycle. In this limiting case, the converter efficiency and the converter output resistance reach the best possible limits. These limits can be used for initial SC converter comparison and selection, and can be derived directly from the converter topological description, as in [a]. The results depend on capacitance values and the switching frequency f, = l/Ts, but the exact knowledge of the network parasitic resistances is not required, as long as the condition r, << T, is satisfied.

the converter provides an ideal dc voltage conversion ratio under no load conditions, and all conversion losses are manifested by voltage drop associated with non-zero load current through the output impedance. The resistive output impedance accounts for capacitor charging and discharging losses and resistive conduction losses. Additional losses due to short-circuit current and parasitic capacitors to ground, in addition to gate-drive losses, can be incorporated into the model. However, they will not be considered initially since these effects are generally application and implementation dependent. For the present, our aim is to provide a general analysis and design framework.

The low-frequency output impedance sets the maximum converter power, constrained by a minimal efficiency objective, and also determines the open-loop load regulation properties. There are two asymptotic limits to output impedance, the slow and fast switching limits. The slow switching limit (SSL) impedance is calculated assuming that the switches and all other conductive interconnects are ideal, and that the currents flowing between input and output sources and capacitors are impulsive, modelled as charge transfers. The fast-switching limit (FSL) occurs when the resistances associated with switches, capacitors and interconnect dominate, and the capacitors act effectively as fixed voltage sources. In the FSL, current flow occurs in a frequency-independent piecewise constant pattern, while the SSL impedance is inversely proportional to switching frequency. The set of converters considered in this paper is limited to two-phase converters made solely of ideal capacitors, resistive switches, and input and output voltage sources.

4.2 Slow-Switching Limit Impedance

For the slow-switching limit (SSL) impedance analysis, the finite resistances of the switches, capacitors, and interconnect are neglected. A pair of charge multiplier vectors a 1 and a 2 can be derived for any standard non-degenerate two-phase SC converter. The charge multiplier vectors correspond to charge flows that occur immediately after the switches are closed to initiate each respective phase of the SC circuit. Each element of a charge multiplier vector corresponds to a specific capacitor or independent voltage source, and represents the charge flow into that component, normalized with respect to the output charge flow.

CHAPTER 5

INVERTERS

5.1 THREE PHASE INVERTER

An inverter is a power electronic device, used to change the power from one form to other like DC to AC at the necessary frequency & voltage o/p. The classification of this can be done based on the source of supply as well as related topology in the power circuit. So these are classified into two types (voltage source inverter) and CSI (current source inverter). The VSI type inverter has a DC voltage source with less impedance at the input terminals of an inverter. The CSI type inverter has a DC current source with high impedance. This article discusses an overview of a three-phase inverter like a circuit, working and its applications.

What is Three Phase Inverter?

Definition: We know that an inverter converts DC to AC. We have already discussed different types of inverters. A three-phase inverter is used to change the DC voltage to three-phase AC supply. Generally, these are used in high power and variable frequency drive applications like HVDC power transmission.

3 Phase Inverter

In a 3 phase, the power can be transmitted across the network with the help of three different currents which are out of phase with each other, whereas in single-phase inverter, the power can transmit through a single phase. For instance, if you have a three-phase connection in your home, then the inverter can be connected to one of the phases.

5.2 WORKING PRINCIPLE

A three-phase inverter working principle is, it includes three inverter switches with single-phase where each switch can be connected to load terminal. For the basic control system, the three switches operation can be synchronized so that single switch works at every 60 degrees of basic o/p waveform to create a line-to-line o/p waveform including six steps. This waveform includes a zero voltage stage among the two sections like positive &negative of the square-wave. Once PWM techniques based on the carrier are applied to these waveforms, then the basic shape of the waveform can be taken so that the third harmonic including its multiples will be canceled.

5.3 SINGLE PHASE INVERTERS

These inverters are available in two types like full-bridge type and half-bridge type

The full-bridge type inverter circuit mainly used to change DC to AC. This can be achieved through the opening and closing of the switches within the right sequence. This kind of inverter includes four dissimilar operating states where these switches work on closed switches. The half-bridge type inverter circuit is the basic building block in a full-bridge type inverter. This inverter includes two switches where each type of switch includes capacitors that have output voltage. Additionally, these switches complement each other, because if the first switch is turned ON then the remaining switch will be turned OFF.

5.4 THREEPHASE INVERTER CIRCUIT

The circuit diagram of a three-phase inverter is shown below. The main function of this kind of inverter is to change the input of DC to the output of three-phase AC. A basic 3 phase inverter includes 3 single phase inverter switches where each switch can be connected to one of the 3 load terminals.

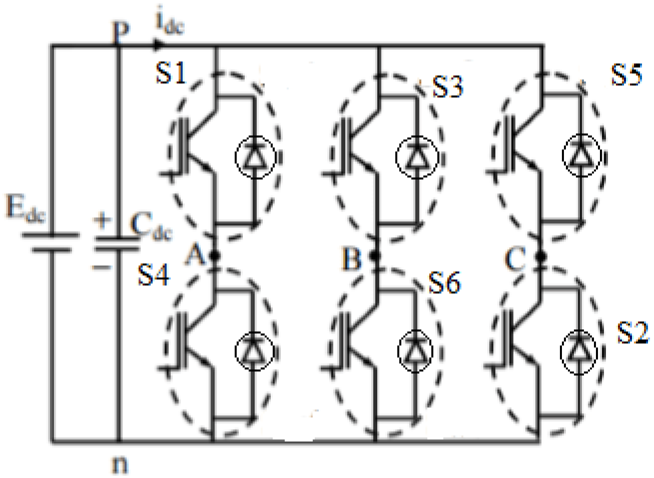


fig 5.2Three Phase Inverter Circuit

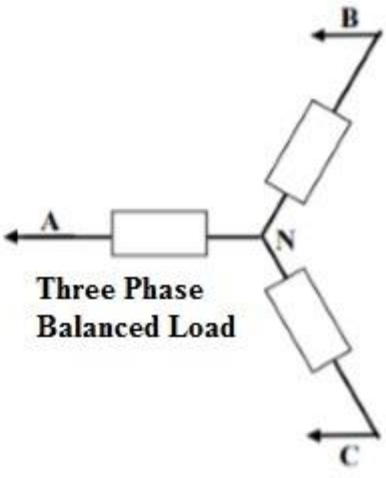
Generally, the three arms of this inverter will be delayed with 120 degrees angle to generate a 3 phase AC supply.

The switches used in the inverter have 50% of ratio and switching can be occurred after every 60 degrees angle. The switches like S1, S2, S3, S4, S5, and S6 will complement each other. In this, three inverters with single-phase are placed across a similar DC source. The pole voltages within the three-phase inverter are equivalent to the pole voltages within the half-bridge inverter with a single phase.'

The two types of inverters like the single-phase and three-phase include two conduction modes like 180 degrees conduction mode and 120 degrees conduction mode.

5.4.1 180° Conduction Mode

In this conduction mode, each device will be in conduction with 180° where they are activated at intervals with 60°. The output terminals like A, B, and C are connected to the star or 3 phase delta connection of the load.



Balanced Load

The balanced load for three phases is explained in the following diagram. For 0 to 60 degrees, the switches like S1, S5 & S6 are in conduction mode. The load terminals like A & C are linked to the source on its positive point, whereas the B terminal is associated with the source on its negative point. Furthermore, the R/2 resistance is available among the two ends of neutral & the positive whereas R resistance is available among the neutral & the negative terminal.

In this mode, the voltages of load are given in the following.

$$\mathbf{VAN = V/3,}$$
$$\mathbf{VBN = -2V/3,}$$
$$\mathbf{VCN = V/3}$$

The line voltages are given in the following.

$$\mathbf{VAB = VAN - VBN = V,}$$
$$\mathbf{VBC = VBN - VCN = -V,}$$
$$\mathbf{VCA = VCN - VAN = 0}$$

5.4.2 120° Conduction Mode

In this type of conduction mode, every electronic device will be in a conduction state with 120°. It is apt for a delta connection within a load as it results within a six-step kind of waveform across one of its phases. So, at any instant, only these devices will conduct every device that will conduct at 120° only.

The connection of ‘A’ terminal on the load can be done through the positive end whereas the B terminal can be connected toward the negative terminal of the source. The ‘C’ terminal on the load will be in conduction is known as the floating state. Also, the phase voltages are equivalent to the voltages of load which is given below.

Phase voltages are equal to line voltages, so

$$\mathbf{VAB = V}$$
$$\mathbf{VBC = -V/2}$$
$$\mathbf{VCA = -V/2}$$

5.4.3 Three Phase Inverter Applications

The applications of this type of inverter include the following.

- These inverters are utilized in variable frequency drive applications
- Used in high-power applications like HVDC power transmission.
- A three-phase square wave inverter is used in a UPS circuit and a low-cost solid-state frequency charger circuit.

Thus, this is all about an overview of a three-phase inverter, working principle, design or circuit diagram, conduction modes, and its applications. A 3 phase inverter is used to convert a DC i/p into an AC output. It includes three arms which are usually delayed through 120° of an angle to produce a 3 phase AC supply. The switches in an inverter have a 50% of ratio & switching happens after each T/6 of the time with 60° of angle interval

CHAPTER 6

BLDC MOTOR

BLDC MOTOR:

The BLDC motor is an AC synchronous motor with permanent magnets on the rotor (moving part) and windings on the stator (fixed part). Permanent magnets create the rotor flux and the energized stator windings create electromagnet poles. The rotor (equivalent to a bar magnet) is attracted by the energized stator phase. By using the appropriate sequence to supply the stator phases, a rotating field on the stator is created and maintained. This action of the rotor, chasing after the electromagnet poles on the stator, is the fundamental action used in synchronous permanent magnet motors. The lead between the rotor and the rotating field must be controlled to produce torque and this synchronization implies knowledge of the rotor position.

Conventional dc motors have many attractive properties such as high efficiency and linear torque-speed characteristics. The control of dc motors is also simple and does not require complex hardware however main drawback of the dc motor is to need periodic maintenance. The brushes of the mechanical commutator have other undesirable effects such as sparks. Despite the name, BLDC motors are actually a type of permanent magnet synchronous motors. They are driven by DC voltage but current commutation is done by solid state switches. Long operating life High dynamic response,

- High efficiency
- Better speed versus torque characteristics
- Noiseless operation
- Higher speed range

DC motors are available in many different power ratings from very small motors as used in hard drives to larger motors used in electric vehicles. Three phase motors are most common but two-phase motors are also found in many applications. A simple approach to current sensing and PWM current control of BLDC motors has been presented. This method will be applied here using hysteresis band control, PWM Control and variables DC link voltage control.

6.1 Introduction of BLDC Motor

Brushless DC motors (BLDC motors, BL motors) also known as electronically commutated motors (ECMs, EC motors) are synchronous electric motors powered by direct-current (DC) electricity and having electronic commutation systems, rather than mechanical commutators and brushes. The current-to-torque and voltage-to-speed relationships of BLDC motors are linear.

BLDC motors may be described as stepper motors, with fixed permanent magnets and possibly more poles on the stator than the rotor, or reluctance. The latter may be without permanent magnets, just poles that are induced on the rotor then pulled into alignment by timed stator windings. However, the term stepper motor tends to be used for motors that are designed specifically to be operated in a mode where they are frequently stopped with the rotor in a defined angular position; this page describes more general BLDC motor principles, though there is overlap.

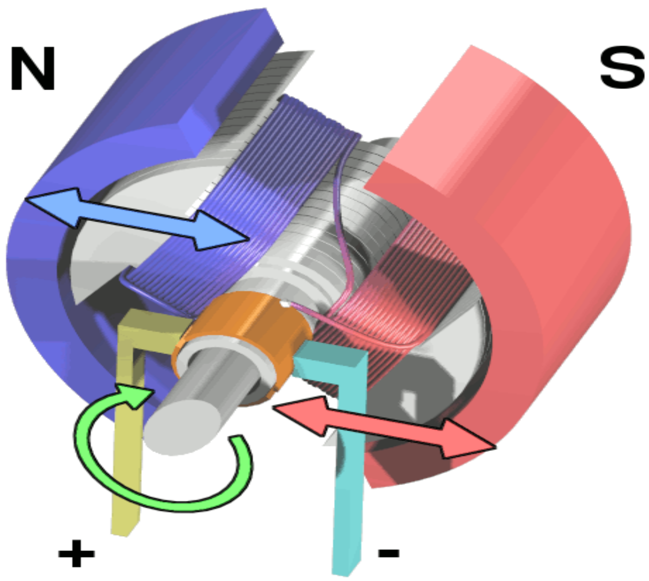


Fig 6.1

When a current passes through the coil wound around a soft iron core, the side of the positive pole is acted upon by an upwards force, while the other side is acted upon by a downward force. According to Fleming’s, the forces cause a turning effect on the coil, making it rotate. To make the motor rotate in a constant direction, "direct current" commutators make the current reverse in direction every half a cycle (in a two-pole motor) thus causing the motor to continue to rotate in the same direction.

A problem with the motor shown above is that when the plane of the coil is parallel to the magnetic field—i.e. when the rotor poles are 90 degrees from the stator poles—the torque is zero. In the pictures above, this occurs when the core of the coil is horizontal—the position it is just about to reach in the last picture on the right. The motor would not be able to start in this position. However, once it was started, it would continue to rotate through this position by inertia.

There is a second problem with this simple pole design. At the zero-torque position, both commutator brushes are touching (bridging) both commutator plates, resulting in a short-circuit. The power leads are shorted together through the commutator plates, and the coil is also short-circuited through both brushes (the coil is shorted twice, once through each brush independently). Note that this problem is independent of the non-starting problem above; even if there were a high current in the coil at this position, there would still be zero torque. The problem here is that this short uselessly consumes power without producing any motion (nor even any coil current.) In a low-current battery-powered demonstration this short-circuiting is generally not considered harmful. (Here, low-current means that the battery is intrinsically limited to low current and will not overheat if loaded with a short circuit; this is usually the case for an AA alkaline cell but not the case for batteries like the Li-ion cells used in many laptop batteries in this first decade of the 21st century.) However, if a two-pole motor were designed to do actual work with several hundred watts of power output, this shorting could result in severe commutator overheating, brush damage, and potential welding of the brushes—if they were metallic—to the commutator. Carbon brushes, which are often used, would not weld. In any case, a short like this is very wasteful, drains batteries rapidly and, at a minimum, requires power supply components to be designed to much higher standards than would be needed just to run the motor without the shorting.

One simple solution is to put a gap between the commutator plates which is wider than the ends of the brushes. This increases the zero-torque range of angular positions but eliminates the shorting problem; if the motor is started spinning by an outside force it will continue spinning. With this modification, it can also be effectively turned off simply by stalling (stopping) it in a position in the zero-torque (i.e. commutator non-contacting) angle range. This design is sometimes seen in homebuilt hobby motors, e.g. for science fairs and such designs can be found in some published science project books. A clear downside of this simple solution is that the motor now coasts through a substantial arc of rotation twice per revolution and the torque is pulsed. This may work for electric fans or to keep a flywheel spinning but there are many applications, even where starting and stopping are not necessary, for which it is completely inadequate, such as driving the capstan of a tape transport, or any instance where to speed up and slow down often and quickly is a requirement. Another disadvantage is that, since the coils have a measure of self inductance, current flowing in them cannot suddenly stop. The current attempts to jump the opening gap between the commutator segment and the brush, causing arcing.

Even for fans and flywheels, the clear weaknesses remaining in this design—especially that it is not self-starting from all positions—make it impractical for working use, especially considering the better alternatives that exist. Unlike the demonstration motor above, DC motors are commonly designed with more than two poles, are able to start from any position, and do not have any position where current can flow without producing electromotive power by passing through some coil. Many common small brushed DC motors used in toys and small consumer appliances, the simplest mass-produced DC motors to be found, have three-pole armatures. The brushes can now bridge two adjacent commutator segments without causing a short circuit. These three-pole armatures also have the advantage that current from the brushes either flows through two coils in series or through just one coil. Starting with the current in an individual coil at half its nominal value (as a result of flowing through two coils in series), it rises to its nominal value and then falls to half this value. The sequence then continues with current in the reverse direction. This results in a closer step-wise approximation to the ideal sinusoidal coil current, producing a more even torque than the two-pole motor where the current in each coil is closer to a square wave. Since current changes are half those of a comparable two-pole motor, arcing at the brushes is consequently less.

If the shaft of a DC motor is turned by an external force, the motor will act like a generator and produce an Electromotive force (EMF). During normal operation, the spinning of the motor produces a voltage, known as the counter-EMF (CEMF) or back EMF, because it opposes the applied voltage on the motor. The back EMF is the reason that the motor when free-running does not appear to have the same low electrical resistance as the wire contained in its winding. This is the same EMF that is produced when the motor is used as a generator (for example when an electrical load, such as a light bulb, is placed across the terminals of the motor and the motor shaft is driven with an external torque). Therefore, the total voltage drop across a motor consists of the CEMF voltage drop, and the parasitic voltage drop resulting from the internal resistance of the armature's windings. The current through a motor is given by the following equation:

$$I = \frac{V_{applied} - V_{cemf}}{R_{armature}}$$

The mechanical power produced by the motor is given by:

$$P = I \cdot V_{cemf}$$

As an unloaded DC motor spins, it generates a backwards-flowing electromotive force that resists the current being applied to the motor. The current through the motor drops as the rotational speed increases, and a free-spinning motor has very little current. It is only when a load is applied to the motor that slows the rotor that the current draw through the motor increases.

"In an experiment of this kind made on a motor with separately excited magnets, the following figures were obtained:

Revolutions per minute	0	50	100	160	180	195

Amperes	20	16.2	12.2	7.8	6.1	5.1

Apparently, if the motor had been helped on to run at 261.5 revolutions per minute, the current would have been reduced to zero. In the last result obtained, the current of 5.1 amperes was absorbed in driving the armature against its own friction at the speed of 195 revolutions per minute

6.2 SPEED TORQUE CHARACTERISTICS

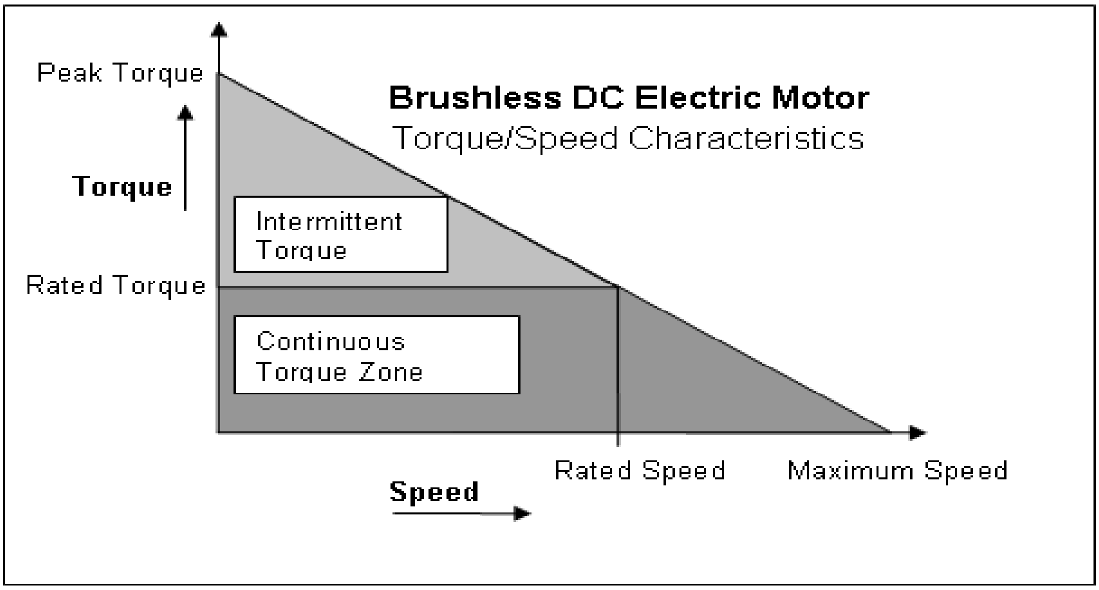
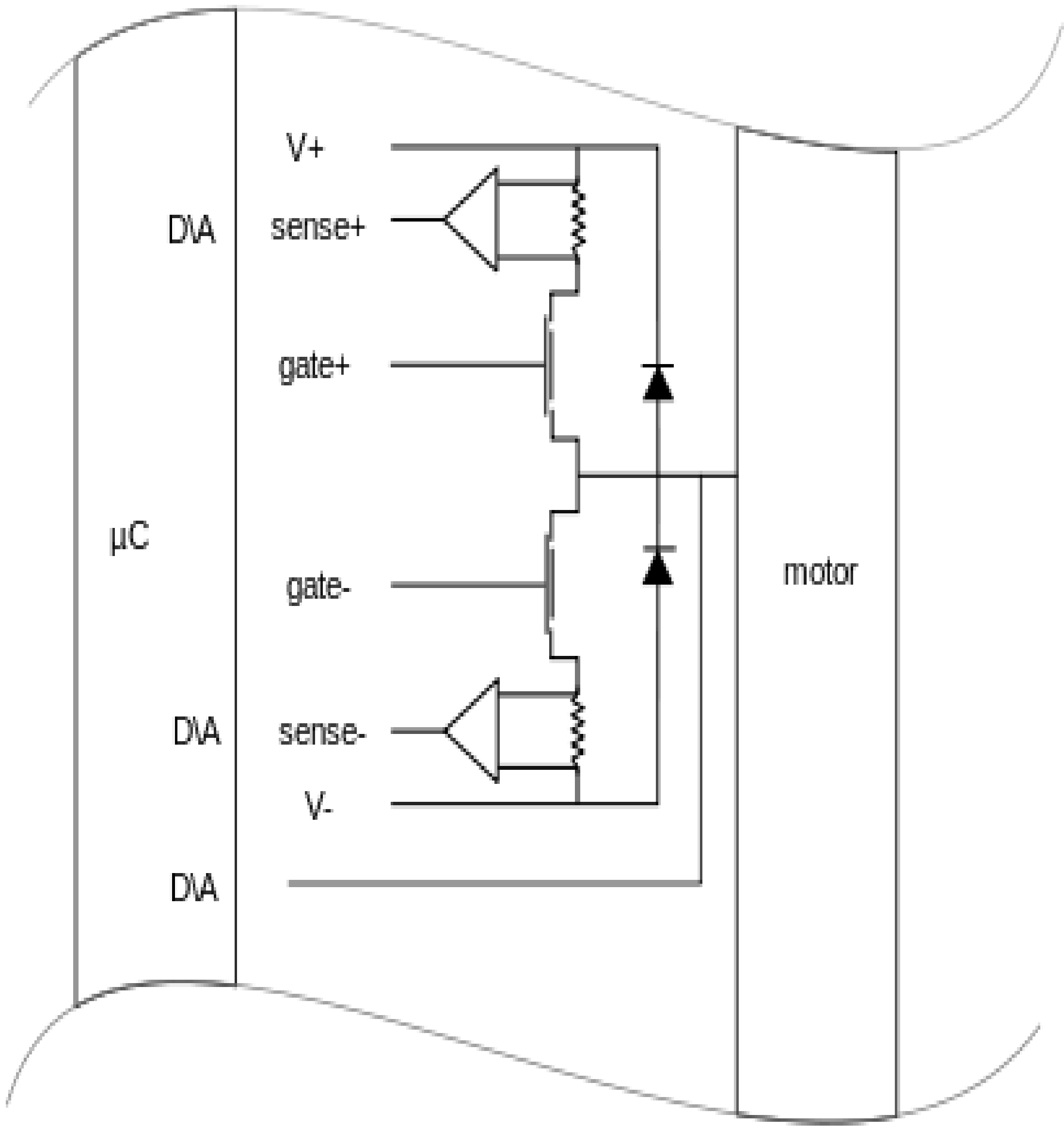


Fig 6.2 speed torque characteristics


V+
D\A
sense+
gate+
µC
gate-
motor
D\A
sense-
V-
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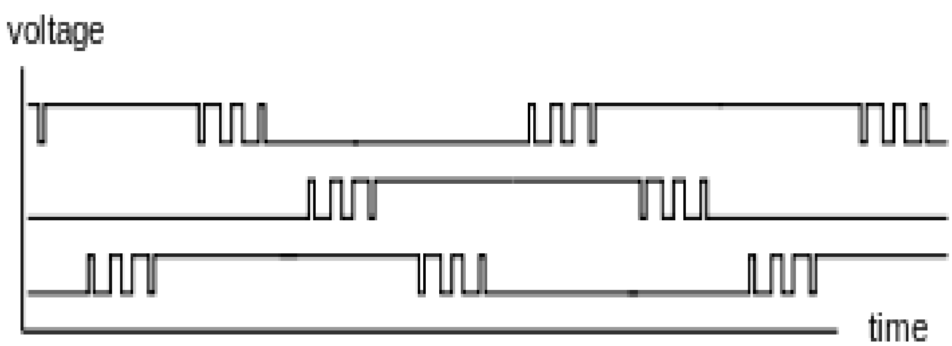

voltage
time

6.3 CONTROLLER IMPLEMENTATIONS

Because the controller must direct the rotor rotation, the controller requires some means of determining the rotor's orientation/position (relative to the stator coils.) Some designs use Hall effect sensors or a rotary encoder to directly measure the rotor's position. Others measure the back EMF in the un driven coils to infer the rotor position, eliminating the need for separate Hall effect sensors, and therefore are often called *sensor less* controllers. Like an AC motor, the voltage on the un driven coils is sinusoidal, but over an entire commutation the output appears trapezoidal because of the DC output of the controller. The controller contains 3 bi-directional drivers to drive high-current DC power, which are controlled by a logic circuit. Simple controllers employ comparators to determine when the output phase should be advanced, while more advanced controllers employ a microcontroller to manage acceleration, control speed and fine-tune efficiency.

Controllers that sense rotor position based on back-EMF have extra challenges in initiating motion because no back-EMF is produced when the rotor is stationary. This is usually accomplished by beginning rotation from an arbitrary phase, and then skipping to the correct phase if it is found to be wrong. This can cause the motor to run briefly backwards, adding even more complexity to the startup sequence. Other senseless controllers are capable of measuring winding saturation caused by the position of the magnets to infer the rotor position.

6.4 VARIATIONS IN CONSTRUCTIONS

, the radial-relationship between the coils and magnets is reversed; the stator coils form the center (core) of the motor, while the permanent magnets spin within an overhanging rotor which surrounds the core. The flat type, used where there are space or shape limitations, uses stator and rotor plates, mounted face to face. Out runners typically have more poles, set up in triplets to maintain the three groups of windings, and have a higher torque at low RPMs. In all BLDC motors, the coils are stationary.

There are also two electrical configurations having to do with how the wires from the windings are connected to each other (not their physical shape or location). The delta configuration connects the three windings to each other (series circuits) in a triangle-like circuit, and power is applied at each of the connections. The wye ("Y"-shaped) configuration, sometimes called a star winding, connects all of the windings to a central point (parallel circuits) and power is applied to the remaining end of each winding. A motor with windings in delta configuration gives low torque at low rpm, but can give higher top rpm. Wye configuration gives hi BLDC motors can be constructed in several different physical configurations: In the 'conventional' (also known as 'in runner') configuration, the permanent magnets are part of the rotor. Three stator windings surround the rotor. In the 'out runner' (or external-rotor) configuration go torque at low rpm, but not as high-top rpm

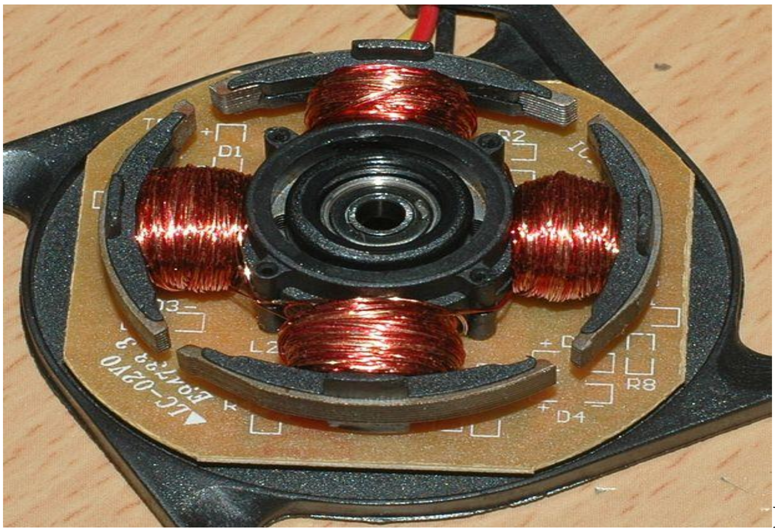


Fig 6.3

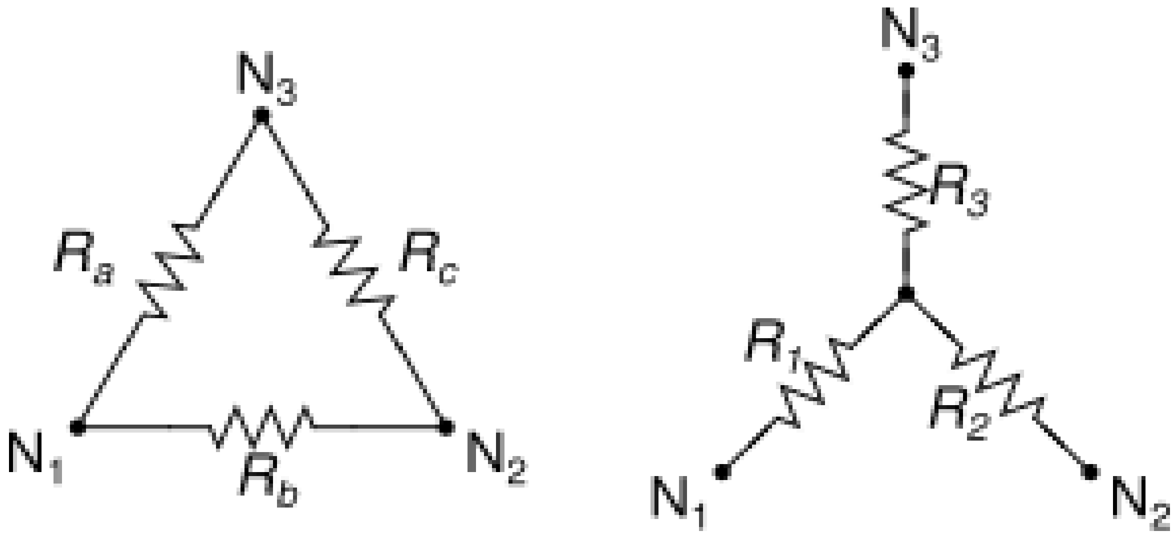


Fig 6.4

6.5 CONTROL OF BLDC MOTOR

An electronic commutation of BLDC motor includes proper switching of VSI in such a way that a symmetrical dc current is drawn from the dc link for 120◦ and placed symmetrically at the centre of back-EMF of each phase. A Hall effect position sensor is used to sense the rotor position on a span of 60◦; which is required for the electronic commutation of BLDC motor. When two switches of VSI, are in conduction states, a line current is drawn from the dc link capacitor whose magnitude depends on applied dc link voltage , back EMF's, resistances , and self and mutual inductance of stator windings. This current produces the electromagnetic torque which in turn increases the speed of the BLDC motor.

6.6 MODELING OF PROPOSED PMBLDCM DRIVE

PMBLDCM drive consists of modelling of various components of the PFC converter and PMBLDCM drive in the form of mathematical equations. The combination of these individual models represents a complete model of proposed PFC drive.

1) ***Voltage Reference Generator:*** This is used to generate a reference voltage at DC link which is equivalent to the desired reference speed of the PMBLDCM. Therefore, it is an important component of the controller as the accuracy of the speed control depends upon the equivalent DC link voltage reference.

2) ***Rate Limiter:*** The rate limiter introduced in the reference voltage maintains a constant voltage error (Ve) at DC link during transient states so that the motor current (Idc) rises in a controlled manner. The rise of the motor current ΔIdc depends upon the equivalent resistance (Req) of the PMBLDC motor appearing at DC link and the voltage rise rate ΔVe at DC link. Therefore the rate limiter considers various parameters of PMBLDCM such as rated terminal voltage (VT), winding resistance per phase (Ra), maximum allowable motor current per phase (Idc max), and mechanical time constant (τm).

3) ***Voltage Controller:*** The voltage controller is a proportional and integral (PI) controller which tracks the error voltage between reference voltage and sensed voltage at DC link and generates a control signal Ic based on the Kp and Ki the proportional and integral gains of the PI controller, respectively.

4) Reference Current Generator: The reference current at input of isolated zeta converter (id*) is generated using the unit template of the AC mains voltage and the output of the PI controller.

5) PWM Controller: The PWM controller processes the current error (Δid) between the reference input current (id*) of the isolated zeta converter and the DC current (id) sensed after DBR. The PWM controller amplifies this current error (Δid) by gain kd and compares with a fixed frequency (fs) saw-tooth carrier waveform md (t) [8] to get the switching signal for the MOSFET of the PFC converter.

6) Electronic Commutator: The electronic commutator uses signals from Hall effect position sensors to generate the switching sequence for the VSI.

7) Voltage Source Inverter: The voltage source inverter employed in the proposed PMBLDCM drive uses insulated gate bipolar transistors (IGBTs) because of its operation at lower frequency compared to PFC converter. The output of VSI to be fed to phase ‘a’ of the PMBLDC motor through the equivalent circuit of a VSI fed PMBLDCM where vao, vbo, vco, and vno are the voltages the three phases (a,b,c) and neutral point (n) with respect to virtual mid-point of the DC link voltage ‘o’. The voltages van, vbn, vcn are voltages of three phases with respect to neutral terminal of the motor (n) and Vdc is the DC link voltage. The values 1 and 0 for Sa1 or Sa2 represent ‘on’ and ‘off’ condition of respective IGBTs of the VSI. The voltages for other two phases of the VSI feeding the PMBLDC motor i.e., vbo, vco, vbn, vcn and the switching pattern of other IGBTs of the VSI (i.e. Sb1, Sb2, Sc1, Sc2) are generated in a similar way.

8) PMBLDC Motor: It represent the dynamic model of the PMBLDC motor where p represents differential operator (d/dt), ia, ib, ic are currents, λa, λb, λc are flux linkages and ean, ebn, ecn are phase to neutral back emfs of PMBLDCM, in respective phases, R is resistance of motor windings/phase. Other symbols are Ls as self-inductance/ph, M as mutual inductance/ph, Te as developed electromagnetic torque, ωr as motor angular speed, P as number of poles, Tl as load torque, J as moment of inertia and B as friction coefficient.

CHAPTER 7

MATLAB

7.1 INTRODUCTION TO MATLAB

MATLAB is a software package for computation in engineering, science, and applied mathematics.

It offers a powerful programming language, excellent graphics, and a wide range of expert knowledge. MATLAB is published by and a trademark of The MathWorks, Inc. The focus in MATLAB is on computation, not mathematics: Symbolic expressions and manipulations are not possible (except through the optional Symbolic Toolbox, a clever interface to maple). All results are not only numerical but inexact, thanks to the rounding errors inherent in computer arithmetic. The limitation to numerical computation can be seen as a drawback, but it's a source of strength too: MATLAB is much preferred to Maple, Mathematical, and the like when it comes to Numerics.

On the other hand, compared to other numerically oriented languages like C++ and FORTRAN,

MATLAB is much easier to use and comes with a huge standard library.1 the unfavourable comparison here is a gap in execution speed. This gap is not always as dramatic as popular lore has it, and it can often be narrowed or closed with good

MATLAB programming (see section 6). Moreover, one can link other codes into MATLAB, or vice versa, and MATLAB now optionally supports parallel computing. Still, MATLAB is usually not the tool of choice for maximum-performance

Computing.

The MATLAB niche is numerical computation on workstations for non-experts in computation.

This is a huge niche—one way to tell is to look at the number of MATLAB-related books on mathworks.com. Even for supercomputer users, MATLAB can be a valuable environment in which to explore and fine-tune algorithms before more laborious coding in another language.

Most successful computing languages and environments acquire a distinctive character or culture.

In MATLAB, that culture contains several elements: an experimental and graphical bias, resulting from the interactive environment and compression of the write-compile-link-execute analyse cycle; an emphasis on syntax that is compact and friendly to the interactive mode, rather than tightly constrained and verbose; a kitchen-sink mentality for providing functionality; and a high degree of openness and transparency (though not to the extent of being open-source software).

The fifty-cent tour

When you start MATLAB, you get a multipaneled **desktop**. The layout and behaviour of the desktop and its components are highly customizable (and may in fact already be customized for your site).

The component that is the heart of MATLAB is called the **Command Window**, located on the 1Here and elsewhere I am thinking of the “old FORTRAN,” FORTRAN 77. This is not a commentary on the usefulness of FORTRAN 90 but on my ignorance of it.

7.1 INTRODUCTION

Right by default. Here you can give MATLAB commands typed at the prompt, >>. Unlike FORTRAN and other compiled computer languages, MATLAB is an **interpreted** environment—you give a command, and MATLAB tries to execute it right away before asking for another.

At the top left you can see the **Current Directory**. In general MATLAB is aware only of files in the current directory (folder) and on its **path**, which can be customized. Commands for working with the directory and path include cd, what, add path, and edit path (or you can choose "File/Set path. . . " from the menus). You can add files to a directory on the path and thereby add commands to MATLAB; we will return to this subject in section 3.

Next to the Current Directory tab is the **Workspace** tab. The workspace shows you what variable names are currently defined and some information about their contents. (At start-up it is, naturally, empty.) This represents another break from compiled environments: variables created in the workspace persist for you to examine and modify, even after code execution stops. Below the Command Window/Workspace window is the **Command History** window. As you enter commands, they are recorded here. This record persists across different MATLAB sessions, and commands or blocks of commands can be copied from here or saved to files.

As you explore MATLAB, you will soon encounter some **toolboxes**. These are individually packaged sets of capabilities that provide in-depth expertise on particular subject areas. There is no need to load them explicitly—once installed, they are always available transparently. You may also encounter **Simulink**, which is a semi-independent graphical control-engineering package not covered in this document.

Graphical versus command-line usage

MATLAB was originally entirely a command-line environment, and it retains that orientation. But it is now possible to access a great deal of the functionality from graphical interfaces—menus, buttons, and so on. These interfaces are especially useful to beginners, because they lay out the available choices clearly.2 As a rule, graphical interfaces can be more natural for certain types of interactive work, such as annotating a graph or debugging a program, whereas typed commands remain better for complex, precise, repeated, or reproducible tasks. One does not always need to make a choice, though; for instance, it is possible to save a figure’s styles as a template that can be used with different data by pointing and clicking. Moreover, you can package code you want to distribute with your own graphical interface, one that itself may be designed with a combination of graphical and command-oriented tools. In the end, an advanced MATLAB user should be able to exploit both modes of work to be productive.

That said, the focus of this document is on typed commands. In many (most?) cases these have graphical interface equivalents, even if I don’t explicitly point them out.

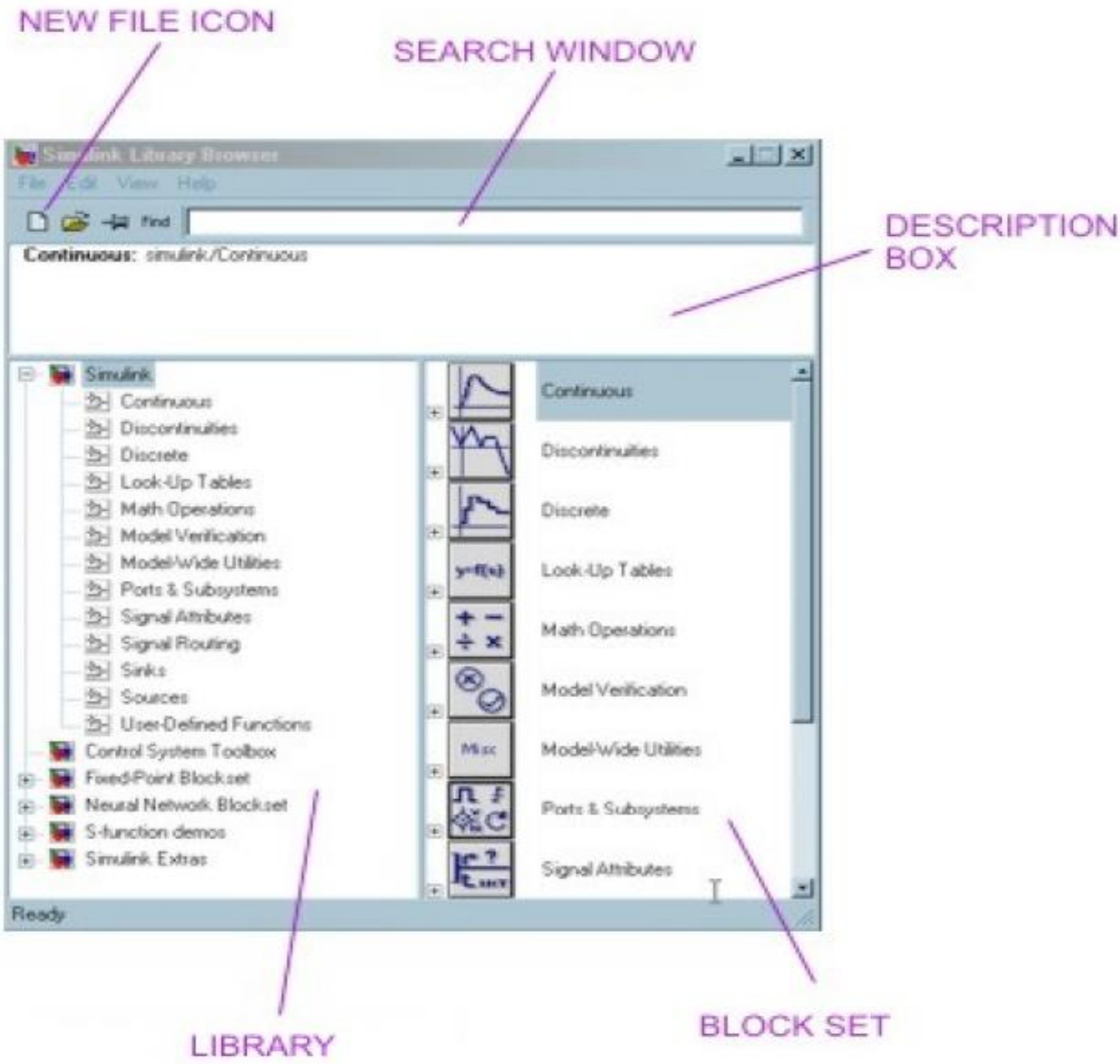
In particular, feel free to right-click (on Control-click on a Mac) on various objects to see what you might be able to do to them.

7.2 Getting Started

To start a Simulink session, you'd need to bring up Matlab program first. From Matlab command window, enter:

>> Simulink

Alternately, you may click on the Simulink icon located on the toolbar as shown

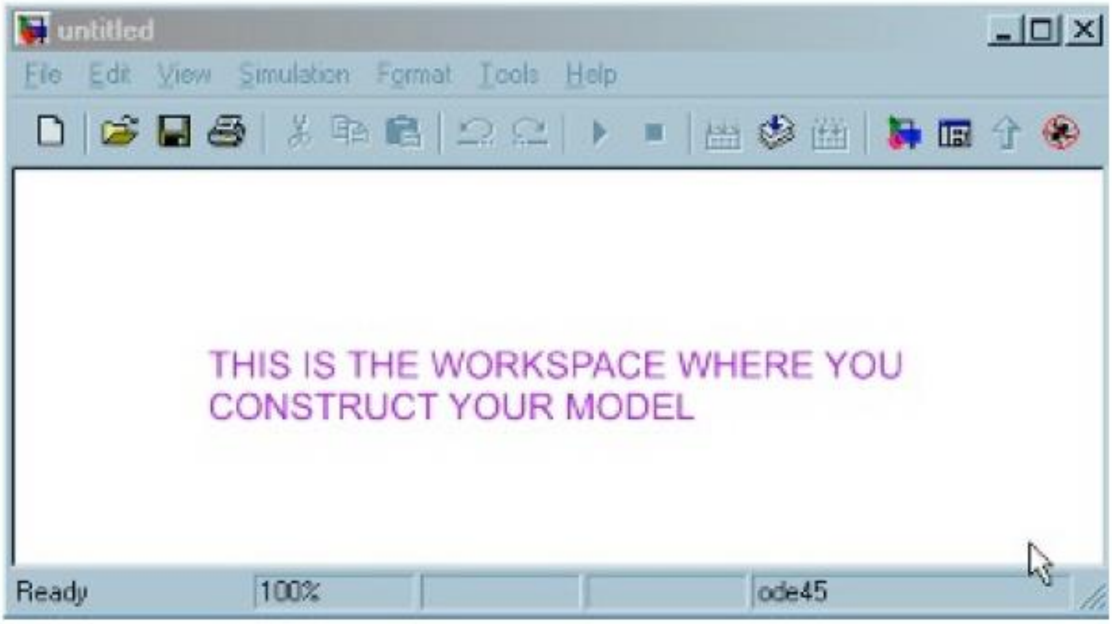


To see the content of the block set, click on the "+" sign at the beginning of each toolbox.

To start a model, click on the NEW FILE ICON as shown in the screenshot above.

Alternately, you may use keystrokes CTRL+N.

A new window will appear on the screen. You will be constructing your model in this window. Also in this window the constructed model is simulated. A screenshot of a typical working (model) window that looks like one shown below:



To become familiarized with the structure and the environment of Simulink, you are encouraged to explore the toolboxes and scan their contents.

You may not know what they are all about but perhaps you could catch on the organization of these toolboxes according to the category. For instant, you may see Control System Toolbox to consist of the Linear Time Invariant (LTI) system library and the MATLAB functions can be found under Function and Tables of the Simulink main toolbox. A good way to learn Simulink (or any computer program in general) is to practice and explore. Making mistakes is a part of the learning curve. So, fear not, you should be.

A simple model is used here to introduce some basic features of Simulink. Please follow the steps below to construct a simple model.

STEP 1: CREATING BLOCKS.

From BLOCK SET CATEGORIES section of the SIMULINK LIBRARY BROWSER window, click on the "+" sign next to the Simulink group to expand the tree and select (click on) Sources.

A set of blocks will appear in the BLOCKSET group. Click on the Sine Wave block and drag it to the workspace window (also known as model window)

A set of blocks will appear in the BLOCKSET group. Click on the Sine Wave block and drag it to the workspace window (also known as model window)

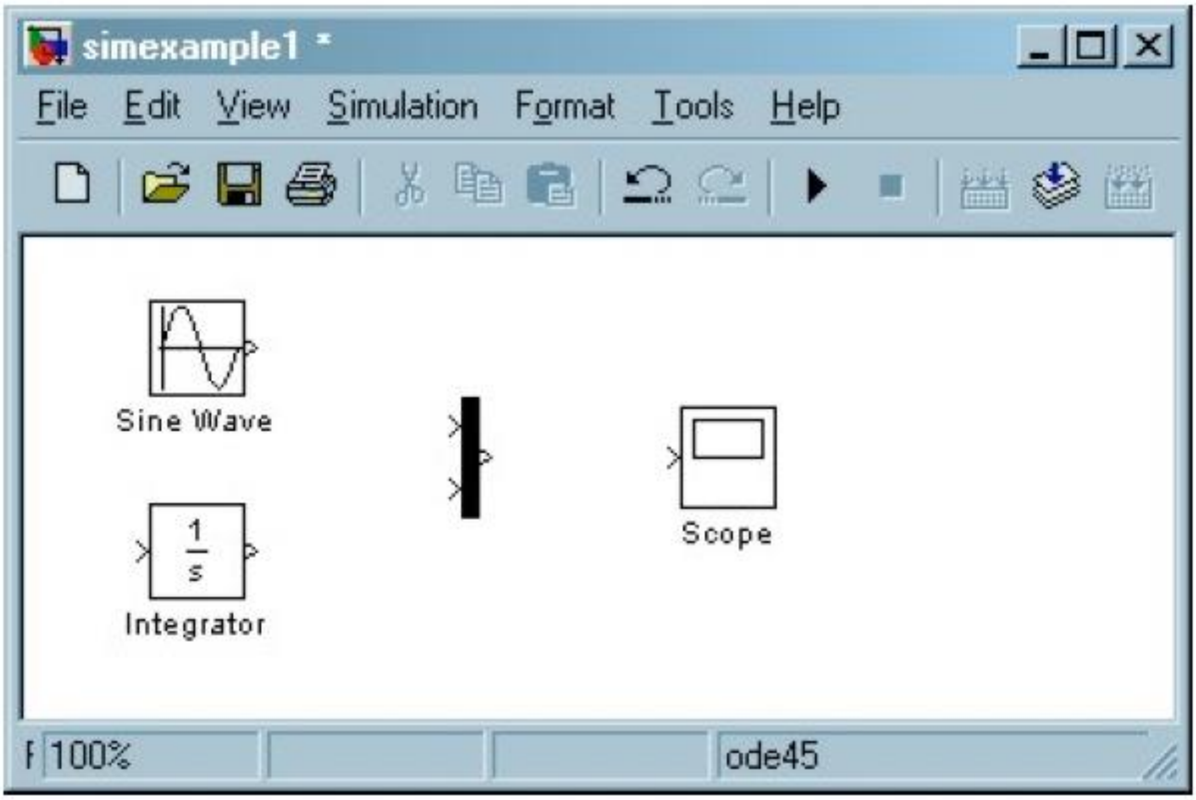
I am going to save this model under the filename: "simexample1". To save a model, you may click on the floppy diskette icon. Or from FILE menu, select Save or

CTRL+S. All Simulink model file will have an extension ".mdl". Simulink recognizes file with .mdl extension as a simulation model (similar to how MATLAB recognizes files with the extension .m as an MFile).

Continue to build your model by adding more components (or blocks) to your model window. We'll continue to add a Scope from Sinks library, an Integrator block from Continuous library, and a Mux block from Signal Routing library.

NOTE: If you wish to locate a block knowing its name, you may enter the name in the SEARCH WINDOW (at Find prompt) and Simulink will bring up the specified block. To move the blocks around, simply click on it and drag it to a desired location.

Once all the blocks are dragged over to the work space should consist of the following components:



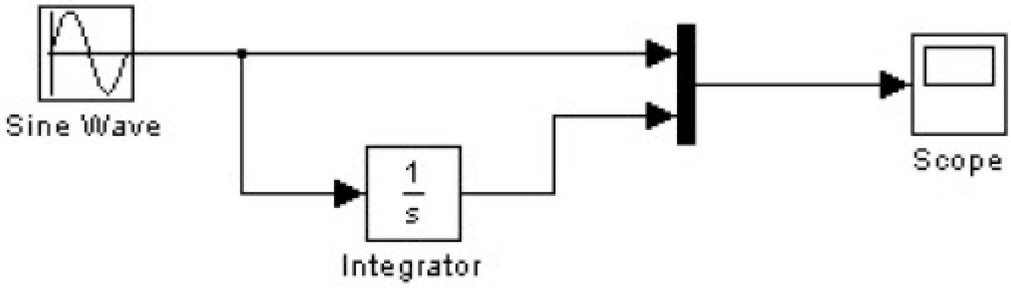
You may remove (delete) a block by simply clicking on it once to turn on the "select mode" (with four corner boxes) and use the DEL key or keys combination CTRL-X.

STEP 2: MAKING CONNECTIONS

To establish connections between the blocks, move the cursor to the output port represented by ">" sign on the block. Once placed at a port, the cursor will turn into a cross "+" enabling you to make connection between blocks.

To make a connection: left-click while holding down the control key (on your keyboard) and drag from source port to a destination port.

The connected model is shown below.

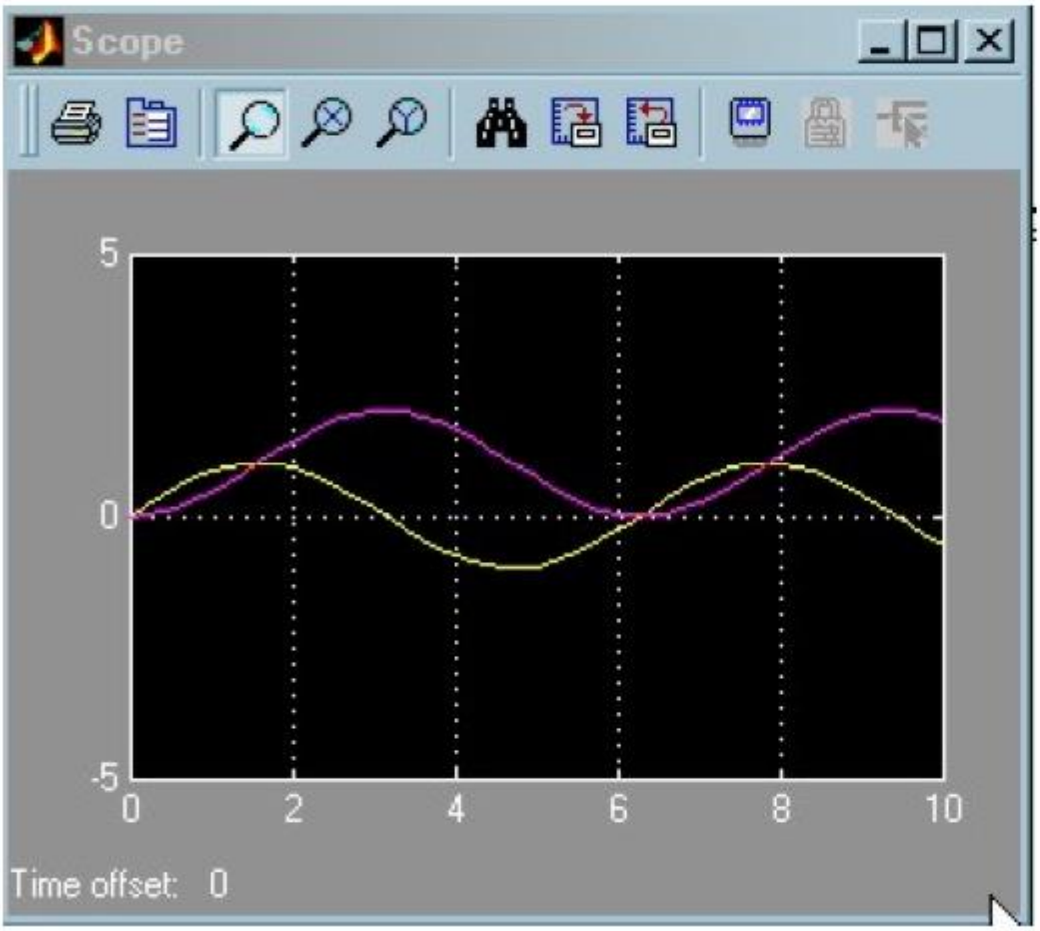


A sine signal is generated by the Sine Wave block (a source) and is displayed by the scope. The integrated sine signal is sent to scope for display along with the original signal from the source via the Mux, whose function is to multiplex signals in form of scalar, vector, or matrix into a bus.

STEP 3: RUNNING SIMULATION

You now can run the simulation of the simple system above by clicking on the play button (alternatively, you may use key sequence CTRL+T, or choose Start submenu under Simulation menu).

Double click on the Scope block to display of the scope.



7.3.1 INTRODUCTION

Sim PowerSystems and other products of the Physical Modelling product family work together with Simulink® to model electrical, mechanical, and control system Sim PowerSystems operates in the Simulink environment. Therefore, before starting this user's guide, you should be familiar with Simulink. For help with Simulink, see the Simulink documentation. Or, if you apply Simulink to signal processing and communications tasks (as opposed to control system design tasks), see the Signal Processing Block set documentation.

Electrical power systems are combinations of electrical circuits and electromechanical devices like motors and generators. Engineers working in this discipline are constantly improving the performance of the systems.

Requirements for drastically increased efficiency have forced power system designers to use power electronic devices and sophisticated control system concepts that tax traditional analysis tools and techniques. Further complicating the analyst's role is the fact that the system is often so nonlinear that the only way to understand it is through simulation. Land-based power generation from hydroelectric, steam, or other devices is not the only use of power systems. A common attribute of these systems is their use of power electronics and control systems to achieve their performance objectives.

What Is Sim PowerSystems

Sim PowerSystems is a modern design tool that allows scientists and engineers to rapidly and easily build models that simulate power systems.

Sim PowerSystems uses the Simulink environment, allowing you to build a model using simple click and drag procedures. Not only can you draw the circuit topology rapidly, but your analysis of the circuit can include its interactions with mechanical, thermal, control, and other disciplines. This is possible because all the electrical parts of the simulation interact with the extensive Simulink modelling library. Since Simulink uses MATLAB® as its computational engine, designers can also use MATLAB toolboxes and Simulink block sets. Sim PowerSystems and Sim Mechanics share a special

Physical Modelling block and connection line interface.

Sim PowerSystems Libraries

You can rapidly put Sim PowerSystems to work. The libraries contain models of typical power equipment such as transformers, lines, machines, and power electronics. These models are proven ones coming from textbooks, and their validity is based on the experience of the Power Systems Testing and Simulation Laboratory of Hydro-Québec, a large North American utility located in Canada, and also on the experience of École de Technologie Supérieure and Université Laval.

The capabilities of Sim PowerSystems for modelling a typical electrical system are illustrated in demonstration files. And for users who want to refresh their knowledge of power system theory, there are also self-learning case studies.

The Supersystems main library, power lib, organizes its blocks into libraries according to their behaviour. The power lib library window displays the block library icons and names. Double-click a library icon to open the library and access the blocks. The main Sim PowerSystems power lib library window also contains the Power Gui block that opens a graphical user interface for the steady-state analysis of electrical circuits.

7.3.2 Nonlinear Simulink Blocks for Sim PowerSystems Models

The nonlinear Simulink blocks of the power lib library are stored in a special\block library named power lib_models. These masked Simulink models are used by Sim PowerSystems to build the equivalent Simulink model of your circuit. See Chapter 3, "Improving Simulation Performance" for a description of the powerlib_models library

You must have the following products installed to use Sim PowerSystems:

• MATLAB

• Simulink

CHAPTER 8

SIMULATION AND OUTPUT WAVEFORMS

8.1 Simulation results

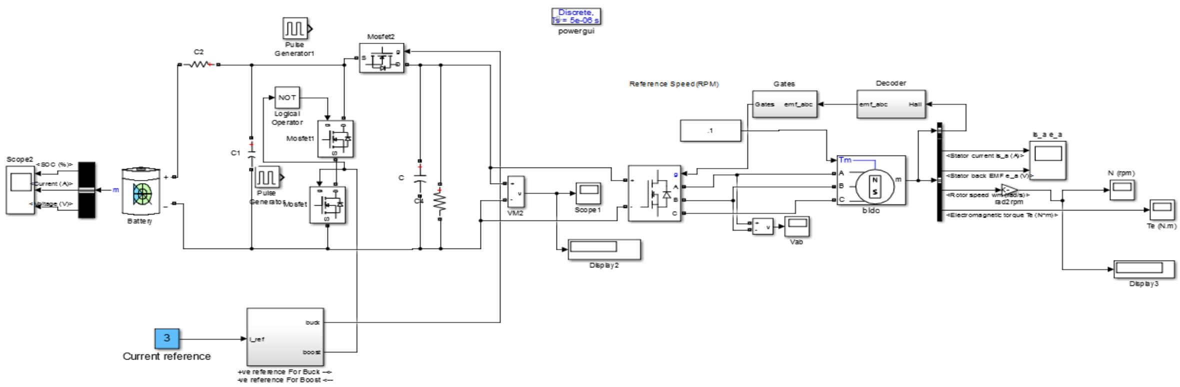


Fig 8.1

8.2 Switched capacitor controller

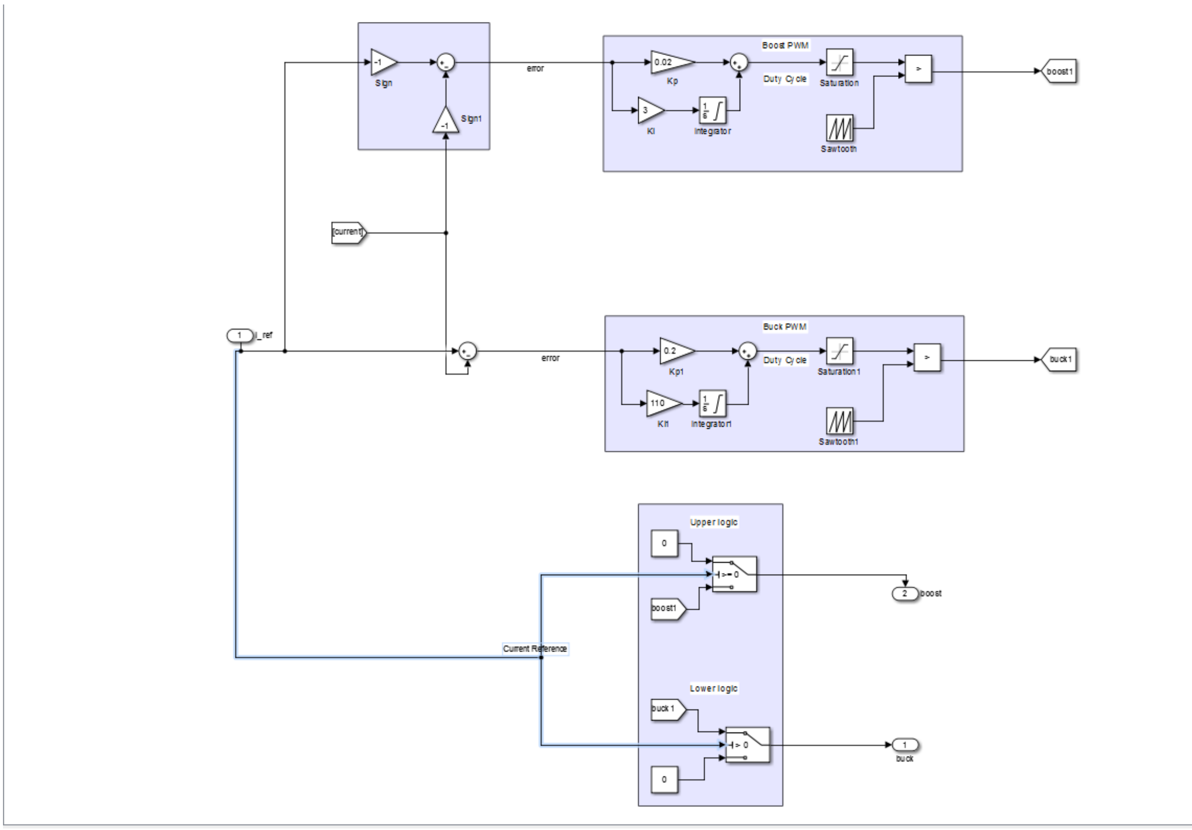


Fig 8.2

8.3 Hall sensor

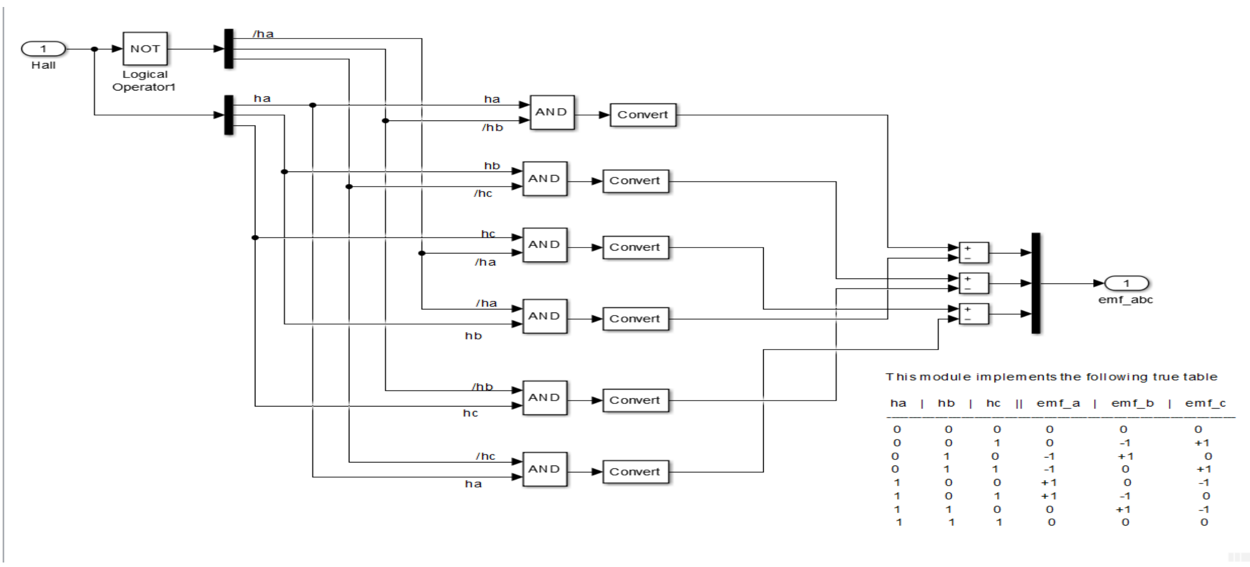


Fig 8.3

8.4 OUTPUT WAVEFORMS

8.4.1 Switched capacitor output voltage

Fig 8.4

8.4.2 Motor speed

Fig 8.5

8.4.3 Stator current and back emf

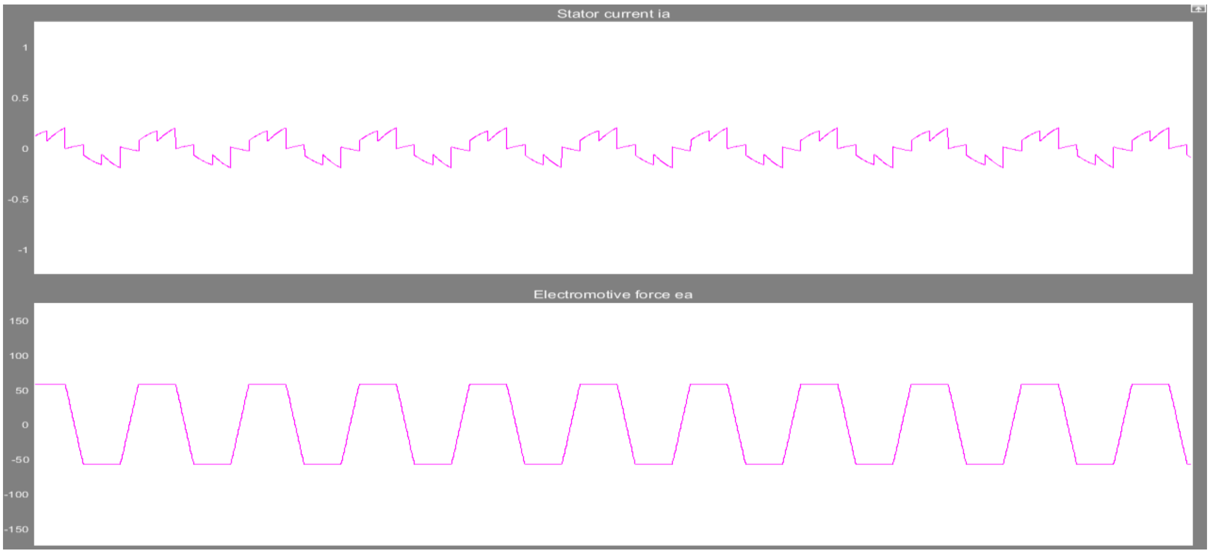


Fig 8.6

CHAPTER 9

CONCLUSION:

This project has presented a new switched-capacitor power converter (SC) for implementing dc-ac and ac-dc power conversion. The SC converter employs a switched-capacitor circuit augmented with the main converter circuit to the power source, thus providing unique features that cannot be attained by the traditional VSI or boost VSI. One of these unique features is doubling the area of the linear modulation region. The SC converter eliminates the need for the cumbersome and costly inductor to boost the voltage. Instead, it relies on only the capacitors to achieve voltage boost, which allows higher power density. The formulation of the maximum voltage drop across the capacitor and the minimum charging current are analytically derived. The analytical results provide a clear insight into the design elements that affect the behaviour of the charging current, thus allowing the operation at higher power. The carrier-based modulation method for the new SC converter is derived from the SVPWM and employs the exact switching sequence of the SVPWM method with minimal computational effort. The analytic derivations, simulation, and experimental results have validated the operating principle and modulation methods of the proposed converter. The SC converter can boost or buck voltage, minimize component count, increase power density, and reduce cost This paper proposes a control method for a low-cost GC micro-inverter with MPPT used in photovoltaic applications. A macro-model is proposed in order to test the proposed system and improve simulation times. In this way different MPPT algorithms can be developed and easily compared. Also, the macro-model speeds-the tuning of the voltage loop and the design of the input filters used for maximum power point tracking. The AM and the circuit used for inverter simulations are validated experimental results.

FUTURE SCOPE

The SC converter can boost or buck voltage, minimize component count, increase power density, and reduce cost This paper proposes a control method for a low cost GC micro-inverter with MPPT used in photovoltaic applications. A macro-model is proposed in order to test the proposed system and improve simulation times. In this way different MPPT algorithms can be developed and easily compared. Also, the macro-model speeds-the tuning of the voltage loop and the design of the input filters used for maximum power point tracking. The AM and the circuit used for inverter simulations are validated experimental results.

REFERENCES

[1] Reda Cherif, Fuad Hasanov, and Aditya Pande, "Riding the Energy Transition: Oil Beyond 2040," IMF Working Papers, May 2017.

[2] Y. Song and B. Wang, "Evaluation Methodology and Control Strategies for Improving Reliability of HEV Power Electronic System," in IEEE Transactions on Vehicular Technology, vol. 63, no. 8, pp. 3661-3676, Oct. 2014.

[3] Y. Song and B. Wang, "Survey on Reliability of Power Electronic Systems," in IEEE Transactions on Power Electronics, vol. 28, no. 1, pp. 591-604, Jan. 2013.

[4] Fang Zheng Peng, "Z-source inverter," in IEEE Transactions on Industry Applications, vol. 39, no. 2, pp. 504-510, March-April 2003.

[5] W. Qian, H. Cha, F. Z. Peng and L. M. Tolbert, "55-kW Variable 3X DCDC Converter for Plug-in Hybrid Electric Vehicles," in IEEE Transactions on Power Electronics, vol. 27, no. 4, pp. 1668-1678, April 2012.

[6] J. O. Estima and A. J. Marques Cardoso, "Efficiency Analysis of Drive Train Topologies Applied to Electric/Hybrid Vehicles," in IEEE Transactions on Vehicular Technology, vol. 61, no. 3, pp. 1021-1031, March 2012.

[7] B. Dong, Y. Li and Y. Han, "Parallel Architecture for Battery Charge Equalization," in IEEE Transactions on Power Electronics, vol. 30, no. 9, pp. 4906-4913, Sept. 2015.

[8] I. N. L. (INL). Advanced Vehicles - Vehicle Testing. [Online]. Available: https://avt.inl.gov/vehicle-type/all-powertrain-architecture.

[9] Z. Rahman, M. Ehsani and K. L. Butler, "An Investigation of Electric Motor Drive Characteristics for EV and HEV Propulsion Systems", 2000 Future Transportation Technology Conference Costa Mesa, California August 21-23, 2000.

[10] A. Deshpande and F. Luo, "Practical Design Considerations for a Si IGBT + SiC MOSFET Hybrid Switch: Parasitic Interconnect Influences, Cost, and Current Ratio Optimization," in IEEE Transactions on Power Electronics, vol. 34, no. 1, pp. 724-737, Jan. 2019.

[11] R. Erickson, D. Maksimovic, K. Afridi, D. Jones, D. Friedrichs, H. Kim, U. Anwar, and J. Zhu, K. Olejniczak, B. Passmore, and T. Mcnutt, "A Disruptive Approach to Eletric Vehicle Power Electronics",