A Hybrid Cascaded Multilevel Converter for Battery Energy Management Applied in Electric Vehicles

A Main project report submitted in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRICAL AND ELECTRONICS ENGINEERING

Submitted by

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(ESTD-1995)

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

RAJEEV GANDHI MEMORIAL COLLEGE OF ENGINEERING & TECHNOLOGY

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BONAFIDE CERTIFICATE

This is to certify that the thesis entitled "A HYBRID CASCADED MULTILEVEL CONVERTER FOR BATTERY ENERGY MANAGEMENT IN ELECTRIC VEHICLES" that is being submitted by **A. V. SANDEEP (18095A0241), G. MEGHANA (17091A0233), P. PAVANI (18095A0224)** have carried out the main project for the fulfilment of the award of Bachelor of Technology in **Electrical and Electronics Engineering** in Rajeev Gandhi Memorial College of Engineering & Technology (Autonomous) and this is a record of the work done by them during the year 2020 – 21.

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ABSTRACT

In electric vehicle (EV) energy storage systems, a large number of battery cells are usually connected in series to enhance the output voltage for motor driving. The difference in electrochemical characters will cause state-of-charge (SOC) and terminal voltage imbalance between different cells. In this paper, a hybrid cascaded multilevel converter which involves both battery energy management and motor drives is proposed for EV. In the proposed topology, each battery cell can be controlled to be connected into the circuit or to be bypassed by a half-bridge converter. All half bridges are cascaded to output a staircase shape dc voltage. Then, an H-bridge converter is used to change the direction of the dc bus voltages to make up ac voltages. The outputs of the converter are multilevel voltages with less harmonics and lower dv/dt, which is helpful to improve the performance of the motor drives. By separate control according to the SOC of each cell, the energy utilization ratio of the batteries can be improved. The imbalance of terminal voltage and SOC can also be avoided, fault-tolerant can be easily realized by modular cascaded circuit, so the life of the battery stack will be extended. Simulations are implemented to verify the performance of the proposed converter.

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INTRODUCTION

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INTRODUCTION

1.1 INTRODUCTION

An energy storage system plays an important role in electric vehicles (EV). Batteries, such as lead-acid or lithium batteries, are the most popular units because of their appropriate energy density and cost. Since the voltages of these kinds of battery cells are relatively low, a large number of battery cells need to be connected in series to meet the voltage requirement of the motor. Because of the manufacturing variability, cell architecture and degradation with use, the characters such as volume and resistance will be different between these cascaded battery cells. In a traditional method, all the battery cells are directly connected in series and are charged or discharged by the same current, the terminal voltage and state-of-charge (SOC) will be different because of the electrochemical characteristic differences between the battery cells. The charge and discharge have to be stopped even though only one of the cells reaches its cut-off voltage. Moreover, when any cell is fatally damaged, the whole battery stack cannot be used anymore. So, the battery cell screening must be processed to reduce these differences, and voltage or SOC equalization circuit is often needed in practical applications to protect the battery cells from overcharging or over discharging.

Generally, there are two kinds of equalization circuits. The first one consumes the redundant energy on parallel resistance to keep the terminal voltage of all cells equal. For example, in charging course, if one cell arrives at its cut-off voltage, the available energy in other cells must be consumed in their parallel-connected resistances. So, the energy utilization ratio is very low. Another kind of equalization circuit is composed of a group of inductances or transformers and converters, which can realize energy transfer between battery cells. The energy in the cells with higher terminal voltage or SOC can be transferred to others to realize the voltage and SOC equalization. Since the voltage balance is realized by energy exchange between cells, the energy utilization ratio is improved. The disadvantage is that a lot of inductances or isolated multi-winding transformers are required in these topologies, and the control of the converters is also complex. Some studies have been implemented to simplify the circuit and improve the balance speed by multistage equalization. Some zero voltage and zero current switching techniques are also used to reduce the loss of the equalization circuit.

Numerous industrial applications require higher power apparatus in recent years. Some medium voltage motor drives and utility applications require medium voltage and megawatt power level. A multilevel power converter structure has been introduced as an alternative in high power and medium voltage situations subsequently; several multilevel converter topologies have been developed. A multilevel converter not only achieves high power ratings but also enables the use of renewable energy sources. The advantages of three-level Inverter topology over conventional two-level topology are

1) The voltage across the switches is only one half of the DC source voltage

2) The switching frequency can be reduced for the same switching losses

3) The higher output current harmonics are reduced by the same switching frequency.

Power electronic inverters are widely used in various industrial drive applications. To overcome the problems of the limited voltage and current ratings of power semiconductors devices, some kinds of series and/or parallel connections are necessary. Recently, the multilevel inverters have received more attention in literature due to their ability to synthesize waveforms with a better harmonic spectrum and to attain higher voltages. They are applied in many industrial applications such as ac power supplies, static VAR compensators, and drive system, etc. One of the significant advantages of multilevel configuration is the harmonics reduction in the output waveform without increasing switching frequency or decreasing the inverter power output. These multilevel inverters, in case of m-level, can increase the capacity by (m-1) times than that of two-level inverter through the series connection of power semiconductor devices without additional circuit to have uniform voltage sharing, comparing with two level inverter system having the same capacity, multilevel inverters have the advantages that the harmonic components of line-to-line voltages fed to load, switching frequency of the devices and EMI problem could be decreased.

The output voltage waveform of a multi-level inverter is composed of a number of levels of voltages starting form three levels and reaching infinity depending upon the number of the dc sources. The main function of a multilevel inverter is to produce a desired ac voltage waveform from several levels of dc voltage sources. These dc voltages may or may not be equal to one another. The dc sources can be obtained from batteries, fuel cells, or solar cells. Conventionally, each phase of a cascaded multilevel converter requires n dc sources for $2n + 1$ levels in applications that involve real power transfer. These dc sources are assumed to have identical amplitudes. The advantages of the multilevel inverters (MLI) include:

1) They provide even voltage sharing, both statically and dynamically

2) Substantial reduction in size and volume is possible due to the elimination of the bulky coupling transformers or inductors and

3) Multilevel inverters can offer better voltage waveforms with less harmonic content and, thus, can significantly reduce the size and weight of passive filter components.

Several multilevel inverter topologies are proposed over the past few years, the most popular multilevel inverters which are mostly used are Diode-clamped, Flying capacitor and the H-bridge multilevel inverter. One aspect which sets the cascaded H-bridge apart from other multilevel inverter is the capability of utilizing different DC voltages on the individual H-bridge cell which results in splitting the power conversion among high voltage low frequency and low voltage high frequency inverters. An alternate method of cascading involves series connection of two three phase inverters through the neutral point connection of the load.

CHAPTER -2
ROLE OF POWER ELECTRONIC CONVERTERS

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2.1 INTRODUCTION TO POWER ELECTRONICS:

Power Electronics is a field which combines Power (electric power), Electronics and Control systems. Power engineering deals with the static and rotating power equipment for the generation, transmission and distribution of electric power. Electronics deals with the study of solid-state semiconductor power devices and circuits for Power conversion to meet the desired control objectives (to control the output voltage and output power).

Power electronics may be defined as the subject of applications of solid-state power semiconductor devices (Thyristors) for the control and conversion of electric power.

Power electronics deals with the study and design of thyristorised power controllers for variety of application like Heat control, Light/Illumination control, and Motor control – AC/DC motor drives used in industries, High voltage power supplies, Vehicle propulsion systems, High voltage direct current (HVDC) transmission.

2.1.1 POWER ELECTRONIC APPLICATIONS:

- **COMMERCIAL APPLICATIONS:**

Heating Systems Ventilating, Air Conditioners, Central Refrigeration, and Lighting, Computers and Office equipment's, Uninterruptible Power Supplies (UPS), Elevators, and Emergency Lamps.

- **DOMESTIC APPLICATIONS:**

Cooking Equipment's, Lighting, Heating, Air Conditioners, Refrigerators & Freezers, Personal Computers, Entertainment equipment's, UPS.

- **INDUSTRIAL APPLICATIONS:**

Pumps, compressors, blowers and fans. Machine tools, arc furnaces, induction furnaces, lighting control circuits, industrial lasers, induction heating, welding equipment's.

- **AEROSPACE APPLICATIONS:**

Space shuttle power supply systems, satellite power systems, aircraft power systems.

- **TELECOMMUNICATIONS:**

Battery chargers, power supplies (DC and UPS), mobile cell phone battery chargers.

- **TRANSPORTATION:**

Traction control of electric vehicles, battery chargers for electric vehicles, electric locomotives, street cars, trolley buses, automobile electronics including engine controls.

- **UTILITY SYSTEMS:**

High voltage DC transmission (HVDC), static VAR compensation (SVC), Alternative energy sources (wind, photovoltaic), fuel cells, energy storage systems, induced draft fans and boiler feed water pumps.

2.2 DIFFERENCES BETWEEN ELECTRONICS AND POWER ELECTRONICS:

This question can be answered in number of ways. The simplest way to say all the electronics devices which deals with power are covered in Power Electronics. There are devices which you do use in general purpose electronics like: Diode, BJT, MOSFETs etc. You will find these devices in electronics & power electronics both. The devices used in Power electronics may differ in term of construction & behavior from those used in electronics.

There are types of devices which you will find only IN PE, ex: IGBT.

- The only difference is that power devices (e.g. MOSFETs) are made to handle much larger power requirements.
- Ordinary devices are low current and low voltage devices.
- Power devices are high current and/or high voltage devices.

2.3 POWER CONVERTERS:

A power converter is an electrical or electro-mechanical device for converting electrical energy. It may be converting AC to or from DC, or the voltage or frequency, or some combination of these.

Amongst the many devices that are used for this purpose are;

- Rectifier
- Inverter
- DC - DC converter
- AC - AC converter

2.3.1 AC - DC CONVERTER (RECTIFIER):

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which is in only one direction, a process known as rectification.

Rectifiers have many uses including as components of power supplies and as detectors of radio signals. Rectifiers may be made of solid state diodes, vacuum tube diodes, mercury arc valves, and other components.

2.3.2 DC - AC CONVERTER (INVERTER):

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.

Solid-state inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.

2.3.3 DC - DC CONVERTER (CHOPPERS):

A dc chopper is a dc-to-dc voltage converter. It is a static switching electrical appliance that in one Electrical conversion, changes an input fixed dc voltage to an adjustable dc output voltage without Inductive or capacitive intermediate energy storage. The name chopper is connected with the fact that the output voltage is a ‘chopped up’ quasi-rectangular version of the input dc voltage.

2.3.4 AC - AC CONVERTER:

An AC/AC converter converts an AC waveform such as the mains supply, to another AC waveform, where the output voltage and frequency can be set arbitrarily.

AC/AC converters can be categorized into

- Cyclo-converters
- Matrix Converters

CHAPTER -3
DESCRIPTION OF THE SWITCHING COMPONENTS

CHAPTER -3
DESCRIPTION OF THE SWITCHING COMPONENTS

POWER ELECTRONIC SWITCHES:

In electronics, a switch is an electrical component that can break an electrical circuit, interrupting the current or diverting it from one conductor to another.

A power electronic switch integrates a combination of power electronic components or power semiconductors and a driver for the actively switchable power semiconductors. The internal functional correlations and interactions of this integrated system determine several.

3.1 DIODE:

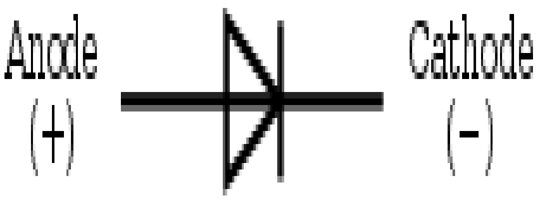
In electronics, a diode is a type of two-terminal electronic component with a nonlinear current–voltage characteristic. A semiconductor diode, the most common type today, is a crystalline piece of semiconductor material connected to two electrical terminals. A vacuum tube diode (now rarely used except in some high-power technologies) is a vacuum tube with two electrodes: a plate and a cathode.

The most common function of a diode is to allow an electric current to pass in one direction (called the diode's forward direction), while blocking current in the opposite direction (the reverse direction). Thus, the diode can be thought of as an electronic version of a check valve. This unidirectional behavior is called rectification, and is used to convert alternating current to direct current, and to extract modulation from radio signals in radio receivers.

However, diodes can have more complicated behavior than this simple on–off action. Semiconductor diodes do not begin conducting electricity until a certain threshold voltage is present in the forward direction (a state in which the diode is said to be forward biased). The voltage drop across a forward biased diode varies only a little with the current, and is a function of temperature; this effect can be used as a temperature sensor or voltage reference.

Semiconductor diodes have nonlinear electrical characteristics, which can be tailored by varying the construction of their P–N junction. These are exploited in special purpose diodes that perform many different functions.

Diodes were the first semiconductor electronic devices. The discovery of crystals' rectifying abilities was made by German physicist Ferdinand Braun in 1874. The first semiconductor diodes, called cat's whisker diodes, developed around 1906, were made of mineral crystals such as galena. Today most diodes are made of silicon, but other semiconductors such as germanium are sometimes used.



3.1.1 SYMBOL OF DIODE

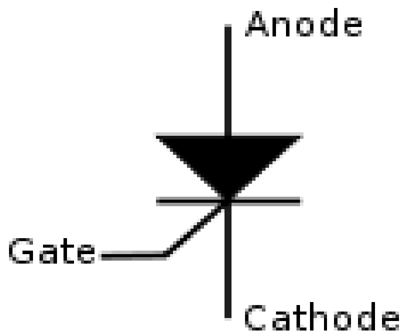
A modern semiconductor diode is made of a crystal of semiconductor like silicon that has impurities added to it to create a region on one side that contains negative charge carriers (electrons), called n-type semiconductor, and a region on the other side that contains positive charge carriers (holes), called p-type semiconductor. The diode's terminals are attached to each of these regions. The boundary within the crystal between these two regions, called a PN junction, is where the action of the diode takes place. The crystal conducts a current of electrons in a direction from the N-type side (called the cathode) to the P-type side (called the anode), but not in the opposite direction. However, conventional current flows from anode to cathode in the direction of the arrow (opposite to the electron flow, since electrons have negative charge).

Another type of semiconductor diode, the Scotty diode, is formed from the contact between a metal and a semiconductor rather than by a p–n junction.

3.2 THYRISTORS:

A thyristor is a solid-state semiconductor device with four layers of alternating n and p-type material. They act as bistable switches, conducting when their gate receives a current pulse, and continue to conduct while they are forward biased (that is, while the voltage across the device is not reversed).

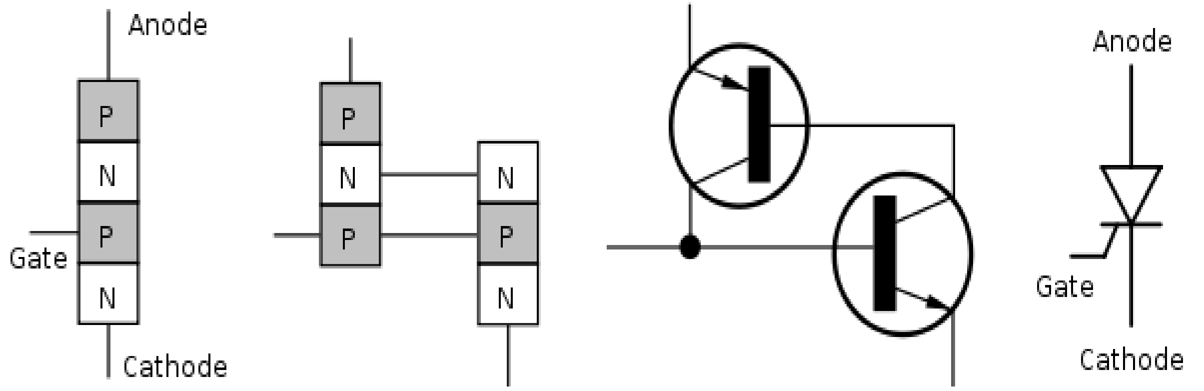
Some sources define silicon-controlled rectifiers and thyristors as synonymous.



3.2.1 CIRCUIT SYMBOL FOR A THYRISTOR

3.2.1 FUNCTION:

The thyristor is a four-layer, three terminal semiconducting devices, with each layer consisting of alternately N-type or P-type material, for example P-N-P-N. The main terminals, labeled anode and cathode, are across the full four layers, and the control terminal, called the gate, is attached to p-type material near to the cathode. (A variant called an SCS—Silicon Controlled Switch—brings all four layers out to terminals.) The operation of a thyristor can be understood in terms of a pair of tightly coupled bipolar junction transistors, arranged to cause the self-latching action:



3.2.2 Structure on the physical and electronic level, and the thyristor symbol.

Thyristors have three states:

1. Reverse blocking mode — Voltage is applied in the direction that would be blocked by a diode
2. Forward blocking mode — Voltage is applied in the direction that would cause a diode to conduct, but the thyristor has not yet been triggered into conduction
3. Forward conducting mode — The thyristor has been triggered into conduction and will remain conducting until the forward current drops below a threshold value known as the "holding current".

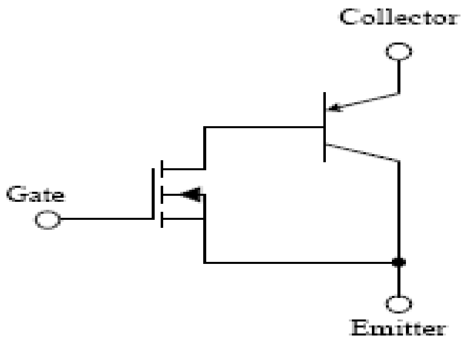
3.3 INSULATED GATE BIPOLAR TRANSISTOR (IGBT):

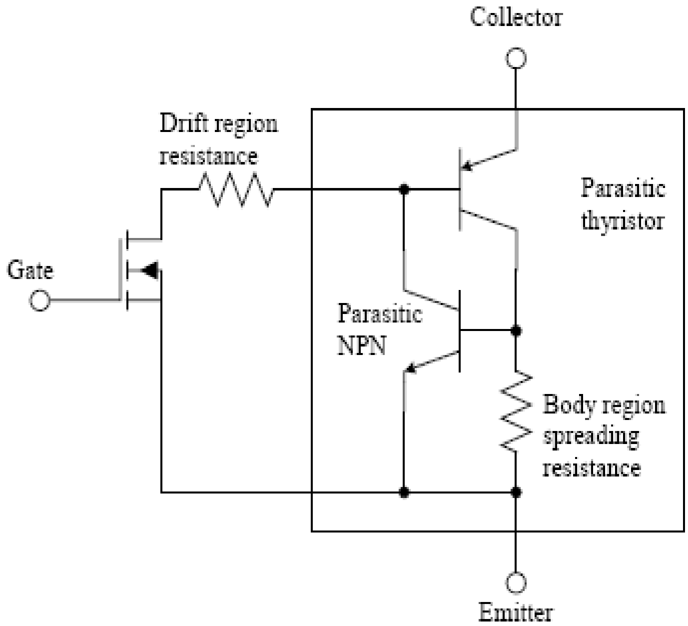
The insulated-gate bipolar transistor or IGBT is a three-terminal power semiconductor device, noted for high efficiency and fast switching. It switches electric power in many modern appliances: electric cars, variable speed refrigerators, air-conditioners, and even stereo systems with digital amplifiers. Since it is designed to rapidly turn on and off, amplifiers that use it often synthesize complex waveforms with pulse width modulation and low-pass filters.

The IGBT combines the simple gate-drive characteristics of the MOSFETs with the high-current and low-saturation-voltage capability of bipolar transistors by combining an isolated-gate FET for the control input, and a bipolar power transistor as a switch, in a single device. The IGBT is used in medium to high power applications such as SMPS, traction motor control and induction heating. Large IGBT modules typically consist of many devices in parallel and can have very high current handling capabilities in the order of hundreds of amps with blocking voltages of 6,000 V.

3.3.1 EQUIVALENT CIRCUIT:

An examination of reveals that if we move vertically up from collector to emitter. We come across p+, n-, p layer s. Thus, IGBT can be thought of as the combination of MOSFET and p+ n^- p layer s. Thus, IGBT can be thought of as the combination of MOSFET and p^+ n^- p transistor Q1. Here Rd is resistance offered by n^- drift region. Approximate equivalent circuit of an IGBT.

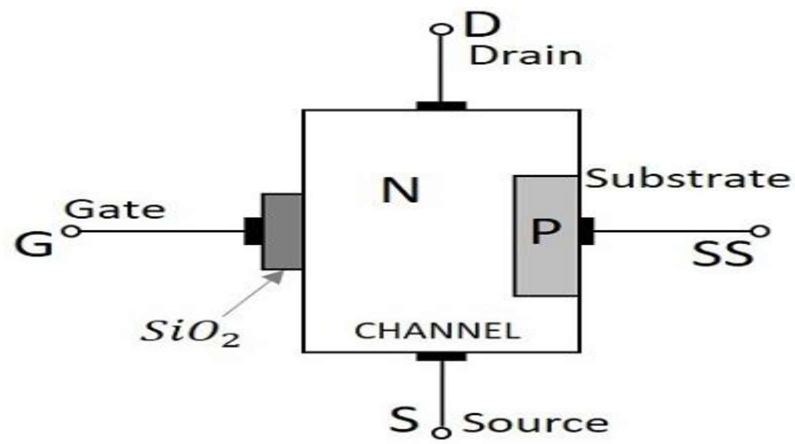


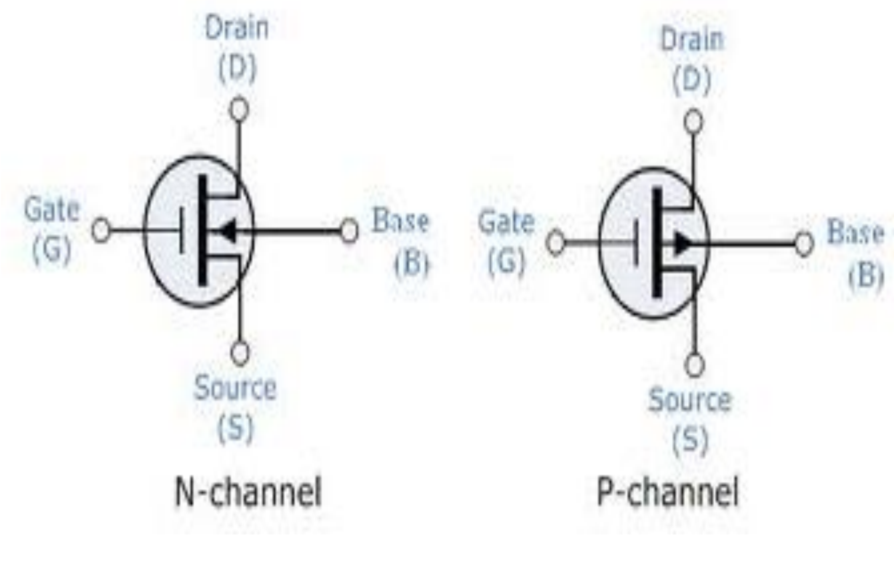


3.3.1 Insulated Gate Bipolar Transistor

3.4 MOSFET:

The metal–oxide–semiconductor field-effect transistor (MOSFET, MOS-FET, or MOS FET) is a transistor used for amplifying or switching electronic signals. The basic principle of this kind of transistor was first proposed by Julius Edgar Lilienfeld in 1925. In MOSFETs, a voltage on the oxide-insulated gate electrode can induce a conducting channel between the two other contacts called source and drain. The channel can be of n-type or p-type (see article on semiconductor devices) and is accordingly called an N-MOSFET or a P-MOSFET (also commonly N-MOS, P-MOS). It is by far the most common transistor in both digital and analog circuits, though the bipolar junction transistor was at one time much more common.





3.4 Metal Oxide Semiconductor Field Effect Transistor

The 'metal' in the name is now often a misnomer because the previously metal gate material is now often a layer of polysilicon (polycrystalline silicon). Aluminium had been the gate material until the mid-1970s, when polysilicon became dominant, due to its capability to form self-aligned gates. Metallic gates are regaining popularity, since it is difficult to increase the speed of operation of transistors without metal gates.

3.4.1 MOSFET OPERATION:

A metal–oxide–semiconductor field-effect transistor (MOSFET) is based on the modulation of charge concentration by a MOS capacitance between a body electrode and a gate electrode located above the body and insulated from all other device regions by a gate dielectric layer which in the case of a MOSFET is an oxide, such as silicon dioxide. If dielectrics other than an oxide such as silicon dioxide (often referred to as oxide) are employed the device may be referred to as a metal–insulator–semiconductor FET (MISFET). Compared to the MOS capacitor, the MOSFET includes two additional terminals (source and drain), each connected to individual highly doped regions that are separated by the body region. These regions can be either p or n type, but they must both be of the same type, and of opposite type to the body region. The source and drain (unlike the body) are highly doped as signified by a '+' sign after the type of doping.

If the MOSFET is an n-channel or N-MOS FET, then the source and drain are 'n+' regions and the body is a 'p' region. As described above, with sufficient gate voltage, holes from the body are driven away from the gate, forming an inversion layer or n-channel at the interface between the p region and the oxide. This conducting channel extends between the source and the drain, and current is conducted through it when a voltage is applied between source and drain. Increasing the voltage on the gate leads to a higher electron density in the inversion layer and therefore increases the current flow between the source and drain.

For gate voltages below the threshold value, the channel is lightly populated, and only a very small sub threshold leakage current can flow between the source and the drain.

If the MOSFET is a p-channel or P-MOS FET, then the source and drain are 'p+' regions and the body is a 'n' region. When a negative gate-source voltage (positive source-gate) is applied, it creates a p-channel at the surface of the n region, analogous to the n-channel case, but with opposite polarities of charges and voltages.

When a voltage less negative than the threshold value (a negative voltage for p-channel) is applied between gate and source, the channel disappears and only a very small sub threshold current can flow between the source and the drain.

The source is so named because it is the source of the charge carriers (electrons for n-channel, holes for p-channel) that flow through the channel; similarly, the drain is where the charge carriers leave the channel.

The device may comprise a Silicon on Insulator (SOI) device in which a Buried Oxide (BOX) is formed below a thin semiconductor layer. If the channel region between the gate dielectric and a Buried Oxide (BOX) region is very thin, the very thin channel region is referred to as an Ultra-Thin Channel (UTC) region with the source and drain regions formed on either side thereof in and/or above the thin semiconductor layer. Alternatively, the device may comprise a Semiconductor on Insulator (SEMOI) device in which semiconductors other than silicon are employed. Many alternative semiconductor materials may be employed.

CHAPTER -4
CASCADED H-BRIDGE INVERTER & MODULATING TECHNIQUES

CHAPTER -4
CASCADED H-BRIDGE INVERTER & MODULATING TECHNIQUES

4.1 MULTILEVEL CONVERTER:

An inverter is an electrical device that converts direct current (DC) to alternating current (AC); the converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits.

Static inverters have no moving parts and are used in a wide range of applications, from small switching power supplies in computers, to large electric utility high-voltage direct current applications that transport bulk power. Inverters are commonly used to supply AC power from DC sources such as solar panels or batteries.

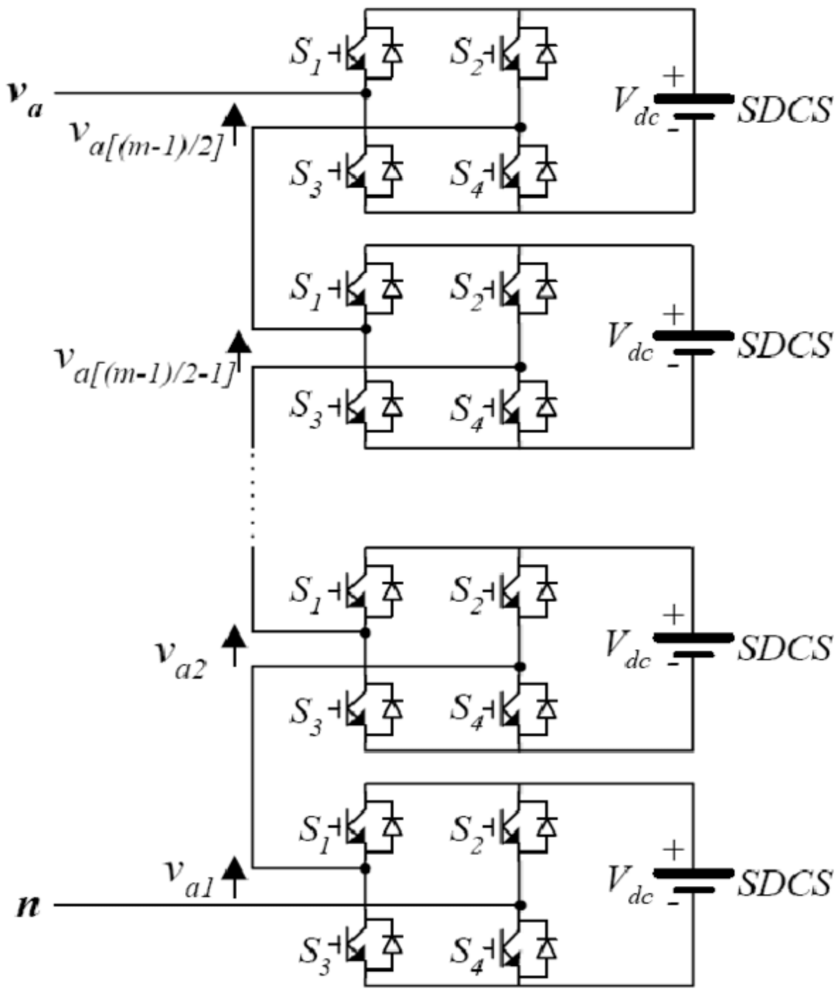
The electrical inverter is a high-power electronic oscillator. It is so named because early mechanical AC to DC converters was made to work in reverse, and thus was "inverted", to convert DC to AC. The inverter performs the opposite function of a rectifier.

4.2 CASCADED H-BRIDGES INVERTER:

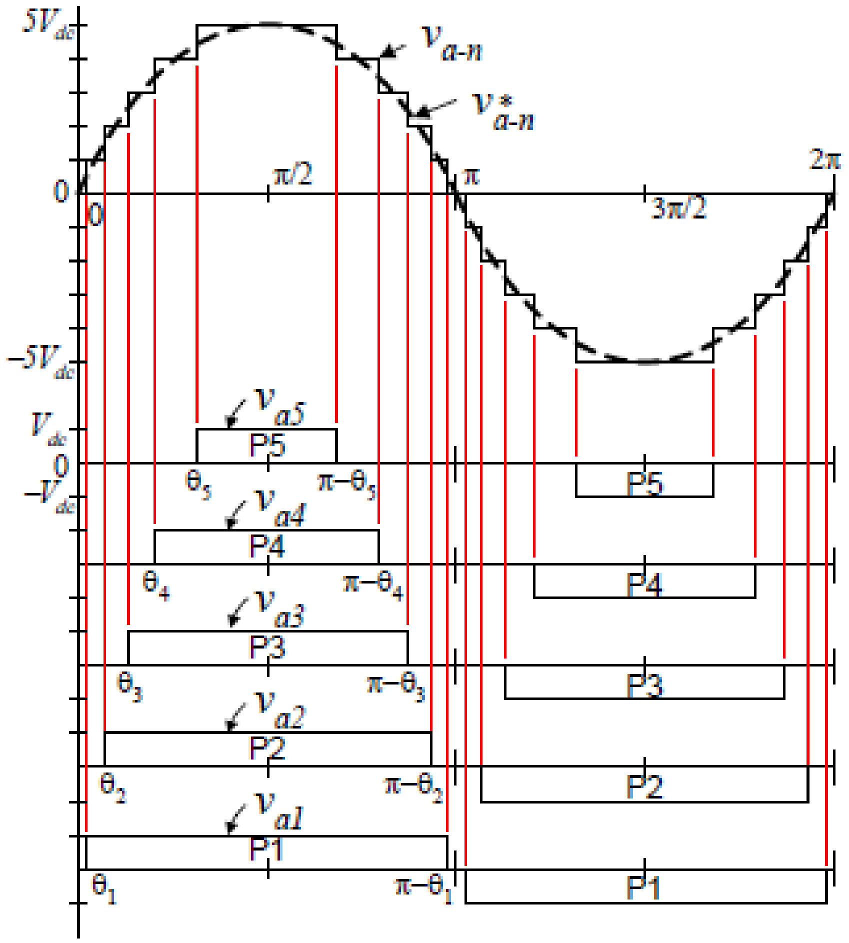
A single-phase structure of an m-level cascaded inverter is illustrated in Figure 31.1. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0, and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S_1, S_2, S_3, and S_4. To obtain $+V_{dc}$, switches S_1 and S_4 are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S_2 and S_3. By turning on S_1 and S_2 or S_3 and S_4, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by m = 2s+1, where s is the number of separate dc sources. An example phase voltage waveform for an 11-level cascaded H-bridge inverter with 5 SDCSs and 5 full bridges is shown in Figure 31.2. The phase voltage $v_{an} = v_{a1} + v_{a2} + v_{a3} + v_{a4} + v_{a5}$.

For a stepped waveform such as the one depicted in Figure 31.2 with s steps, the Fourier Transform for this waveform follows

$$V(\omega t) = \frac{4V_{dc}}{\pi} \sum_{n} \left[\cos(n\theta_1) + \cos(n\theta_2) + \ldots + \cos(n\theta_s)\right] \frac{\sin(n\omega t)}{n}, \quad \text{where } n = 1, 3, 5, 7, \ldots$$



4.2.1 Single-phase structure of a multilevel cascaded H-bridges inverter



4.2.2 Output phase voltage waveform of an 11-level cascade inverter with 5 separate dc sources.

The magnitudes of the Fourier coefficients when normalized with respect to V_{dc} are as follows:

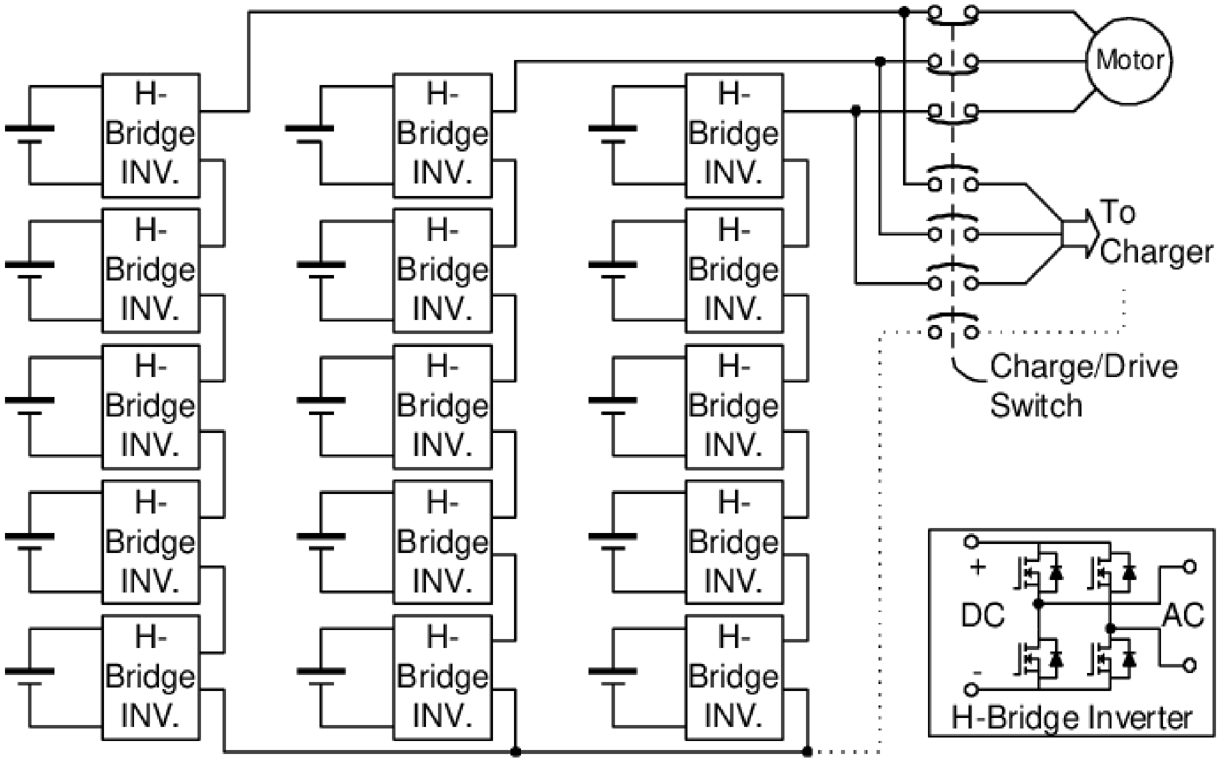
$$H(n) = \frac{4}{\pi n}\left[\cos(n\theta_1) + \cos(n\theta_2) + \ldots + \cos(n\theta_s)\right], \quad \text{where } n = 1, 3, 5, 7, \ldots$$

The conducting angles, θ_1, $\theta_{2....}$, θ_s, can be chosen such that the voltage total harmonic distortion is a minimum. Generally, these angles are chosen so that predominant lower frequency harmonics, 5th, 7th, 11th, and 13^{th}, harmonics are eliminated. More detail on harmonic elimination techniques will be presented in the next section.

Multilevel cascaded inverters have been proposed for such applications as static var generation, an interface with renewable energy sources, and for battery-based applications. Three-phase cascaded inverters can be connected in wye, as shown in Figure, or in delta. Peng has demonstrated a prototype multilevel cascaded static var generator connected in parallel with the electrical system that could supply or draw reactive current from an electrical system.

The inverter could be controlled to either regulate the power factor of the current drawn from the source or the bus voltage of the electrical system where the inverter was connected. Peng [20] and Joos [24] have also shown that a cascade inverter can be directly connected in series with the electrical system for static var compensation. Cascaded inverters are ideal for connecting renewable energy sources with an AC grid, because of the need for separate dc sources, which is the case in applications such as photo Voltaic or fuel cells.

Cascaded inverters have also been proposed for use as the main traction drive in electric vehicles, where several batteries or ultra-capacitors are well suited to serve as SDCSs. The cascaded inverter could also serve as a rectifier/charger for the batteries of an electric vehicle while the vehicle was connected to an ac supply as shown in Figure. Additionally, the cascade inverter can act as a rectifier in a vehicle that uses regenerative braking.



4.2.3 Three- phase wye-connection structure for electric vehicle motor drive and battery charging.

The main advantages and disadvantages of multilevel cascaded H-bridge converters are as follows

ADVANTAGES:

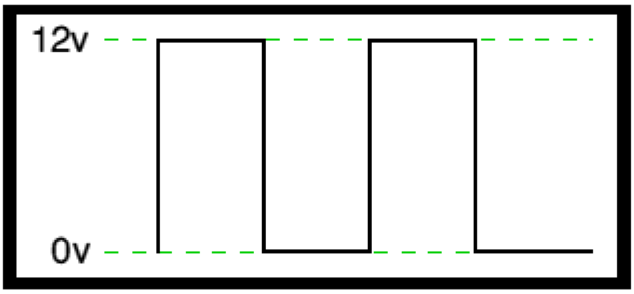
- The number of possible output voltage levels is more than twice the number of dc sources (m = 2s + 1).
- The series of H-bridges makes for modularized layout and packaging. This will enable the manufacturing process to be done more quickly and cheaply.

DISADVANTAGES:

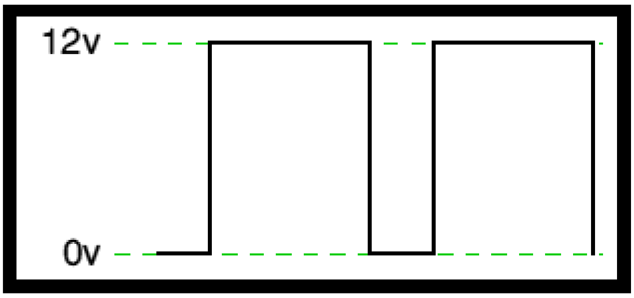
- Separate dc sources are required for each of the H-bridges. This will limit its application to products that already have multiple SDCSs readily available.

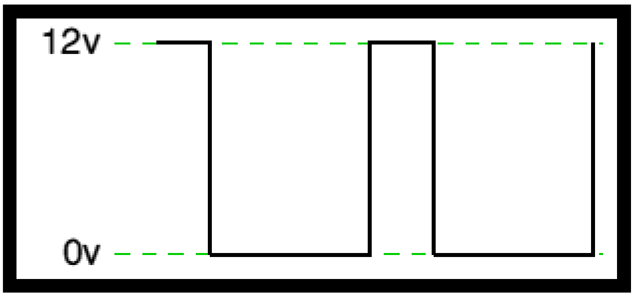
4.3 PWM (Pulse Width Modulation):

Pulse Width Modulation (PWM) is the most effective means to achieve constant voltage battery charging by switching the solar system controller's power devices. When in PWM regulation, the current from the solar array tapers according to the battery's condition and recharging needs Consider a waveform such as this: it is a voltage switching between 0v and 12v. It is obvious that, since the voltage is at 12v for exactly as long as it is at 0v, then a 'suitable device' connected to its output will see the average voltage and think it is being fed 6v - exactly half of 12v. So, by varying the width of the positive pulse - we can vary the 'average' voltage.



Similarly, if the switches keep the voltage at 12 for 3 times as long as at 0v, the average will be 3/4 of 12v - or 9v, as shown below and if the output pulse of 12v lasts only 25% of the overall time, then the average is





By varying - or 'modulating' - the time that the output is at 12v (i.e., the width of the positive pulse) we can alter the average voltage. So, we are doing 'pulse width modulation'. I said earlier that the output had to feed 'a suitable device'. A radio would not work from this: the radio would see 12v then 0v and would probably not work properly. However, a device such as a motor will respond to the average, so PWM is a natural for motor control.

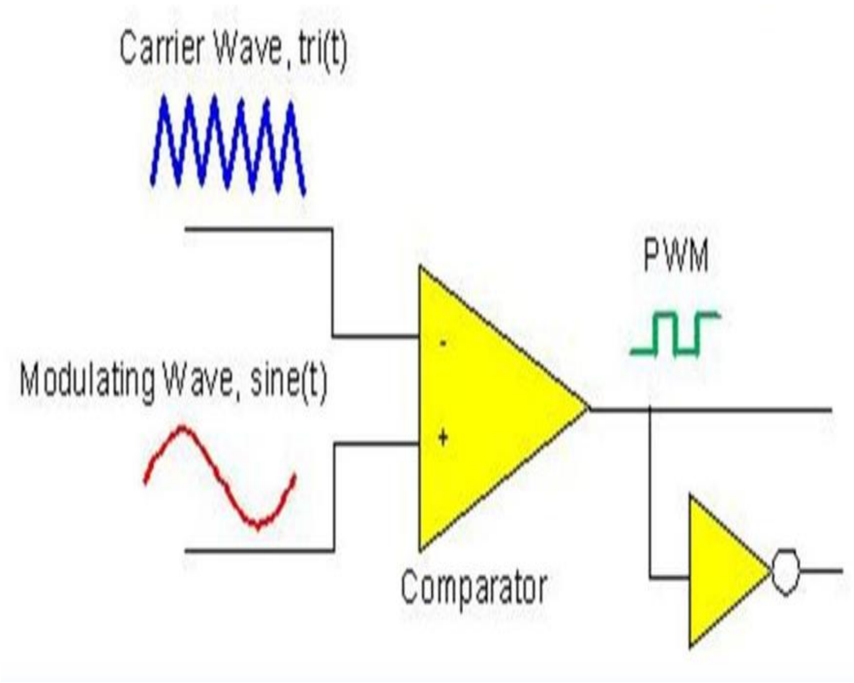
4.3.1 SINUSOIDAL PULSE WIDTH MODULATION:

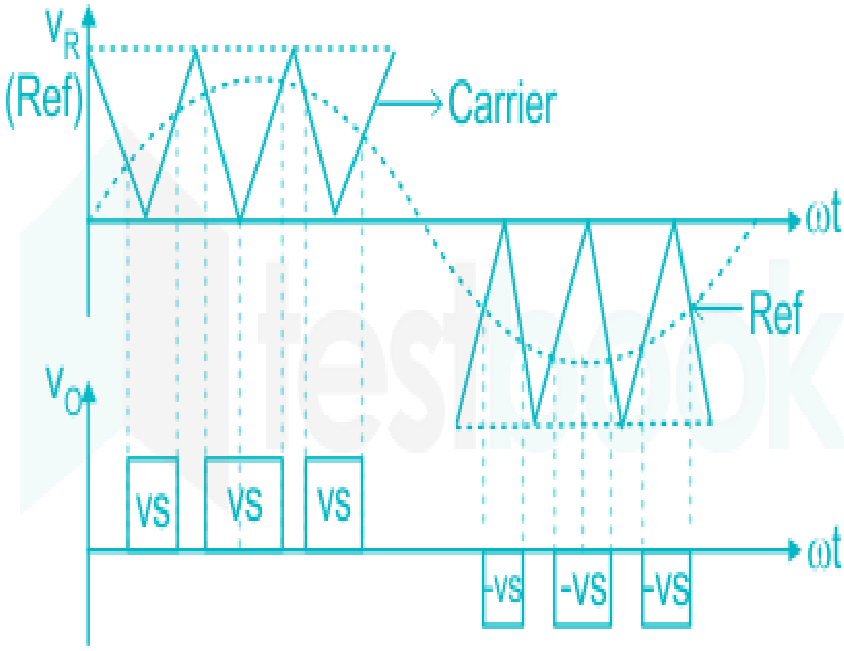
In many industrial applications, Sinusoidal Pulse Width Modulation (SPWM), also called Sine coded Pulse Width Modulation, is used to control the inverter output voltage. SPWM maintains good performance of the drive in the entire range of operation between zero and 78 percent of the value that would be reached by square-wave operation. If the modulation index exceeds this value, linear relationship between modulation index and output voltage is not maintained and the over-modulation methods are required.

Sinusoidal PWM is a typical carrier PWM technique. In this PWM technique, the sinusoidal AC voltage reference (Vref) is compared with the high frequency triangular carrier wave (Vc). After comparing the switching states for each pole can be determined based on the following rule:

Vref > Vc: upper switch is turned on

Vref < Vc: lower switch is turned on





4.3.1 SINUSOIDAL PWM

CHAPTER -5
BRIEFING ABOUT MATLAB SOFTWARE

CHAPTER -5
BRIEFING ABOUT MATLAB SOFTWARE

5.1 Introduction to MATLAB:

MATLAB is a high-performance language for technical computing. The name mat lab stands for matrix laboratory. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. Typical uses include Math and computation Algorithm development Data acquisition Modeling, simulation, and prototyping Data analysis, exploration, and visualization Scientific and engineering graphics Application development, including graphical user interface building.

MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time it would take to write a program in a scalar no interactive language such as C or FORTRAN.

5.2 Sim-Power system:

5.2.1 Introduction:

Sim Power Systems software and other products of the Physical Modeling product family work together with Simulink software to model electrical, mechanical, and control systems.

Sim Power Systems software operates in the Simulink environment. Therefore, before starting this user's guide, make yourself familiar with Simulink documentation. Or, if you perform signal processing and communications tasks (as opposed to control system design tasks), see the Signal Processing Block set documentation.

5.2.2 The Role of Simulation in Design:

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.

Sim Power Systems software is a modern design tool that allows scientists and engineers to rapidly and easily build models that simulate power systems. It 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 modeling library.

Since Simulink uses the MATLAB computational engine, designers can also use MATLAB toolboxes and Simulink block sets. Sim Power Systems software belongs to the Physical Modeling product family and uses similar block and connection line interface.

5.2.3 Sim power systems Libraries:

Sim Power Systems 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

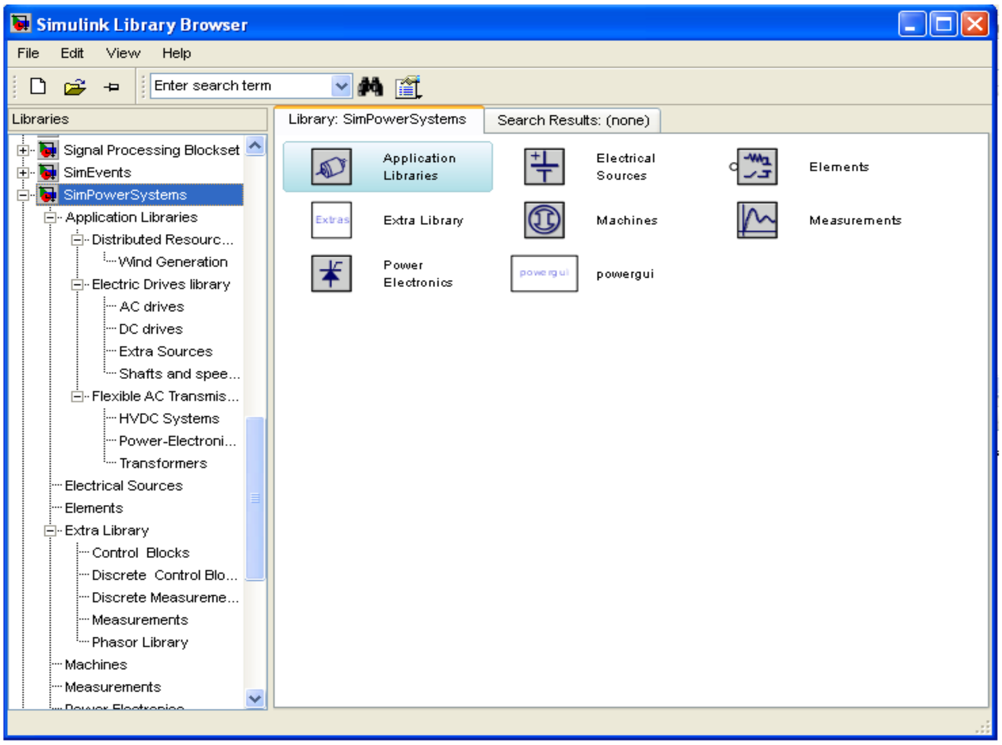
Canada, and on the experience of École de Technology Supierieure and University Laval. The capabilities of Sim Power Systems software for modeling a typical electrical system are illustrated in demonstration files. And for users who want to refresh their knowledge of power system theory, there are also self-learning case studies.

The Sim Power Systems main library, power lib, organizes its blocks into libraries according to their behavior. 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 power lib library window also contains the Power gui block that opens a graphical user interface for the steady-state analysis of electrical circuits.

5.2.4 Nonlinear Simulink Blocks for Sim Power systems 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 Power Systems software to build the equivalent Simulink model of your circuit. See Improving Simulation Performance for a description of the power lib model's library.

5.2.1 Diagram of sim power system



5.3 Applications of MATLAB:

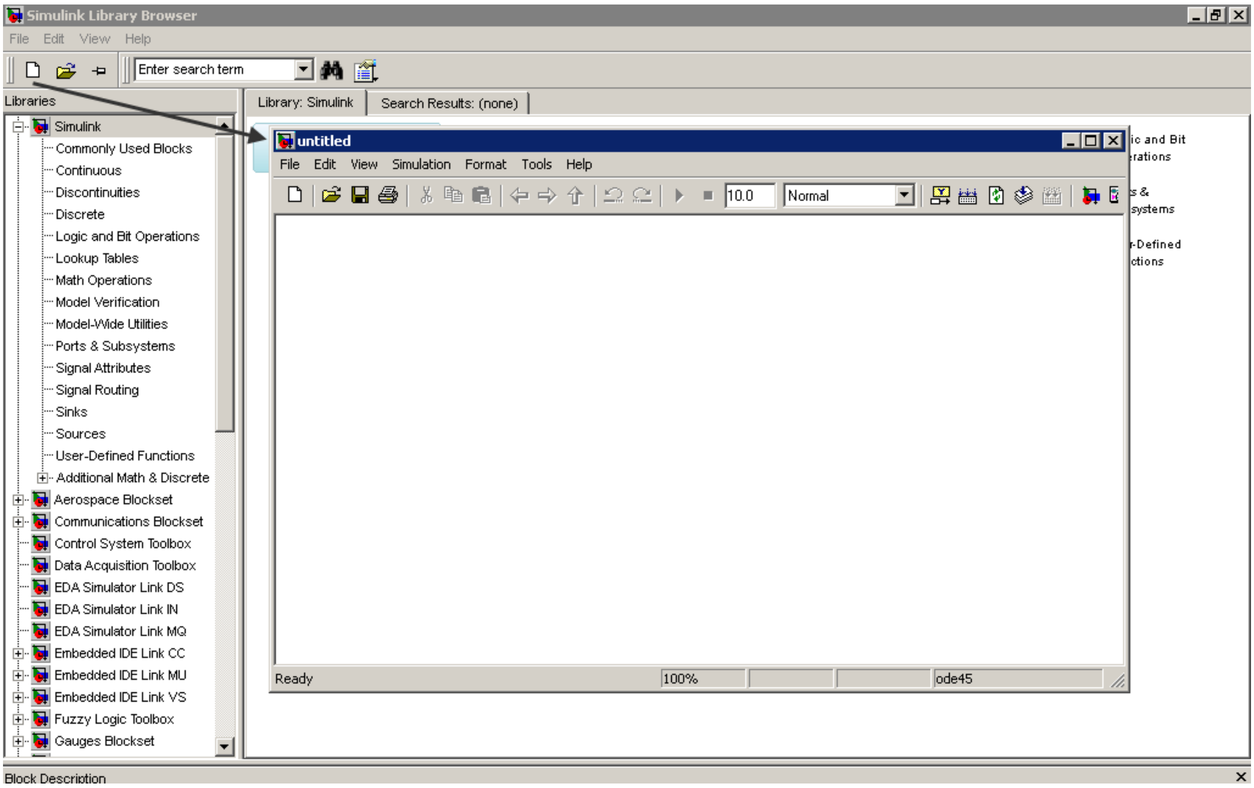
MATLAB is a data-manipulation software package that allows data to be analyzed and visualized using existing functions and user-designed programs. MATLAB is a numerical computing environment and programming language. MATLAB allows easy matrix manipulation, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs in other languages. Although it specializes in numerical computing, an optional toolbox interfaces with the Maple symbolic engine, allowing it to be part of a full computer algebra system.

Some of the mat lab applications listed are:

- Orthogonal frequency division multiplexing
- Genetic algorithm data mining
- Speech recognition using VQ method
- Channel Estimation and Detection in DS-CDMA
- Analysis of iterative channel estimation and multi-user detection in multi path DS-CDMA channels
- Time-domain signal detection
- Time-domain signal detection based on second-order statistics for mimo-OFDM systems
- Space–time block coding
- Space–time block codes for mimo channels
- Blind channel estimation

5.4 Basic circuit designing and analyzing of results:

Click on the file and select new model file and a file will be appeared:



Now a block and right click on it, the block will be appearing in the new model file (untitled)

For example, consider a sine wave in the source block and in order to obtain or to view the output place the scope block. Join those two blocks. Now a simple circuit is ready, now set the simulation time in the tool bar (default it is set to 10.0), simulate the circuit by clicking on the simulation icon (PLAY BUTTON). Simulation is completed now by double clicking on the scope u can view the output, press the auto scale button and o/p will appear clearly.

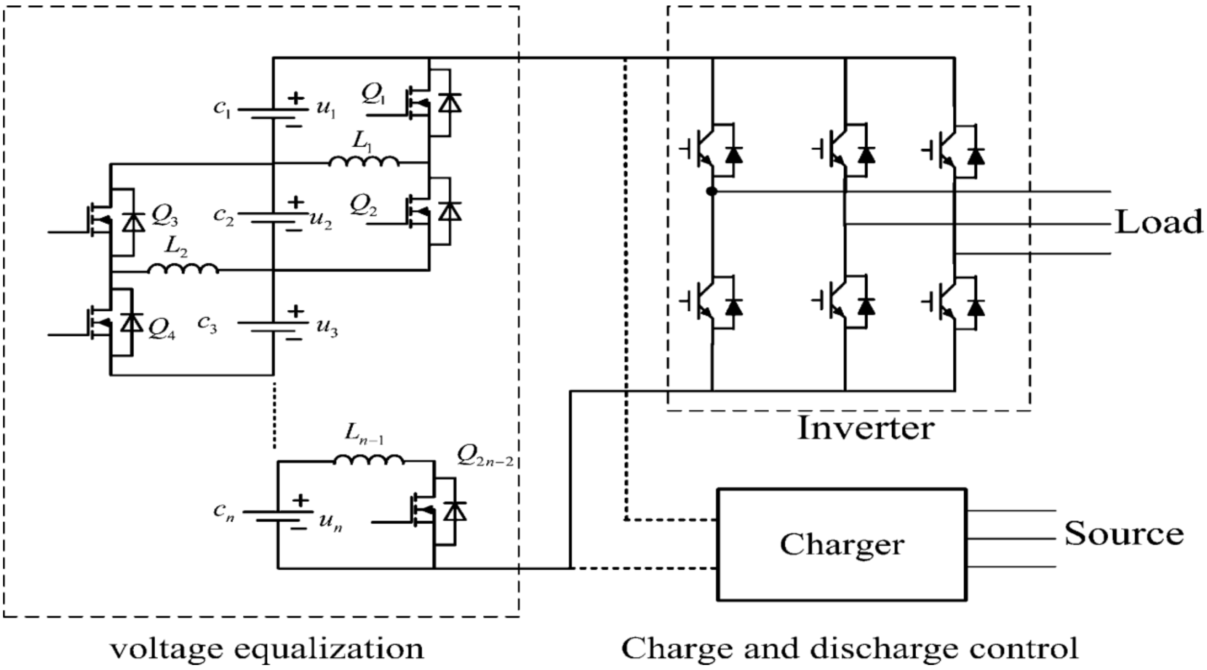
CHAPTER -6
MODELLING & SIMULATION OF MULTILEVEL CONVERTER

CHAPTER -6
MODELLING & SIMULATION OF MULTILEVEL CONVERTER

6.1 Topology of the Hybrid Cascaded Multilevel Converter:

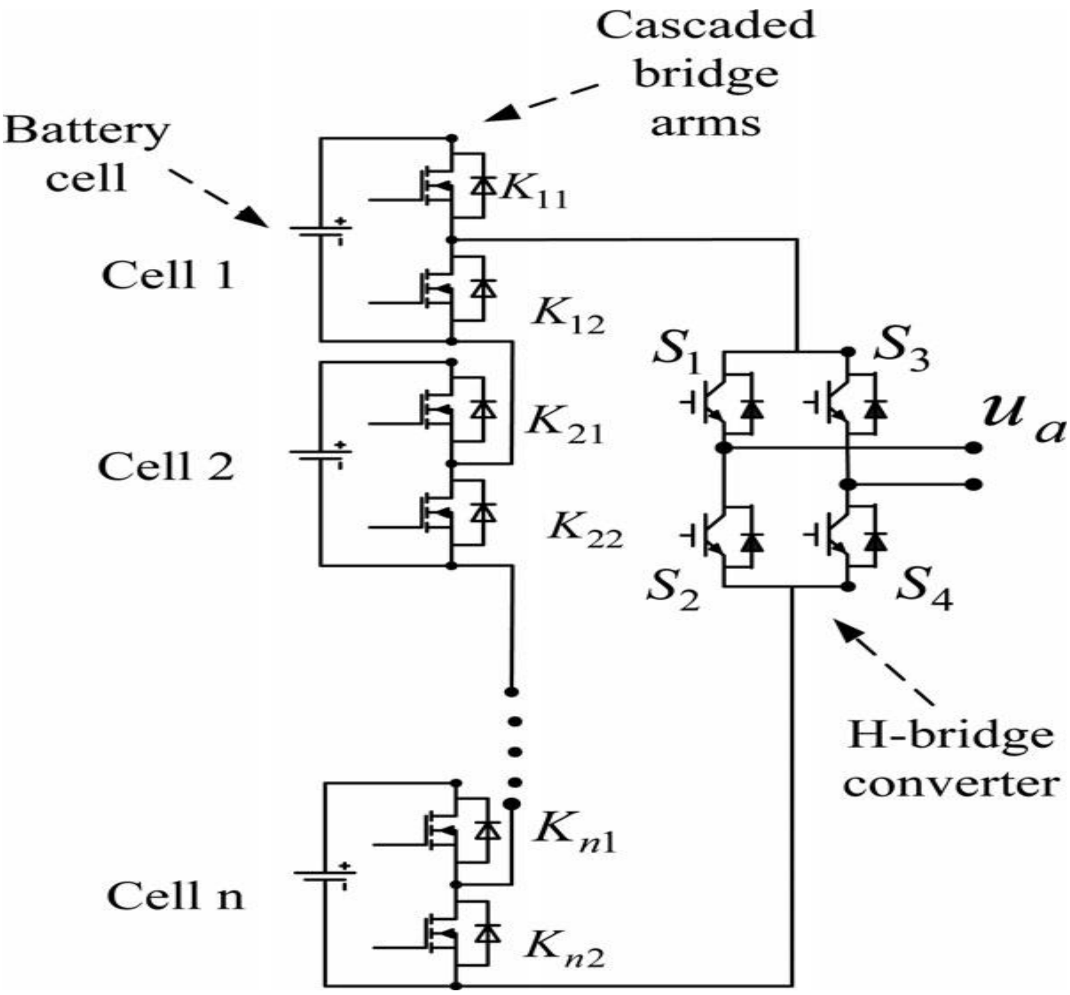
One of the popular voltage balance circuits by energy transfer is shown in Fig 6.1.1. There is a half-bridge arm and an inductance between every two nearby battery Cells. So, the number of switching devices in the balance circuit is 2 and the number of inductances is (n–1) where is the number of the battery cells.

In this circuit, an additional inverter is needed for the motor drive and a charger is usually needed for the battery recharge. In fact, if the output of the inverter is connected with the three-phase ac source by some filter inductances, the battery recharge can also be realized by an additional control block which is similar with the PWM rectifier. The recharging current and voltage can be adjusted by the closed-loop voltage or power control of the rectifier.



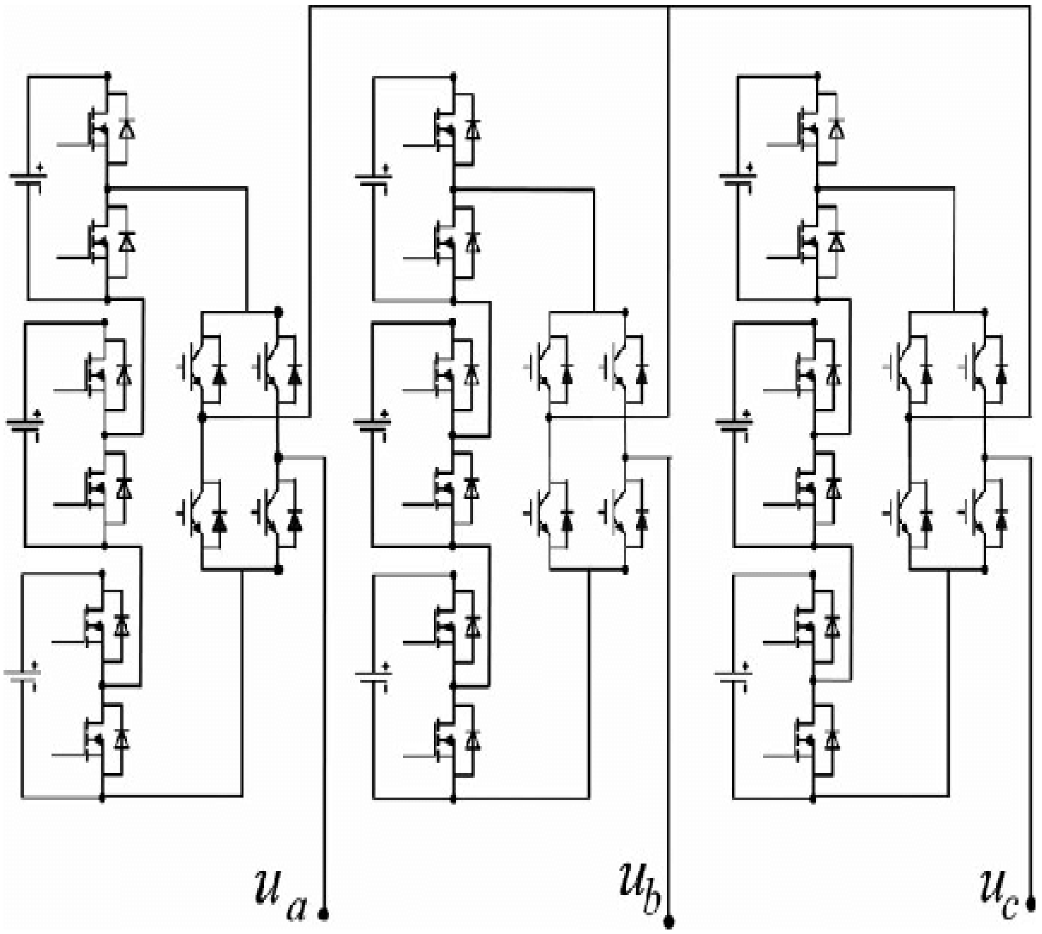
6.1.1 Traditional power storage system with voltage equalization circuit and inverter

The hybrid-cascaded multilevel converter proposed in this paper is shown in below Figure, which includes two parts, the cascaded half-bridges with battery cells shown on the left and the H-bridge inverters shown on the right. The output of the cascaded half-bridges is the dc bus which is also connected to the dc input of the H-bridge. Each half-bridge can make the battery cell to be involved into the voltage producing or to be bypassed. Therefore, by control of the cascaded half-bridges, the number of battery cells connected in the circuit will be changed, that leads to a variable voltage to be produced at the dc bus. The H-bridge is just used to alternate the direction of the dc voltage to produce ac waveforms. Hence, the switching frequency of devices in the H-bridge equals to the base frequency of the desired ac voltage.



6.1.2 HYBRID CASCADED MULTILEVEL CONVERTER

There are two kinds of power electronics devices in the proposed circuit. One is the low voltage devices used in the cascaded half-bridges which work in higher switching frequency to reduce harmonics, such as MOSFETs with low on-resistance. The other is the higher voltage devices used in the H-bridges which worked just in base frequency. So, the high voltage large capacity devices such as GTO or IGBT can be used in the H-bridges.



6.1.3 THREE PHASE HYBRID CASCADED MULTILEVEL CONVERTER

The three-phase converter topology is shown in Fig. 6.1.3. If the number of battery cells in each phase is *n*, then the devices used in one phase cascaded half-bridges is 2∗*n*. Compared to the traditional equalization circuit shown in Fig. 6.1.1, the number of devices is not increased significantly but the inductances are eliminated to enhance the system power density and EMI issues.

Since all the half-bridges can be controlled individually, a staircase shape half-sinusoidal-wave voltage can be produced on the dc bus and then a multilevel ac voltage can be formed at the output side of the H-bridge, the number of ac voltage levels is $2*n-1$ where n is the number of cascaded half-bridges in each phase. On the other hand, the more of the cascaded cells, the more voltage levels at the output side, and the output voltage is closer to the ideal sinusoidal. The dv/dt and the harmonics are very little. So, it is a suitable topology for the energy storage system in electric vehicles and power grid.

6.2 CONTROL METHOD OF THE CONVERTER:

For the cascade half-bridge converter, define the switching state as follows:

$Sx = 1$ upper switch is conducted, lower switch is OFF

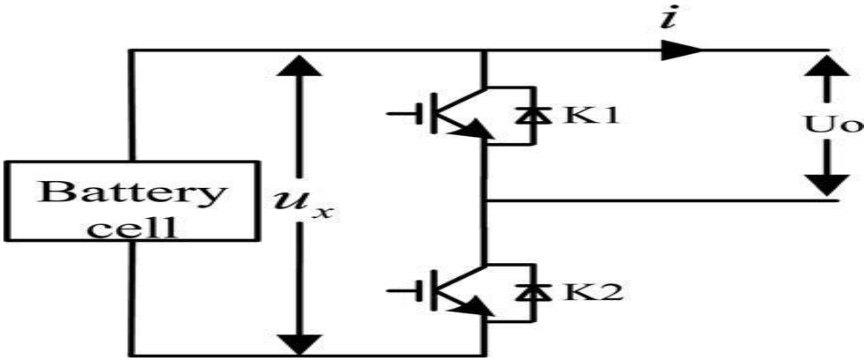
$Sx = 0$ lower switch is conducted; upper switch is OFF.

The modulation ratio mx of each half bridge is defined as the average value of the switching state in a PWM period. In the relative half-bridge converter shown in Fig. 6.2.1, when $Sx = 1$, the battery is connected in the circuit and is discharged or charged which is determined by the direction of the external current. When $Sx = 0$, the battery cell is bypassed from the circuit, the battery is neither discharged nor charged. When $0 < mx < 1$, the half-bridge works in a switching state. The instantaneous discharging power from this cell is

$$P = Sx \cdot Ux \cdot i.$$

Here Ux is the battery cell voltage and i is the charging current on the dc bus. In the proposed converter, the H-bridge is just used to alternate the direction of the dc bus voltage, so the reference voltage of the dc bus is the absolute value of the ac reference voltage, just like a half-sinusoidal-wave at a steady state. It means that not all the battery cells are needed to supply the load at the same time. As the output current is the same for all cells connected in the circuit, the charged or discharged energy of each cell is determined by the period of this cell connected into the circuit, which can be used for the voltage or energy equalization. The cell with higher voltage or SOC can be discharged more or to be charged less in using, then the energy utilization ratio can be improved while the overcharge and over discharged can be avoided.

For the cascaded multilevel converters, generally there are two kinds modulation method: phase-shift PWM and carrier cascaded PWM. As the terminal voltage or SOC balance control must be realized by the PWM, so the carrier-cascaded PWM is suitable as the modulation ratio difference between different cells can be used for the balance control.



6.2.1 Output voltage and current of the battery cell

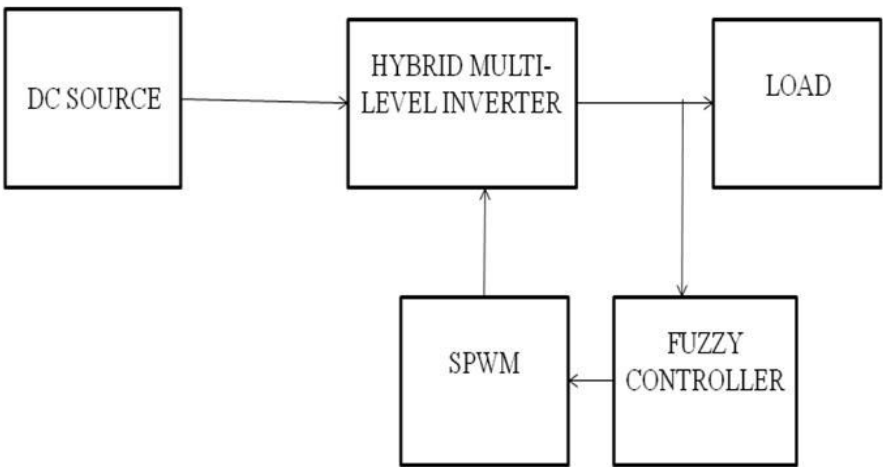
In the carrier-cascaded PWM, only one half-bridge converter in each phase is allowed to work in switching state, the others keep their state unchangeable with *Sx* = 1 or *Sx* = 0, so the switching loss can be reduced. When the converter is used to feed a load, or supply power to the power grid, the battery with higher terminal voltage or SOC is preferentially used to form the dc bus voltage with *Sx* = 1. The battery with lower terminal voltage or SOC will be controlled in switch state with 0 < *mx* < 1 or be bypassed with *Sx* = 0. The control of the converter and voltage equalization can be realized by a modified carrier-cascaded PWM method as shown in Fig. 6.2.1. The position of the battery cells in the carrier wave is determined by their terminal voltages. In the discharging process, the batteries cells with higher voltage are placed at the bottom layer of the carrier wave while the cells with lower voltage at the top layer. Then, the cells at the top layer will be used less and less energy is consumed from these cells.

In the proposed PWM method, the carrier arranged by terminal voltage can realize the terminal voltage balance, while the carrier arranged by SOC can realize the SOC balance. Since the SOC is difficult to be estimated in the batteries in practice, the terminal voltage balance is usually used. Normally, the cut-off voltage during charge and discharge will not change despite the variation of manufacturing variability, cell architecture, and degradation with use. So, the overcharge and over discharge can also be eliminated even the terminal voltages are used instead of the SOC for the carrier-wave arrangement. To reduce the dv/dt and EMI, only one half-bridge is allowed to change its switching state at the same time for the continuous reference voltage.

6.3 CMLI USING HYBRID TOPOLOGY

Multilevel inverters are used to handle high power and high voltage in power system applications. The symmetric and asymmetric multilevel inverter with closed loop is used to control the output voltage. The diode clamped multilevel inverter is cascaded with the H-bridge forming a hybrid topology. In symmetric multilevel inverter the dc sources used is equal to V_{dc}. By using symmetric topology high modularity is achieved. In asymmetric multilevel inverter different dc sources are used. Asymmetric topology using a smaller number of switches to produce a high number of voltages.

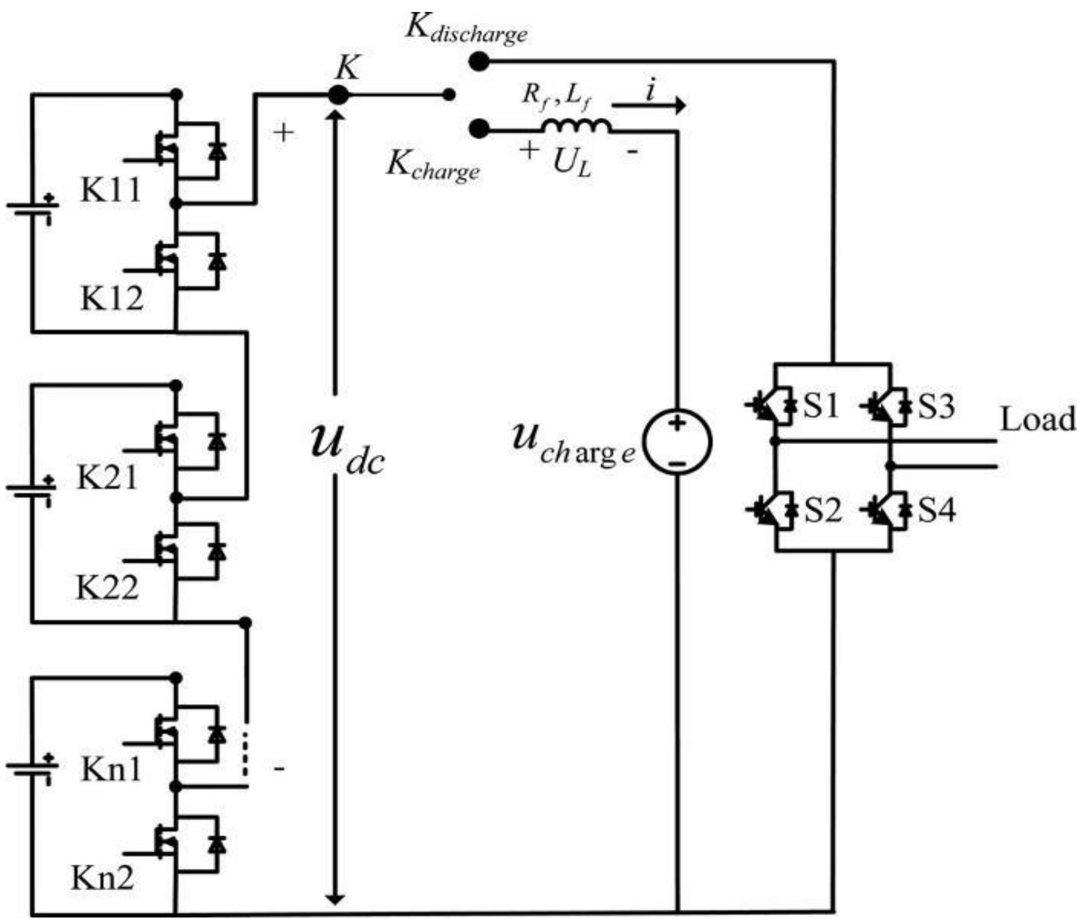
Both symmetric and asymmetric multilevel inverter topology consists of two parts, the level creator part and the H-bridge part. The level creator part produces the output voltage which is always positive, and the H-bridge is used at the output to change the polarity. By using PI controller in the feedback to maintain the output voltage constant.



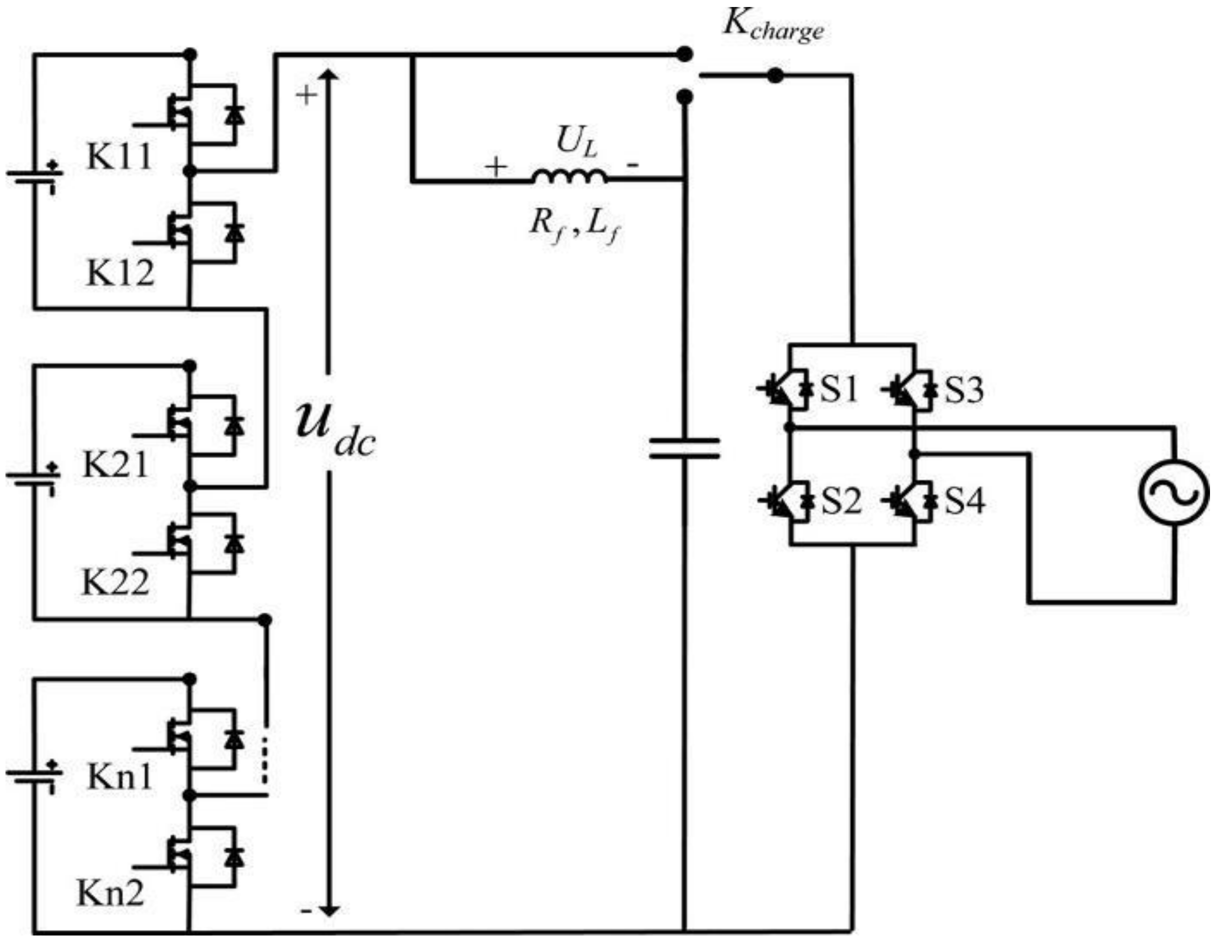
6.3.1. Block diagram of the system.

6.4 CHARGING METHOD

In the system using the proposed circuit in this paper, a dc voltage source is needed for the battery charging. The charging current and voltage can be controlled by the proposed converter itself according to the necessity of the battery cells. The charging circuit is shown in Fig. 6.4.1. A circuit breaker is used to switch the dc bus from the H-bridge to the dc voltage source. Furthermore, a filter inductor is connected in series with the dc source to realize the current control. The dc voltage can also be realized by the H-bridge and a capacitor as shown in Fig. 6.4.2. The H-bridge worked as a rectifier by the diodes and a steady dc voltage is produced with the help of the capacitors.



6.4.1 Charging circuit of battery with DC source



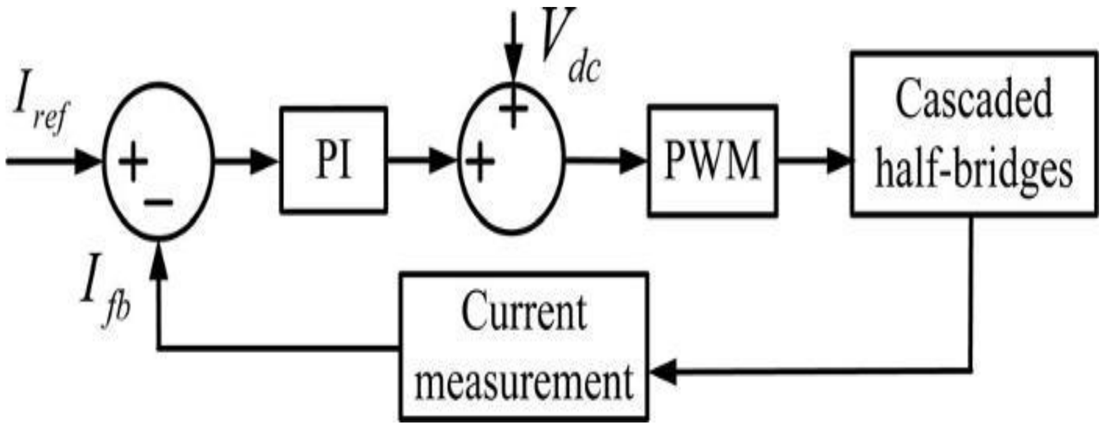
6.4.2 Charging circuit of battery with AC source

In the charging course of the battery, the charging current should be controlled. The current state equation is as follows;

$$R_f * i + L_f (di/dt) = U_{dc} - U_{charge}$$

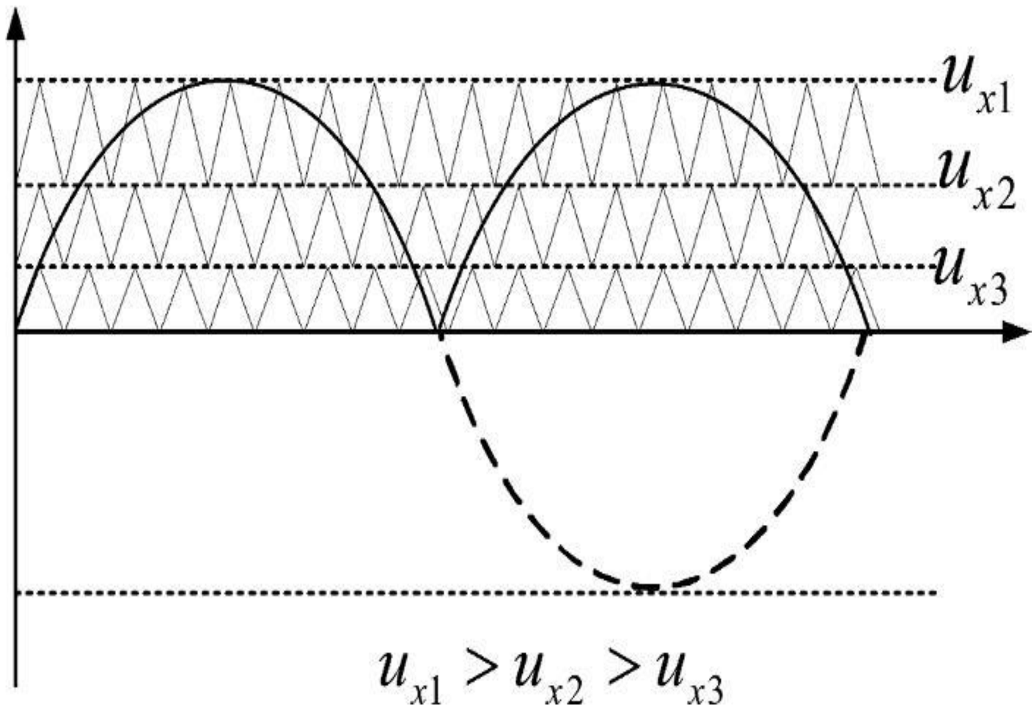
Here U_{dc} is the dc bus voltage output by the cascaded half-bridges, U_{charge} is the voltage of the dc source, and are the resistance and inductance of the inductive filter between the cascaded half- bridges and the dc source. By this charging method, the voltage of the dc source must be smaller than the possible maximum value of the dc bus.

$$U_{charge} <= U_{dc} <= n * U_0$$



6.4.3 Current control scheme for the battery charging

During the charging cycle, the voltages of the battery cells and the dc voltage source might be variable, so the switching states of the cascaded half-bridges will be switched to make the charging current constant. The charging current control scheme is shown in Fig. 6.2.1. A PI regulator is used to make the current constant by changing the output dc voltages of the cascaded cells. The voltage of the dc source is used as a feed-forward compensation at the output of the PI controller. In practical applications, the value of the dc source's voltage is almost constant, so the feed forward compensation can also be removed and the variation of the dc source voltage can be compensated by the feedback of the PI controller.



6.4.4 Carrier wave during charging

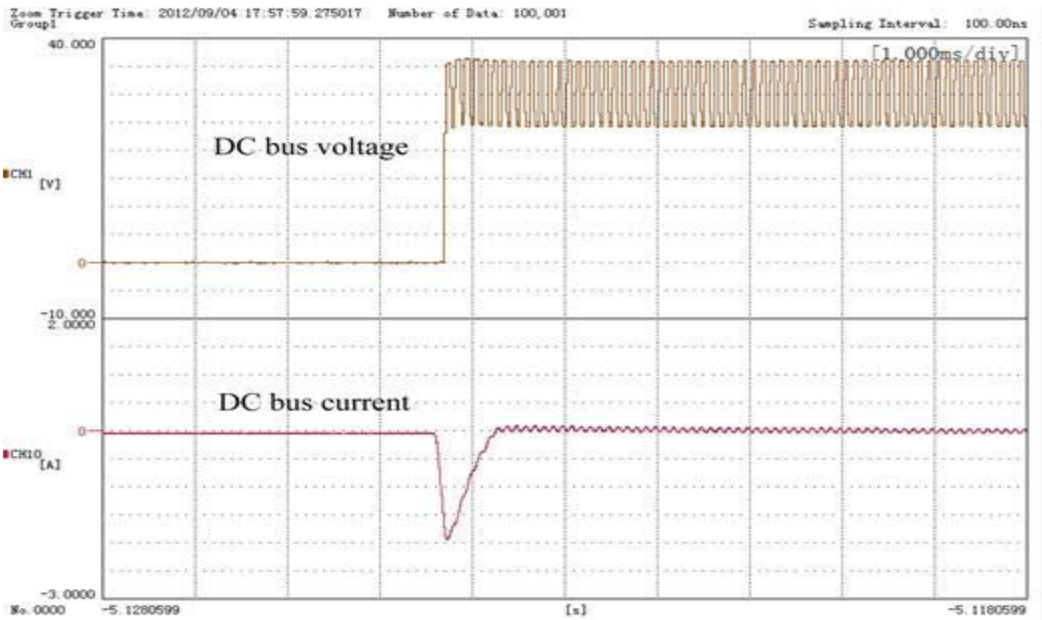
In charging state, the arrangement of the carrier waves will be opposite with discharge state. The battery cell with lower voltage will be placed in the bottom then these cells will absorb more energy from the dc source. The cells with higher voltages will be arranged at the top levels to make these cells absorb less energy.

The energy charged into the battery cell is same as (1)

$$\boldsymbol{P\mathrm{charge} = Ux * i = Sx \cdot Ux \cdot i}$$

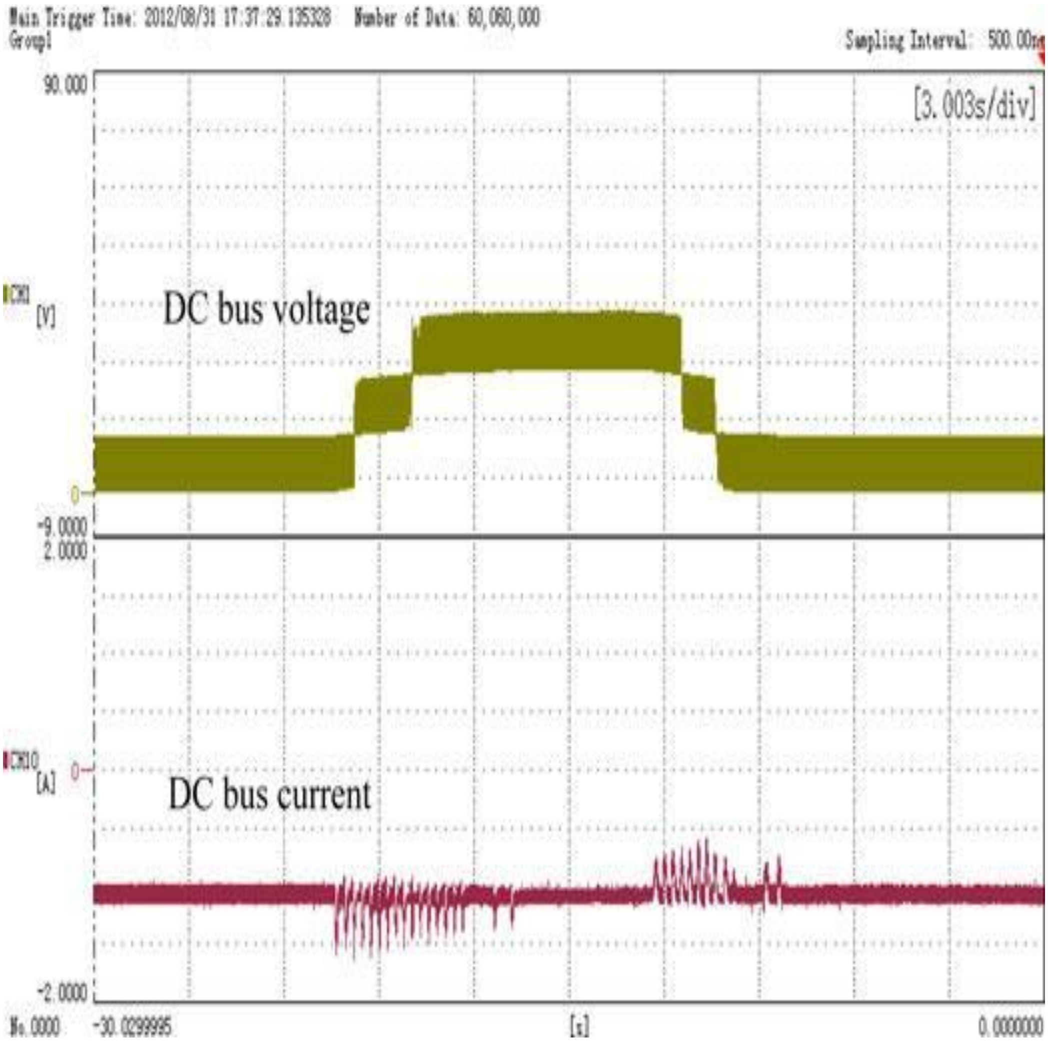
where Sx is the switching state of the bridge arms and i is the charging current controlled.

The dc bus voltage and charging current when connecting with dc source is shown in the fig 6.4.4 It shows when the dc source was connected, the cascaded half – bridges changed their switching state current same as ref value.



6.4.5 DC bus voltage and current when connecting with DC source

During battery charging if voltage of dc source is changed, the charging current control result is shown in fig 6.4.5



6.4.6 DC bus voltage and charging current during dc source voltage change.

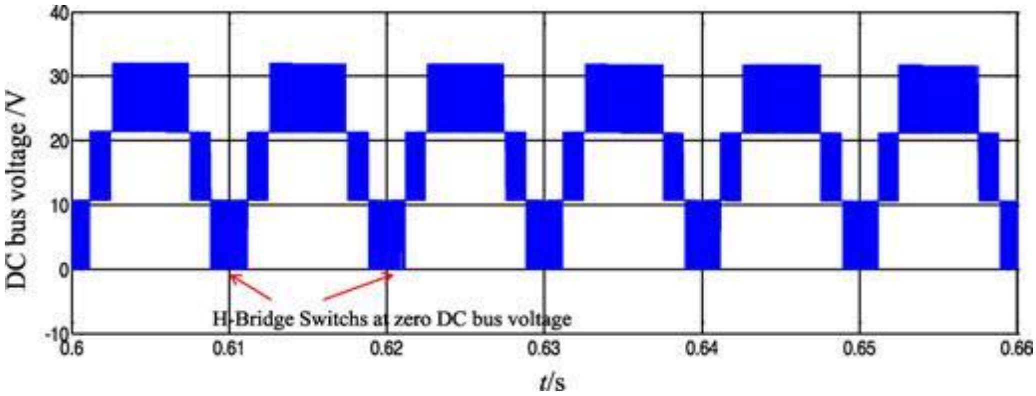
Therefore, it can be seen from figure 6.4.5 and 6.4.6 it is clear that the proposed topology can be charged under external input dc voltage and the feasibility of the proposed charging method for practical EV application is proved.

6.5 LOSS ANALYSIS AND COMPARISON:

Compared to the traditional circuit in Fig. 6.1.1, the circuit topology and voltage balance process is quite different. In the traditional circuit in Fig. 1, the three-phase two-level inverter is used for the discharging control and the energy transfer circuit is used for the voltage balance. In the proposed hybrid-cascaded circuit, the cascaded half-bridges are used for voltage balance control and also the discharging control associated with the H-bridge converters. The switching loss and the conduction losses in these two circuits are quite different. To do a clear comparison, the switching and conduction loss is analysed in this section. In the hybrid-cascaded converter, the energy loss is composed of several parts

$$J_{Loss} = J_{sB} + J_{sH} + J_{cB} + J_{cH}$$

Here, JsB and JsH are the switching losses of the cascaded half-bridges and the H-bridge converters, while JcH and JcB are the conduction losses..



6.5.1 DC bus voltage output by the cascaded-bridges

In the traditional circuit as shown in Fig.6.1.1, the energy loss is composed by

$$J_{Loss} = J_{sI} + J_{sT} + J_{cI} + J_{cT}$$

where J_{sI} and J_{sT} are the switching losses of the three-phase inverter and the energy transfer circuit for voltage balance. JcI and JcT are the conduction losses. In the traditional circuit, the energy transfer circuit only works when there is some imbalance and only the parts between the unbalance cells need to work. So the switching and conduction losses will be very small if the battery cells are symmetrical. First, the switching loss is analysed and compared under the requirement of same switching times in the output ac voltage. That means the equivalent switching frequency of the cascaded half-bridges in hybrid-cascaded converter is the same as the traditional inverter.

In the proposed hybrid-cascaded converter, the H-bridge converter is only used to alternate the direction of the output voltage to produce the desired ac voltage as shown in Fig.6.4.1, the device sin the H-bridge converter always switch when the dc bus voltage is zero. So the switching loss of the H-bridge is almost zero.

$$J_{sH} \approx 0$$

The equivalent switching frequency of the half-bridges is the same as the traditional converter, but only one half-bridge is active at the any instantaneous in each phase. The voltage step of each half-bridge is only the battery cell voltage which is much lower than the whole dc bus voltage in Fig.6.1.1 so in a single switching course, the switching loss is only approximate 1/n of the one in traditional converter if the same device is adopted in both converters. Furthermore, if the lower conduction voltage drop and faster turn-off device such as MOSFET is used in the proposed converter, the switching loss of the half-bridge will be much smaller.

$$J_{sB} < J_{sI}/n$$

In the traditional circuit, the voltage balance circuit will still cause some switching loss determined by the voltage imbalance. So in the proposed new topology, the switching loss is much smaller compared to the traditional two-level inverter.

		loss in a single switching course	Conduction loss power
Traditional circuit	Energy transfer circuit	determined by imbalance	determined by imbalance
	3-phase inverter legs	J_{s_I}	$P_{c\_I} = I^2 R_{c\_I}$
Proposed novel circuit	Cascaded half-bridges	Much less than J_{s_I}/n	$P_{c\_B} = I^2 R_{c\_B} \cdot n$
	H-bridges	Near zero	$P_{c\_H} = I^2 R_{c\_H} \cdot 2$

COMPARISON OF THE SWITCHING AND CONDUCTION LOSS OF THE PROPOSED CIRCUIT AND THE TRADITIONAL ONE

The conduction loss is determined by the on-resistance of the switching devices and the current value. Whatever the switching state, one switch device in each half-bridge and two devices in H-bridge are connected in the circuit of each phase, so the conduction loss power can be calculated by

$$P_{CB} = I^2 R_{CB} \cdot n$$
$$P_{CH} = I^2 R_{CH} \cdot 2$$

Here, I is the rms value of the output current, RcB is the on-resistance of the MOSFET in the half-bridge, RcH is the device on-resistance used in the H-bridge, and n is the number of the cascaded cells. In the traditional three-phase inverter, only one device is connected in the circuit of each phase, the conduction loss power in each phase is just

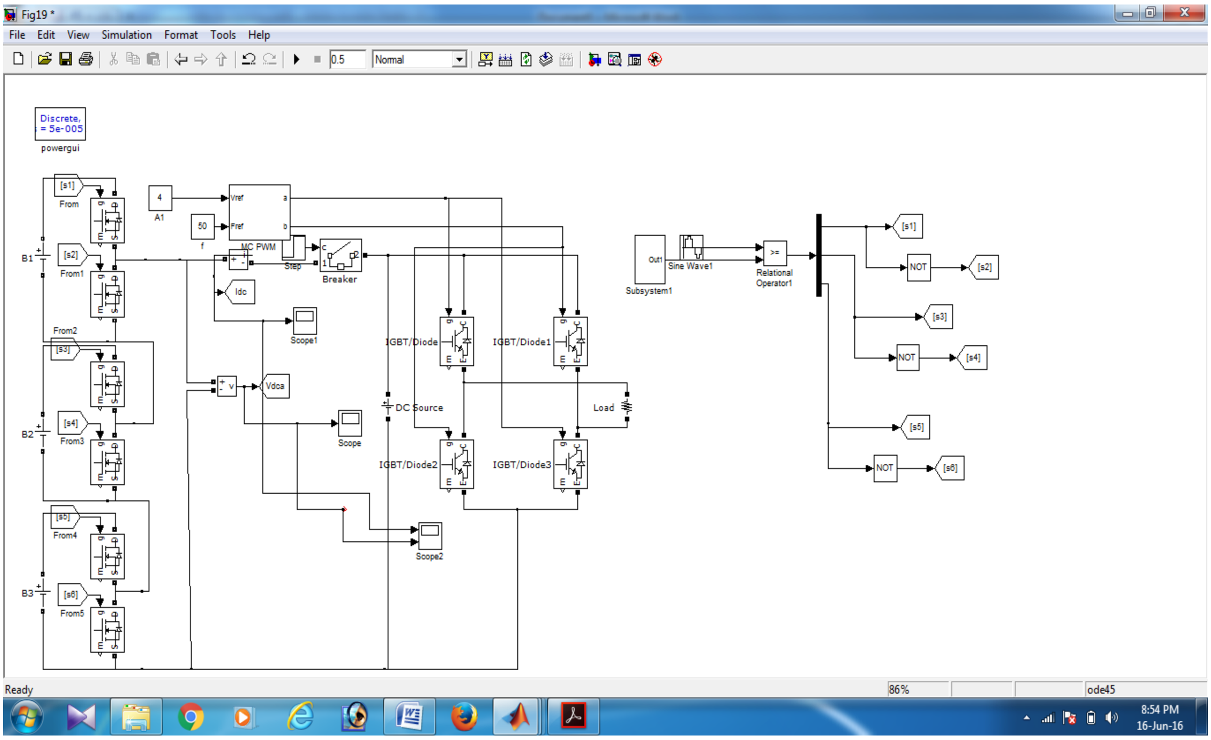
$$P_{CI} = I^2 R_{CI}$$

Where RcI is the on-resistance of the devices used in the inverter. Normally, the same semiconductor devices can be used in the H-bridges and the traditional three-phase inverters, so the on-resistance of the inverters is almost the same as the H-bridges. The on-loss of the H-bridges cannot be reduced, while the on-loss on cascaded half-bridges can be reduced further more by reducing the number of the cascaded cells. In practical applications, the battery module of 12 and 24 V can be used for the cascaded cells instead of the basic battery cell with only 2–3 V. Also the semiconductor devices with low on-resistance are used in the half-bridges.

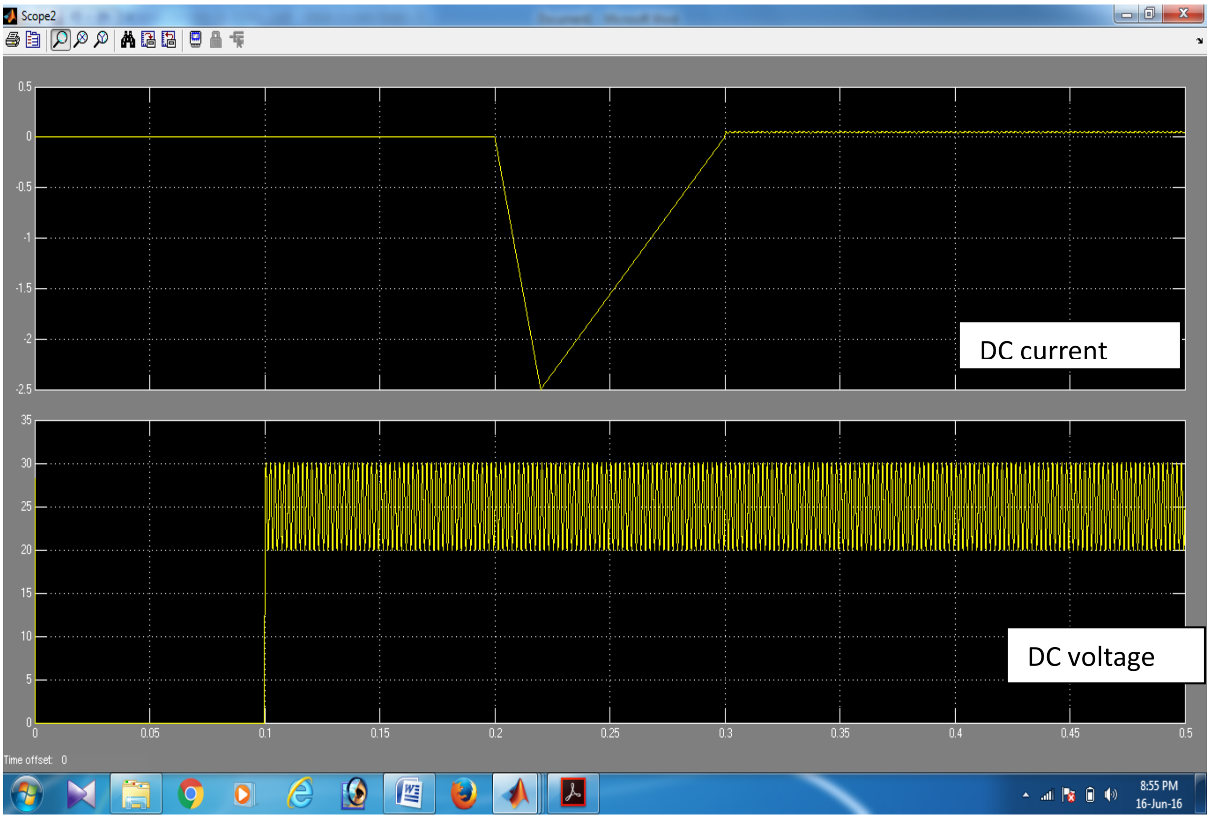
From the above analysis, the switching loss of the proposed converter is much less than the traditional converter, although the on-loss is larger than the traditional converter. The compared results are shown in the above table.

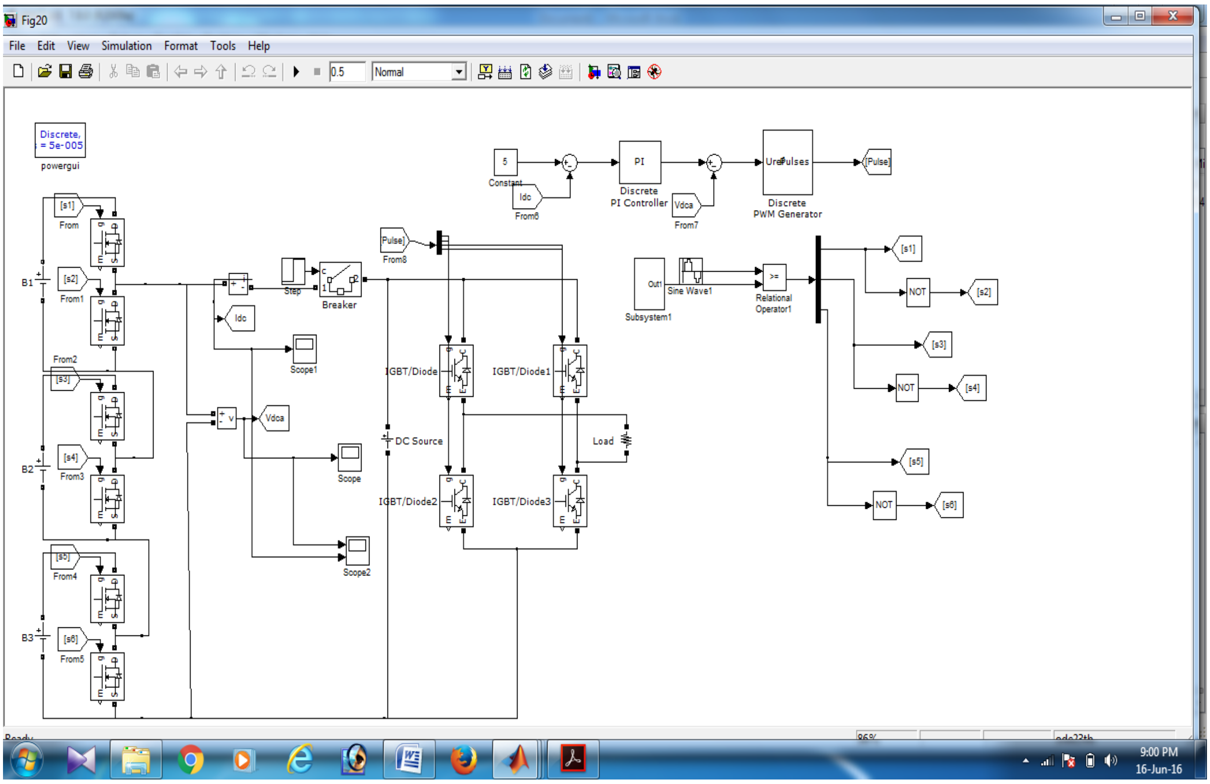
CHAPTER -7
SIMULATION RESULTS

CHAPTER -7
SIMULATION RESULTS

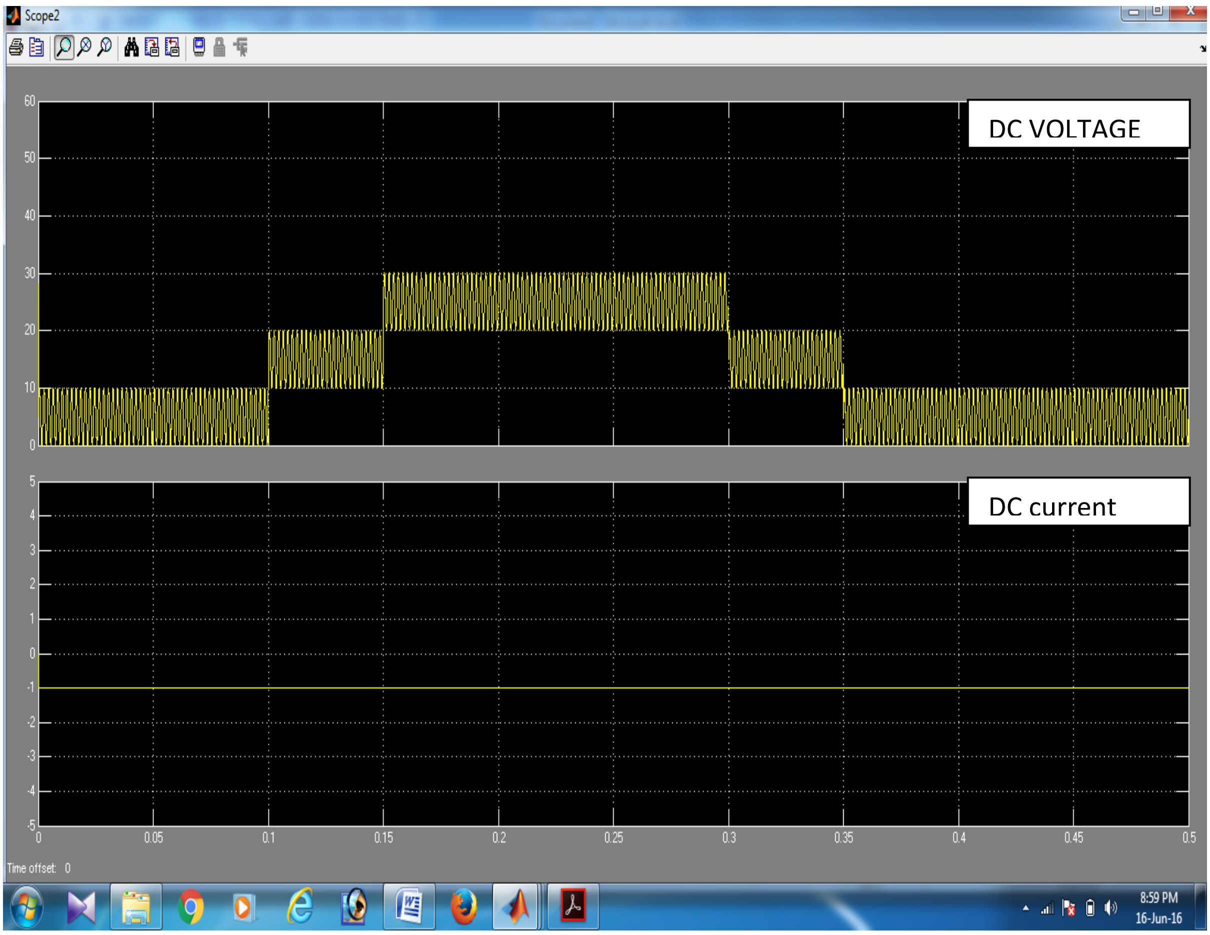


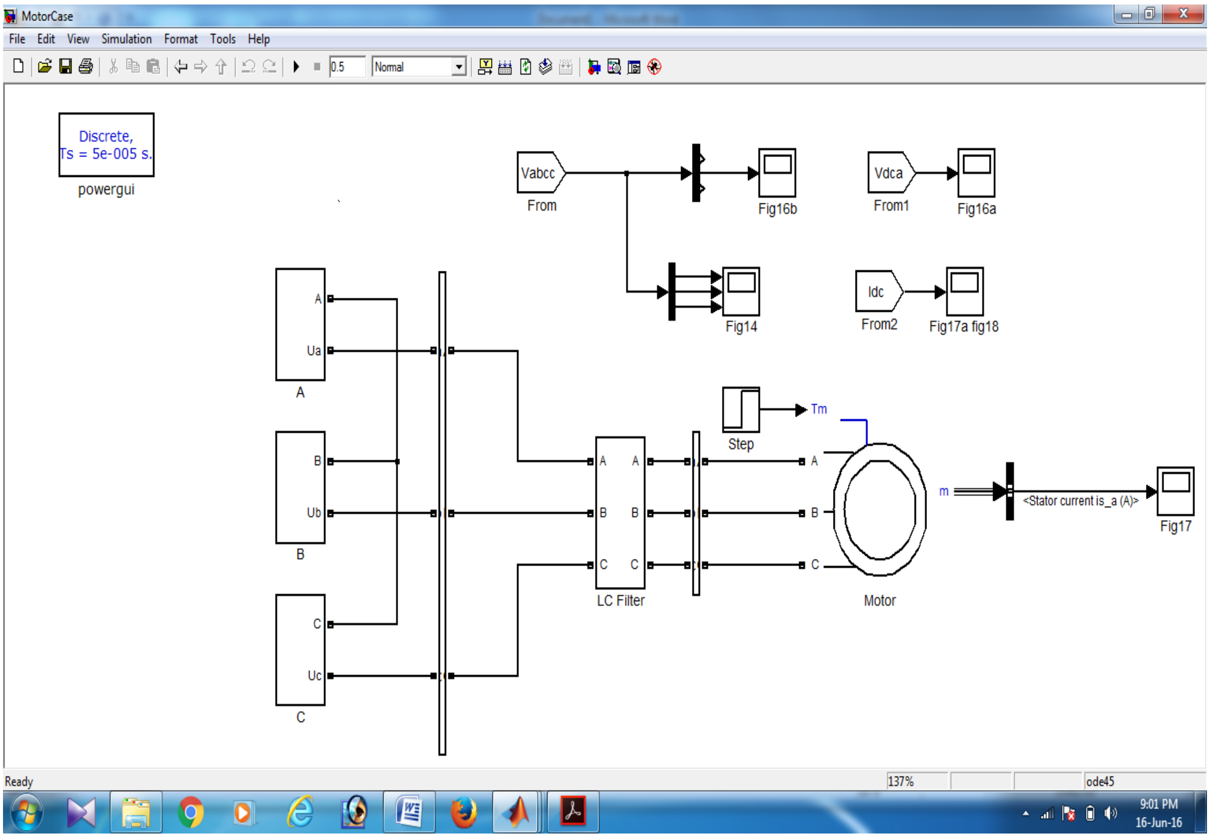
7.1 DC bus current and voltage when connecting with DC source.



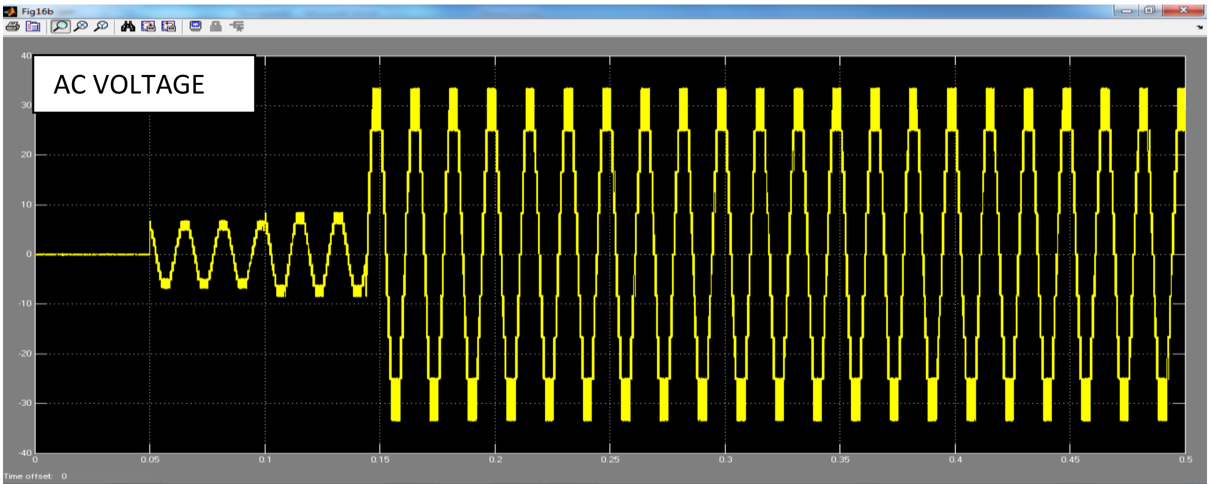


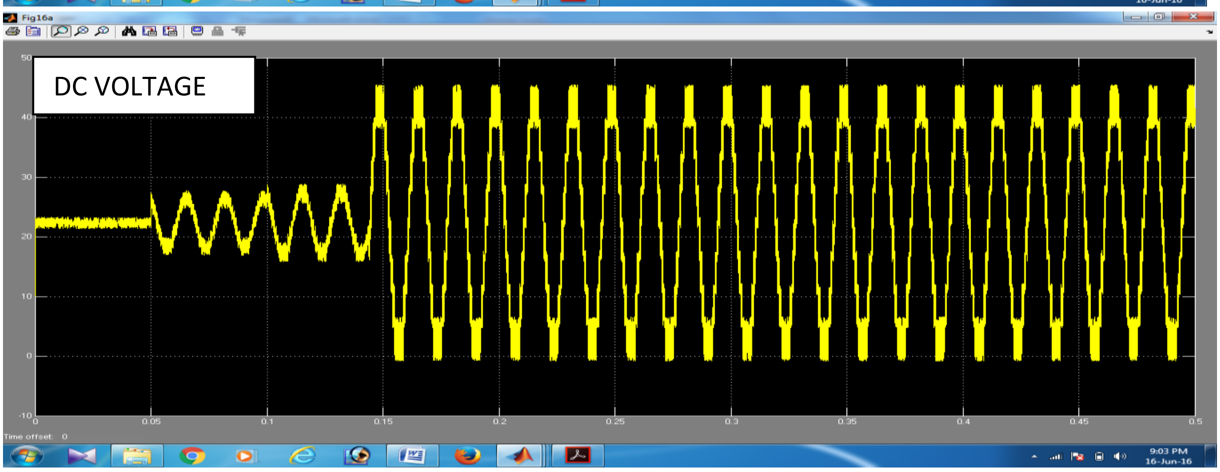
7.2 DC bus voltage and current during dc source voltage change

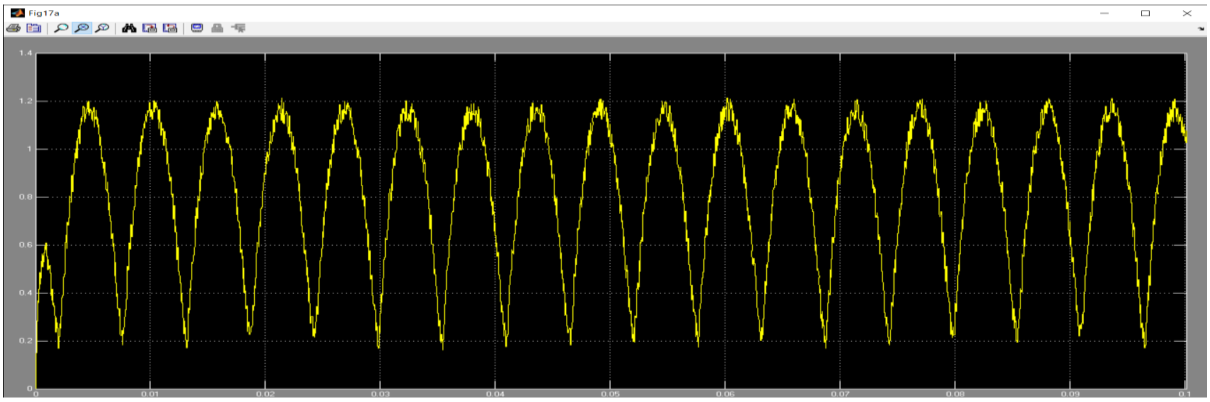




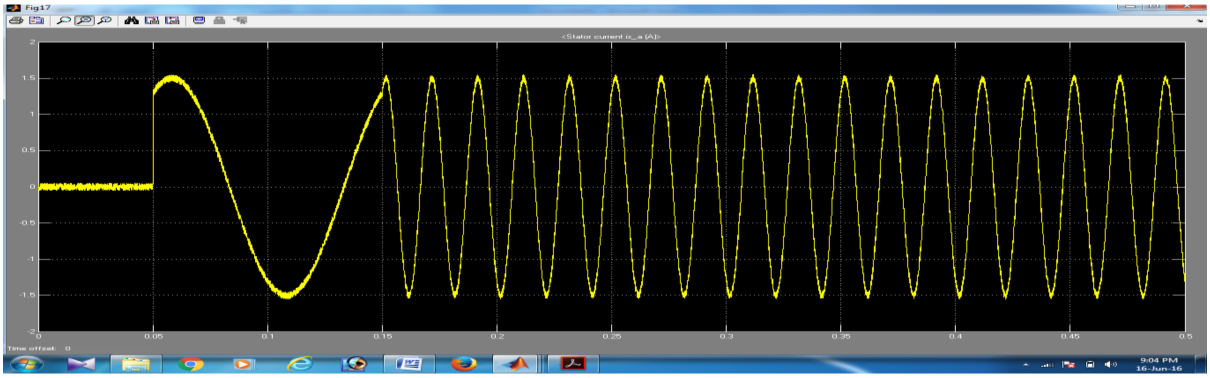
7.3 DC and AC voltage during motor acceleration



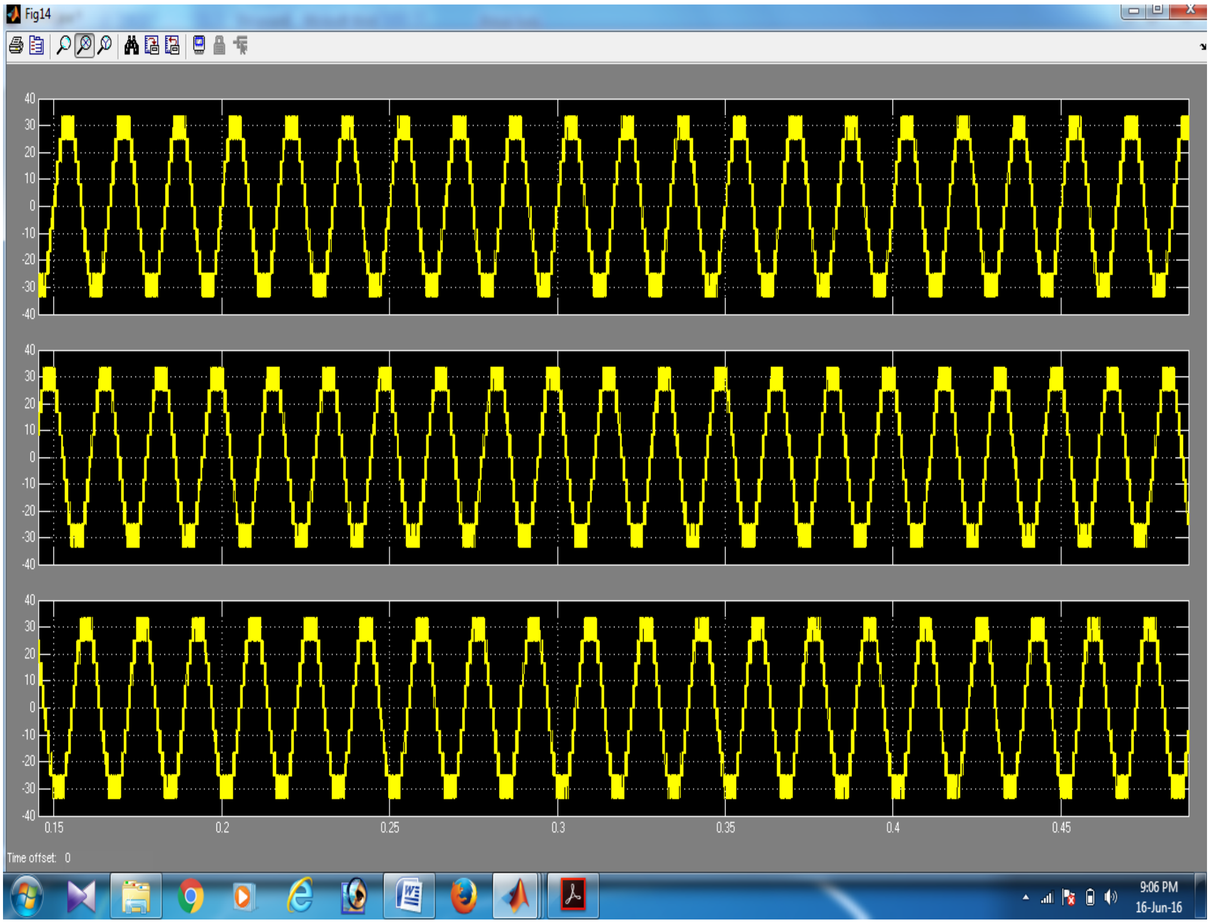




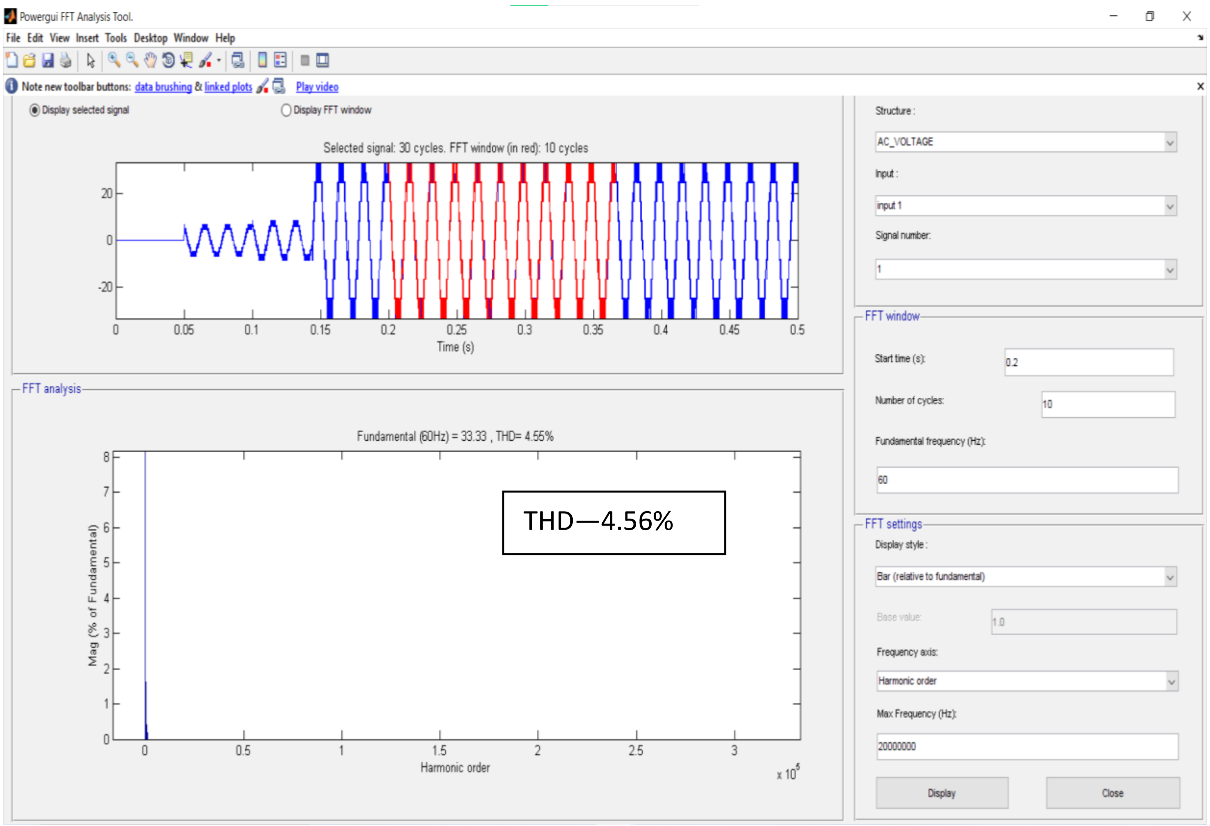
7.4 DC bus current during motor acceleration



7.4 AC current during motor acceleration



7.5 3-phase output voltage of multilevel



7.6 FFT analysis of the output AC voltage

CHAPTER -8
CONCLUSION & FUTURE SCOPE

CHAPTER -8
CONCLUSION & FUTURE SCOPE

8.1 CONCLUSION:

- The hybrid-cascaded multilevel converter proposed in this model have less losses compared to traditional circuit.

- The proposed converter with modular structure can reach any number of cascaded levels and is suitable for the energy storage system control with low-voltage battery cells or battery modules.

- The fault module can be by-passed without affecting the running of the other ones, so the converter has a good fault-tolerant character which can significantly improve the system reliability.

- The output of the circuit is multilevel ac voltages where the number of levels is proportional to the number of battery cells. So the output ac voltage is nearly the ideal sinusoidal wave which can improve the control performance of the motor control in EVs.

- A dc bus current control method for battery charging with external dc or ac source is also studied where the constant-current control can be realized and the additional charger is not needed anymore.

8.2 FUTURE SCOPE:

Although this work has covered most of the interesting issues and challenges of the battery energy management in E-Vehicles using Hybrid Cascaded Multilevel Converter, additional work has been left for future research. The proposed converter provides less THD value with less switching losses compared to the traditional circuit. So, there is a great chance of implementing the converter in E-Vehicle in future. The proposed converter can be used in speed control of AC drives, industrial applications, and electric vehicles where smooth operation of motor is important.

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