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MODIFIED MULTI LEVEL INVERTER (9LEVEL)

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Abstract: In this project, a modified multilevel DC-AC inverter is proposed. The proposed multilevel inverter generates nine levels AC output voltage with the appropriate gate signals design. Also, the low pass filter is used to reduce the total harmonic distortion of the sinusoidal output voltage. The operating principles of the proposed inverter and the voltage balancing method of input capacitors are discussed. Finally, a laboratory prototype multilevel inverter with 400 V input voltage and output 220 Vrms is implemented. The multilevel inverter is controlled with sinusoidal pulse-width modulation by PIC16F877 microcontroller. Firstly, we describe briefly the structural parts of the inverter then switching strategy and operational principles of the proposed inverter are explained and operational topologies are given The proposed topology reduces the number of switches, losses, installation area and converter cost. Finally, the simulation results are provided to validate the proposed theory. Experimental results show that the maximum efficiency is 96.9% and the full load efficiency is 94.6%. The proposed system was verified through simulation and implement in prototype.

I. INTRODUCTION

Inverter is the inter medium which transmit power to other electrical equipment such as uninterruptible power supply, servo motor, air-conditioning system, and smart compose of renewable energy. Most industrial processes need to increase efficiency and reduce production costs. This is achieved by increasing the size of installations and increasing the power of all electrical machines and equipment. This increase in power is reached in two ways: 1) by developing high-voltage semiconductors with voltage blocking capabilities of 3300, 4500, and 6500 V and 2) by developing a multilevel inverter. Now, it is possible to directly connect the power converter to the medium-voltage (MV)

The main concept of this inverter is to use diodes and provides the multiple voltage levels through the different phases to the capacitor banks which are in series. A diode transfers a limited amount of voltage, thereby reducing the stress on other electrical devices. The maximum output voltage is half of the input DC voltage. It is the main drawback of the diode clamped multilevel inverter. This problem can be solved by increasing the switches, diodes, capacitors. Due to the capacitor balancing issues, these are limited to the three levels. This type of inverters provides the high efficiency because the fundamental frequency used for all the switching devices and it is a simple method of the back to back power transfer systems.The purpose of multilevel topology is to reduce voltage rating of power switch. Therefore, it usually use at high power application. By combining output voltages in multilevel form, it has advantages of low dv/dt, low input current distortion, and lower switching frequency.The need of multilevel converter is to give a high output power from medium voltage source. Sources like batteries, super capacitors, solar panel are medium voltage sources. The multi-level inverter consists of several switches. In the multi-level inverter the arrangement switches' angles are very important.

II. BLOCK DIAGRAM OF MODIFIED MULTILEVEL

DC-AC INVERTER

The block diagram of the modified multi-level inverter is shown in figure below.it consist of rectifier, diode clamped multi-level inverter , control strategies and load.

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A. BLOCKDIAGRAM

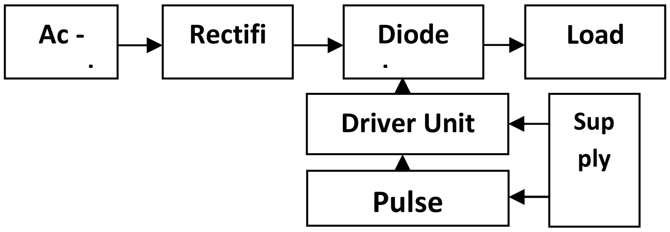

Fig 3.1. Block diagram of nine level multi-level inverter

The above figure 3.1 shows block diagram of 9 level modified multilevel inverter. Various blocks like rectifier, diode clamped multi-levelinverter, driver unit, pulse generating unit and load

B. RECTIFIER CIRCUIT

A rectifier is an electrical device that converts alternating current (AC), which periodically reverses direction, to direct current (DC), which flows in only one direction. The process is known as rectification. Physically, rectifiers take a number of forms, including vacuum tube diodes, mercury-arc valves, copper and selenium oxide rectifiers, semiconductor diodes, silicon-controlled rectifiers and other silicon-based semiconductor switches. Historically, even synchronous electromechanical switches and motors have been used. Early radio receivers, called crystal radios, used a "cat's whisker" of fine wire pressing on a crystal of galena (lead sulfide) to serve as a point-contact rectifier or "crystal detector". [4] discussed about E-plane and H-plane patterns which forms the basis of Microwave Engineering principles.

Because of the alternating nature of the input AC sine wave, the process of rectification alone produces a DC current that, though unidirectional, consists of pulses of current. Many applications of rectifiers, such as power supplies for radio, television and computer equipment, require a steady constant DC current (as would be produced by a battery). In these applications the output of the rectifier is smoothed by an electronic filter (usually a capacitor) to produce a steady current.

C.INVERTER TECHNIQUE

Semiconductor Devices:

Theelectronicsemiconductor device act as a switching device in the power electronic converters. In general, the characteristics of the device are utilized in such a way that it acts as a short circuit when closed. In addition to, an ideal switch also consumes less power to switch from one state to other.

Semiconductor is defined as the material whose conductivity depends on the energy (light, heat, etc.,) falling on it. They don't conduct at absolute zero temperature. But, as the temperature increases, the current conducted by the semi conductor increases as it gets energy in the form of heat. The increase in current is proportional to the temperature rise. Semiconductor switches are diodes, SCR, MOSFET, IGBT, BJT, TRIAC etc.,

The Insulated-Gate Bipolar Transistor or 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

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as a switch, in a single device. The IGBT is used in medium- to high-power applications such as switched-mode power supply, 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.

The IGBT is a fairly recent invention. The first-generation devices of the 1980s and early 1990s were relatively slow in switching, and prone to failure through such modes as latchup and secondary breakdown. Second-generation devices were much improved, and the current third-generation ones are even better, with speed rivaling MOSFETs, and excellent ruggedness and tolerance of overloads.

The extremely high pulse ratings of second- and third-generation devices also make them useful for generating large power pulses in areas like particle and plasma physics, where they are starting to supersede older devices like thyratrons and triggered spark gaps.

Their high pulse ratings, and low prices on the surplus market, also make them attractive to the high-voltage hobbyist for generating large amounts of high-frequency power to drive experiments like coils. Availability of affordable, reliable IGBTs is a key enabler for electric vehicles and hybrid cars. Toyota's second generation hybrid Prius has a 50 kW IGBT inverter controlling two AC motor/generators connected to the DC battery pack.

D. Device Structure

An IGBT cell is constructed similarly to a n-channel vertical construction power MOSFET except the n+ drain is replaced with a p+ collector layer, thus forming a vertical PNP bipolar junction transistor.

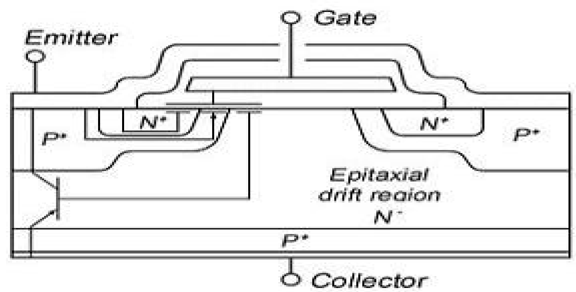

Fig 3.2 MOSFET Structure

Cross section of a typical IGBT showing internal connection of MOSFET and Bipolar DeviceThis additional p+ region creates a cascade connection of a PNP bipolar junction transistor with the surface n-channel MOSFET. This connection results in a significantly lower forward voltage drop compared to a conventional MOSFET in higher blocking voltage rated devices. As the blocking voltage rating of both MOSFET and IGBT devices increases, the depth of the n- drift region must increase and the doping must decrease, resulting in roughly square relationship increase in forward conduction loss compared to blocking voltage capability of the device. By injecting minority carriers (holes) from the collector p+ region into the n- drift region during forward conduction, the resistance of the n- drift region is considerably reduced. However, this resultant reduction in on-state forward voltage comes with several penalties:

The additional PN junction blocks reverse current flow. This means that IGBTs cannot conduct in the reverse direction, unlike a MOSFET. In bridge circuits where reverse current flow is needed an additional diode (called a freewheeling diode) is placed in parallel with the IGBT to conduct current in the opposite direction. The penalty isn't as severe as first assumed though, because at the higher voltages where IGBT usage dominates, discrete diodes are of significantly higher performance as the body diode of a MOSFET. The reverse bias rating of the N- drift region to collector P+ diode is usually only of 10's of volts, so if the circuit application applies a reverse voltage to the IGBT, an additional series diode must be used. The minority carriers injected into the n- drift region take time to enter and exit or recombine at turn on and turn off. This result in longer switching time and hence higher switching loss compared to a power MOSFET.

The additional PN junction adds a diode-like voltage drop to the device. At lower blocking voltage ratings, this additional drop means that an IGBT would have a higher on-state voltage drop. As the voltage rating of the device increases, the advantage of the reduced N-drift region resistance overcomes the penalty of this diode drop and the overall on-state voltage drop is lower (the crossover is around 400 V blocking rating). Thus IGBTs are rarely used where the blocking voltage requirement is below 600 V

E. GATE DRIVER CIRCUIT

In contrast to bipolar transistors, MOSFETs do not require constant power input, as long as they are not being switched on or off. The isolated gate-electrode of the MOSFET forms a capacitor (gate capacitor), which must be charged or discharged each time the MOSFET is switched on or off. As a transistor requires a particular gate voltage in order to switch on, the gate capacitor must be charged to at least the required gate voltage for the transistor to be switched on. Similarly, to switch the transistor off, this charge must be dissipated, i.e. the gate capacitor must be discharged.

When a transistor is switched on or off, it does not immediately switch from a non-conducting to a conducting state; and may transiently support both a high voltage and conduct a high current. Consequently, when gate current is applied to a transistor to cause it to switch, a certain amount of heat is generated which can, in some cases, be enough to destroy the transistor. Therefore, it is necessary to keep the switching time as short as possible, so as to minimize switching loss. Typical switching times are in the range of microseconds. The switching time of a transistor is inversely proportional to the amount of current used to charge the gate. Therefore, switching currents are often required in the range of several hundred mill amperes, or even in the range of amperes. For typical gate voltages of approximately 10-15V, several watts of power may be required to drive the switch. When large currents are switched at high frequencies, e.g. in DC-to-DC converters or large electric motors, multiple transistors are sometimes provided in parallel, so as to provide sufficiently high switching currents and switching power.

The switching signal for a transistor is usually generated by a logic circuit or a microcontroller, which provides an output signal that typically is limited to a few mille amperes of current. Consequently, a transistor which is directly driven by such a signal would switch very slowly, with correspondingly high power loss. During switching, the gate capacitor of the transistor may draw current so quickly that it causes a current overdraw in the logic circuit or microcontroller, causing overheating which leads to permanent damage or even complete destruction of the chip. To prevent this from happening, a gate driver is provided between the microcontroller output signal and the power transistor.

F. PULSE GENERATING UNITS

Pulse generators may use digital techniques, analog techniques, or a combination of both techniques to

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form the output pulses. For example, the pulse repetition rate and duration may be digitally controlled but the pulse amplitude and rise and fall times may be determined by analog circuitry in the output stage of the pulse generator. With correct adjustment, pulse generators can also produce a 50% duty cycle square wave. Pulse generators are generally single-channel providing one frequency, delay, width and output. Energy stored in a capacitor bank of the pulse generator is switched to the load through a pair of insulated gate bipolar transistors (IGBT). The circuit can then recover the remaining energy and transfer it back to the capacitor bank without reversing the capacitor voltage. A third IGBT device is employed to control the initial charge to the capacitor bank, a command charging technique, and to compensate for pulse to pulse power losses. The rack mounted pulse generator contains a 525 μF capacitor bank. It can deliver 500 A at 900V into inductive loads up to 3 mH. The current amplitude and discharge time are controlled to 0.02% accuracy by a precision controller through the SLAC central computer system. This pulse generator drives a series pair of extraction dipoles.

The PWM switching frequency has to be much higher than what would affect the load (the device that uses the power), which is to say that the resultant waveform perceived by the load must be as smooth as possible. The rate (or frequency) at which the power supply must switch can vary greatly depending on load and application, for example Switching has to be done several times a minute in an electric stove; 120 Hz in a lamp dimmer; between a few kilohertz (kHz), to tens of kHz for a motor drive; and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies. The term *duty cycle* describes the proportion of 'on' time to the regular interval or 'period' of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on.The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on and power is being transferred to the load, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.PWM has also been used in certain communication systems where its duty cycle has been used to convey information over a communications channel. Depending on whether the signal voltage is larger or smaller than the carrier waveform, either the positive or negative dc bus voltage is applied at the output. Note that over the period of one triangle wave, the average voltage applied to the load is proportional to the amplitude of the signal (assumed constant) during this period. The resulting chopped square waveform contains a replica of the desired waveform in its low frequency components, with the higher frequency components being at frequencies of an close to the carrier frequency.

In electric cookers, continuously variable power is applied to the heating elements such as the hob or the grill using a device known as a simmerstat. This consists of a thermal oscillator running at approximately two cycles per minute and the mechanism varies the duty cycle according to the knob setting. The thermal time constant of the heating elements is several minutes, so that the temperature fluctuations are too small to matter in practice.SPWM (Sine–triangle pulse width modulation) signals are used in micro-inverter design (used in solar and wind power applications). These switching signals are fed to the FETsthat are used in the device. The device's efficiency depends on the harmonic content of the PWM signal. There is much research on eliminating unwanted harmonics and improving the fundamental strength, some of which involves using a modified carrier signal instead of a classic sawtooth signal in order to decrease power losses and improve efficiency. Another common application is in robotics where PWM signals are used to control the speed of the robot by controlling the motors.The waveform

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belowshows the operating principle of a pulse width modulation by comparing the carrier signal and reference wave forms.

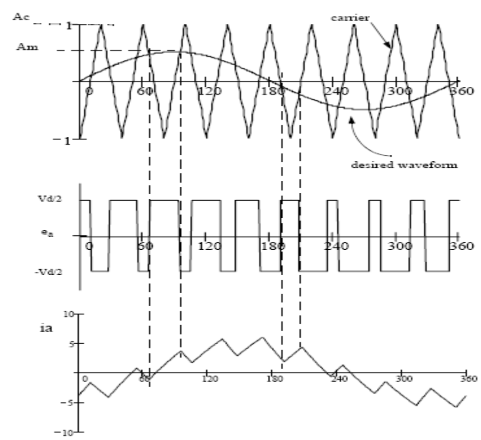

FIGURE3.4 Principle Of Pulse Width Modulation

Notice that in the SPWM strategy developed above, a large number of switching's are required, with the consequent associated switching losses. With the method of Selective Harmonic Elimination, only selected harmonics are eliminated with the smallest number of switching's. This method however can be difficult to implement on-line due to computation and memory requirements. For a two level PWM waveform with odd and halfwave symmetries and n chops per quarter cycle.However, the problematic harmonics are shifted to higher orders, thereby making filtering much easier. Often, the filtering is carried out via the natural high-impedance characteristic of the load.PWM is also used in efficient voltage regulators. By switching voltage to the load with the appropriate duty cycle, the output will approximate a voltage at the desired level. The switching noise is usually filtered with an inductor and a capacitor.

III. NINE LEVEL MULTI-LEVEL INVERTER.

A cascade multilevel inverter consists of a series of H-bridge(single-phase full bridge) inverter units in each of itsthree phases. Each H-bridge unit has its own dc source,which for an electric vehicle would be a battery unit. Thiscascade inverter makes EVS more accessible/safer and openwiring possible for most of an EV'S power system becauseeach low voltage (<50 V) battery is isolated throughswitching devices.

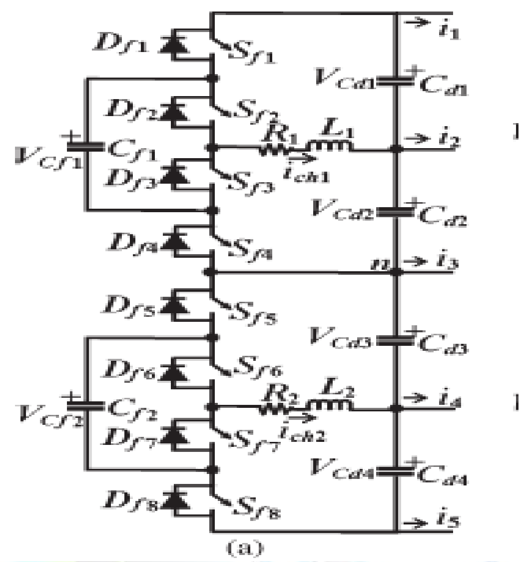

Figure: 4.1 Nine Level Multi-level Inverter

When switching devices are in an off state, the leakage current is far less than the safety limit (10mA), which makes access possible to any point of the system. The output voltage of the inverter is almostsinusoidal, and it has less than 5°/0 THD with each of theH-bridges switching only at fundamental frequency. Each HV bridge unit generates a quasi-square waveform by phase shifting its positive and negative phase legs' switchingtimings. Shows the switching timings to generate aquasi-square waveform. Note that each switching devicealways conducts for 180° (or'% cycle) regardless of the pulsewidth of the quasi-square wave. This switching methodmakes all of the

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switching devices' current stress equal;the system configuration of an EV motor drive using thecascade inverter. In the motoring mode,power flows from the batteries through the cascade invertersto the motor. In the charging mode, the cascade convertersact as rectifiers, and power flows from the charger (acsource) to the batteries. The cascade converters can also act as rectifiers to help recover the kinetic energy of the vehicleif regenerative braking is used. The cascade inverter can alsobe used in parallel HEV configurations.

If this same pattern of duty cyclesis used on a motor drive continuously, then the level 1 batteryis cycled on for a much longer duration than the level 5battery. This means that the level 1 battery will discharge much sooner than the level 5 battery. However, by using a switching pattern swapping scheme among the various levels and all batteries will be equallyused (discharged) or charged.The combination of the 180° conducting method the pattern-swapping schememake the cascadeinverter's voltage and current stresses the same and batteryvoltage balanced. Identical H-bridge inverter units can be utilized, thus improving modularity and manufacturabilityand greatly reducing production costs.

Electromagnetic interference (EMI) and common mode voltage are also much less than what would result in PWM inverter because of the inherently low dV/dt (21times less than a two-level PWM drive) and sinusoidalvoltage output.In summary, the main advantages of using the cascadeinverter in an electric vehicle include: (1) It makes EVS moreaccessible/safer and open wiring possible for most of an EV'spower system. (2) Traditional 230 V or 460 V motors can be used, thus higher efficiency is expected as compared to lowvoltage motors. (3) No EMI problem or common-mode voltage/current problem exists. (4) Low voltage switchingdevices can be used. (5) No charge unbalances problem existsin both charge mode and drive mode.

IV. SIMULATION OF NINE LEVEL MULTILEVEL INVERTER

CIRCUIT MODEL FOR SEVEN LEVEL INVERTER

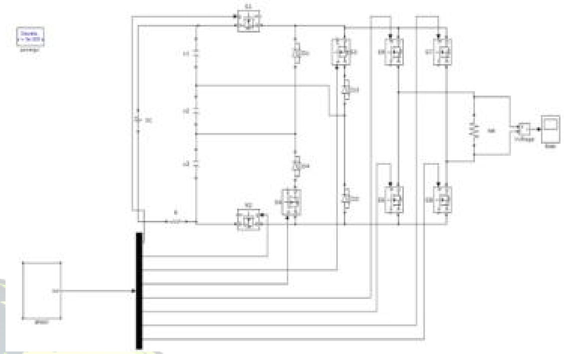

FIGURE: 4.1 Simulation model for seven level inverter

Figure: 6.1 shows the configuration of proposed seven-level inverter. Two switches *S*b5 and *S*b6, resonant inductor *L*r, and resonant capacitor *C*r are added. In this application, switches *S*b1, *S*b3, and *S*b5 are turned on at the same time; *S*b2, *S*b4, and *S*b6 are turned on at the same time. The duty of each switch is equal to 50%.System detects output voltage first, and compares this signal with a built-in reference. Then, the system feedbacks an error to PI controller. Finally, the PI controller exports a control signal to gate driver.The main idea of modified SPWM is to record the previous error of output voltage, and generate a suitable correction at the latest cycle. Because the frequency of carrier is 18 kHz and the frequency of output sine wave is 60 Hz, the number of times of switching is 300 times.

WAVE FORM FOR SEVEN LEVEL INVETER

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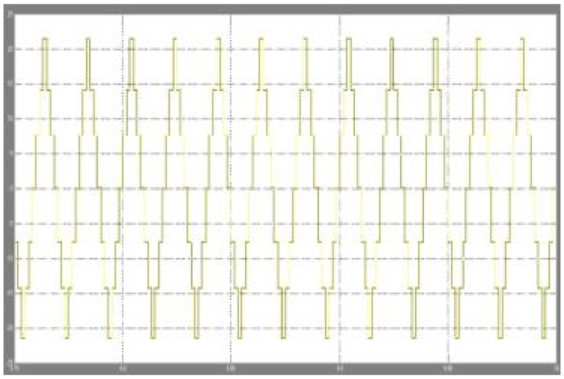

FIGURE: 6.2 Output voltage of seven level inverter

Since the voltage deviation causes larger harmonics distortion in the output voltage, voltage balancing circuits are indispensable for the capacitors in the multilevel inverters. By using resonant switching capacitor converter, the voltage balance of input capacitors is achieved. The duty cycle of every switch is equal to 50%. The voltage of $C1$ is higher than the voltage of $C2$. Since the average current of $C1$ is higher than that of $C2$ at one switching cycle, most of the charges flow from $C1$ to $C2$. After few switching cycles, the voltage of $C1$ and $C2$ are equal.

The term duty cycle describes the portion of on time to the regular interval or period of time; a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on. By quickly changing the state between fully on and fully off(typically less than 100 nanoseconds), the power dissipation in the switches can be quite low compared to the power being delivered to the load.

A. SIMULATION OF NINE LEVEL MULTI-LEVEL INVERTER

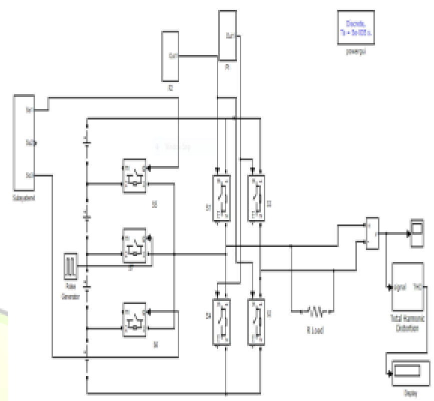

FIGURE: 4.2 Simulation model for nine level inverter

The nine level multi-level inverter is simulated. The MOSFET is connected with the coupled inductor and the advantage of coupled inductor, L is to improve the inverter efficiency during the leakage reactance power loss. It is added to output voltage, so that the inverter efficiency is high than the normal inverter

By quickly changing the state between fully on and fully off (typically less than 100 nanoseconds), the power dissipation in the switches can be quite low compared to the power being delivered to the load. The term duty cycle describes the proportion of 'on' time to the regular interval or 'period' of time, a low duty cycle corresponds to low power, because the power is off for most of the time. Duty cycle is expressed in percent, 100% being fully on.

Typically switching has to be done several times a minute in an electric stove, 120 Hz in a lamp dimmer, from kilohertz (KHz)to tens of KHz for a motor drive and well into the tens or hundreds of KHz in audio amplifiers and computer power supplies.

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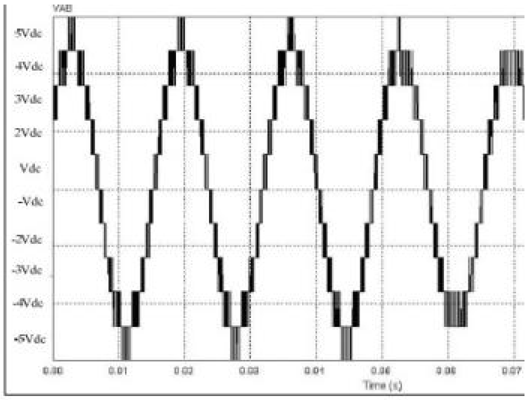

FIGURE: 6.4 Output voltage for modified nine –level inverter

The plots and plotting tools section of the MATLAB graphics documentation fully describes the MATLAB figure window, which displays the plot, and the types of graph you can creating figure windows. It also discusses the various interactive tools available for editing and customizing MATLAB graphics.

High frequency PWM power control systems are realizable with semi-conductor switches. However, during the transitions between on and off states, both voltage and current are nonzero and thus power dissipated in the switches. By quickly changing the state between fully on and off, the power dissipation in the switches can be quiet low compared to the power being delivered to the load.

Modern semi-conductor switches such as MOSFETS or insulated gate bipolar transistors(IGBTs) are well suited components for high efficiency controllers. Frequency converters used to control AC motors may have efficiency exceeding 98%.

Switching power supplies have lower efficiency due to low output voltage levels (often less than 2 V for microprocessors are needed) but still more than 70-805 efficiency can be achieved. The switching frequency of MOSFET is about 50 Hz, gate driver circuit produce the gate pulse which is driven interchangeably.

CONCLUSION

A nine–level multilevel inverter has been proposed for dc capacitor voltage equalization in a DCMLI. The main idea of the proposed configuration is to reduce the number of power device. The reduction of power device is proved by compare with traditional structures. But it requires additional capacitors. These are different in capacitor and semiconductor device count and correspondingly reduce the device voltage stresses by half and one-third, respectively.

Easily adaptable driving scheme and simple topology along with high efficiency make good choice to apply in low voltage photovoltaic system. Application of inverter is connected to grid in future development by increasing the levels of inverter.

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