ANALYSIS AND CONSTRUCTION OF PUSH PULL CONVERTER

NOOR RULMUNA BINTI MOHD SARMIN

This Project Report Is Submitted In Partial Fulfilment of Requirements for the Degree of Bachelor in Electrical Engineering (Industry Power)

Faculty of Electrical Engineering
Kolej Universiti Teknikal Kebangsaan Malaysia

May 2006

ABSTRACT

The purpose of this project is to develop a converter that convert a value of direct current to another value of direct current that can produce 360V output voltage from 12V input voltage. Some of the components that use in this project is a high frequency transformer, integrate circuit SG 3525A and full bridge rectifier. The hardware implementation also use two MOSFET as a switching device due to its high power rating and high switching speed. Consequently, the design circuit will deliver accurate output value with low power losses and small output ripple because this converter have its own filter.

ABSTRAK

Tujuan projek ini adalah untuk membina satu penukar untuk satu nilai arus terus ke satu nilai arus terus yang lain yang boleh menghasilkan voltan keluaran tinggi sebanyak 360V dari voltan masukan 12V. Antara komponen penting yang digunakan ialah pengubah berfrekuensi tinggi, litar bersepadu SG 3525A dan litar penerus. Projek ini juga menggunakan dua MOSFET sebagai alat pensuisan kerana ia mempunyai kadar kuasa yang tinggi dan tempoh pensuisan yang cepat. Penukar yang direka ini akan menghasilkan voltan keluaran dengan kehilangan kuasa minimum dan riak pada voltan keluaran adalah kecil kerana ia mempunyai penuras sendiri.

CHAPTER 1

INTRODUCTION

1.1 DC – DC CONVERTER

A dc – dc converters are widely used in regulated switch – mode dc power supplies and in dc motor drive applications. Often the input to the converters is an unregulated dc voltage, which is obtained by rectifying the line voltage, and therefore it will fluctuate due to changes in the line voltage magnitude.

Switch mode dc – dc converters are used to convert the unregulated dc input into a controlled dc output at a desired voltage level. Converters are very often used with an electrical isolation transformer in the switch – mode dc power supplies and almost always without an isolation transformer in case of dc motor drives.

The aim of this project is to design and to analysis the push pull converter. Push pull type dc - dc converter is suitable to boost up the voltage from low to high voltage. This converter may be used in conjunction with a high frequency transformer to boost the output voltage with the advantage of providing isolation between the input and output stage.

This project will use a push pull converter topology, which will step up a 12Vdc voltage supply to 360Vdc output voltage. A 12V power supply will be used as the input supply. ORCAD P - SPICE software is used to analyze the output of center tap transformer. Output of the hardware implementation is analyzed using the oscilloscope and multimeter.

1.2 OBJECTIVE

The main objective of this project is to design a push pull converter, which can gain output 360V dc from 12V dc input. This project also try to implement P - SPICE simulation of push pull converter with a center tap high frequency transformer.

1.3 PROJECT SCOPE

The scope of this project is using push pull converter that convert 12Vdc input voltage to 360Vdc as the output voltage. The design consist of parallel connected MOSFET, full bridge rectifier, SG 3525A control chip for feedback control, high frequency transformer, coupled inductor and bulk capacitor. The circuit is constructed on the PCB board.

CHAPTER 2

LITERATURE REVIEW

2. 1 INTRODUCTION TO PUSH PULL TRANSFORMER

Push pull converter is one of dc -dc converter that has transformer isolation. As with the forward converter, the transformer magnetizing inductance is not a design parameter. The transformer is assumed to be equal for this analysis. The push pull transformer configuration is widely used in converting direct current (d.c.) voltage into another value of dc voltage, and in inverters. Inverters convert direct current into alternating current (a.c.). The push pull transformer is usually the preferred choice in high power switching transformer applications exceeding one kilowatt. It is usually used in a circuit known as a forward converter circuit.

The core in a push pull transformer has bipolar operation. Both "B" and "H" cross zero value and reverse polarity. Bipolar operation is depicted graphically in Figure 2.1. Note that the "dB" value (change in B) in Figure 2.1 for the bipolar push pull transformer can be more than twice the "dB" value for the unipolar forward converter (assuming the same core material). Push pull transformer (bipolar) operation permits one to handle the same amount of power in a smaller package than for that of a unipolar operation. The push pull transformer operation requires more switching elements and its control circuitry is more complicated.

Consequently a push pull transformer application is more expensive. The voltage pulses must be adequately controlled to avoid phenomena known as saturation walk. Center tapped push pull transformers have winding capacitance issues at higher frequencies. Winding imbalances can contribute to saturation walk. Power ratings for push pull transformer can vary from a fraction of a Watt to Kilowatt.

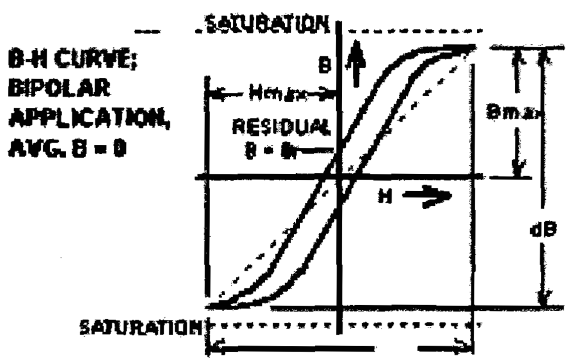


Figure 2.1 : Bipolar operation

2.1.1 Push pull schematic diagram

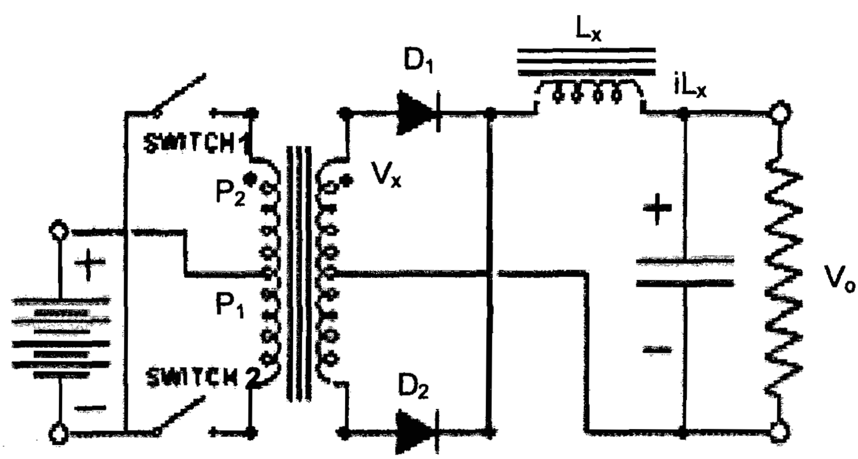


Figure 2.2 : Push pull converter diagram

2.1.2 **Push Pull analysis**

i) Switch Sw_1 closed

The voltage across primary winding P_1 at :

$$vp_1 = Vs \tag{2.1}$$

Diode D_1 is forward biased, D_2 is reversed biased. Assuming a constant output voltage V_o, the voltage across L_x is a constant, resulting in a linear increasing current in L_X. In the interval when Sw_1 is closed, The change in current L_x is :

$$(\Delta iLx)closed = \frac{Vs(Ns/Np) - Vo}{Lx}[DT] \tag{2.2}$$

ii) Switch Sw_2 closed

Closing Sw_2 establishes the voltage across primary winding P_2 at :

$$vp_1 = -Vs \tag{2.3}$$

Diode D_2 is forward biased, D_1 is reversed biased. The current Lx increases linearly while Sw_2 is closed and current L_x is :

$$(\Delta iLx)closed = \frac{Vs(Ns/Np) - Vo}{Lx}[DT] \tag{2.4}$$

iii) Both switches open

The current in each of the primary winding is zero. The current in the filter inductor L_X maintain continuity, resulting both D_1 and D_2 becoming forward biased. Inductor current divides evenly between the transformer secondary windings. The voltage across each secondary windings is zero.

$$v_x = 0 \tag{2.4}$$

$$vL_x = v_x - V_o \tag{2.5}$$

2.1.3 Theoretical push pull converter waveform

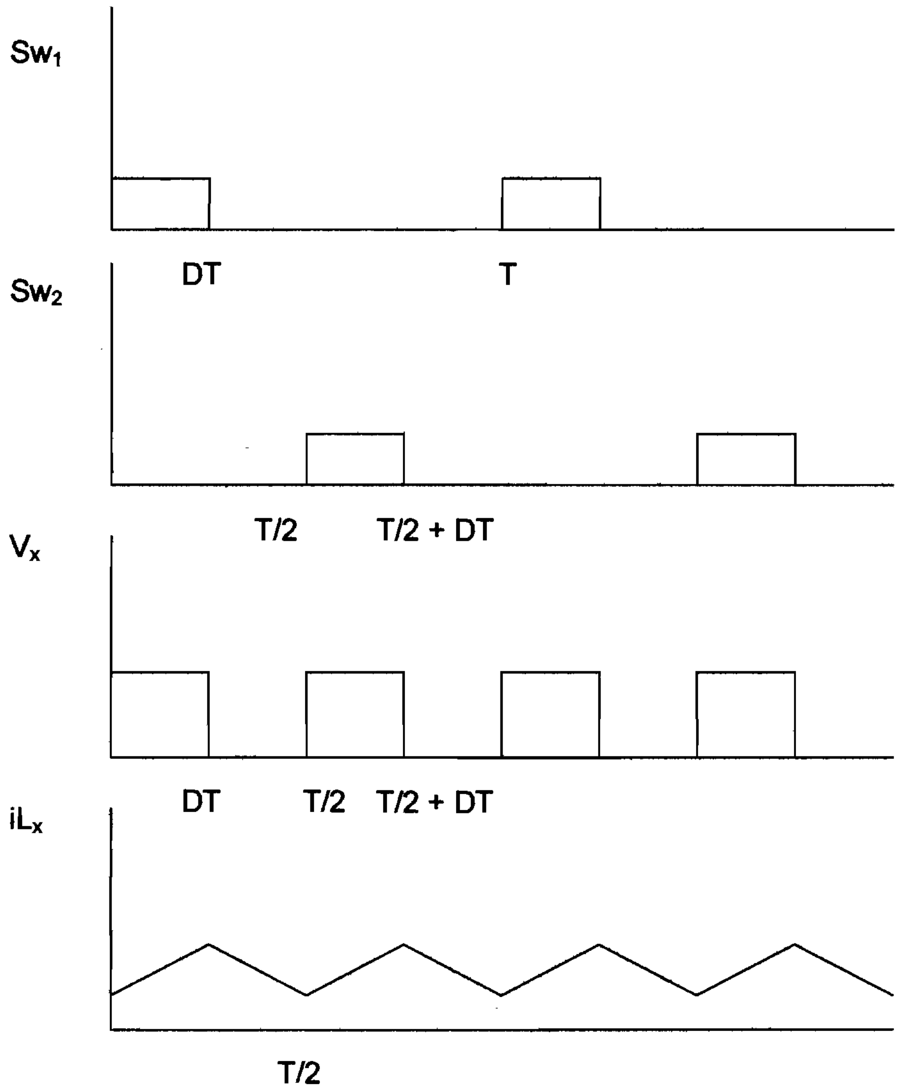


Figure 2.3 : Output waveform

2.2 CONTROL OF DC – DC CONVERTER

In dc – dc converters, the average dc output voltage must be controlled to equal a desired level, though the input voltage and the output load may fluctuate. Switch – mode dc - dc converters utilize one or more switches to transform dc from one level to another. In a dc- dc converter with a given input voltage, the average output voltage is controlled by controlling the switch on and off durations (t_{on} and t_{off}). To illustrate the switch – mode conversion concept, consider a basic dc – dc converter shown in Figure 2.4.

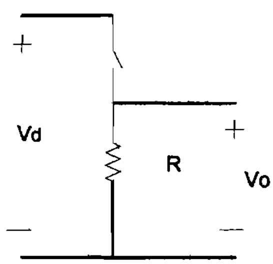


Figure 2.4 : Switch mode dc – dc conversion

The average value of V_0 of the output voltage employs switching at a constant (hence, a constant switching time period $T_S = t_{on} + t_{off}$) and adjusting the on duration of the switch to control the average output voltage. In this method, called pulse width modulation (PWM) switching,the switch duty ratio D , which is defined as the ratio of the on duration to the switching time period, is varied.

In the PWM switching at a constant switching frequency, the switch control signal,which control voltage $v_{control}$ with a repetitive waveform as shown in Figure 2.5. The control voltage generally is obtained by amplifying the error, or the difference between the actual output voltage and its desired value.

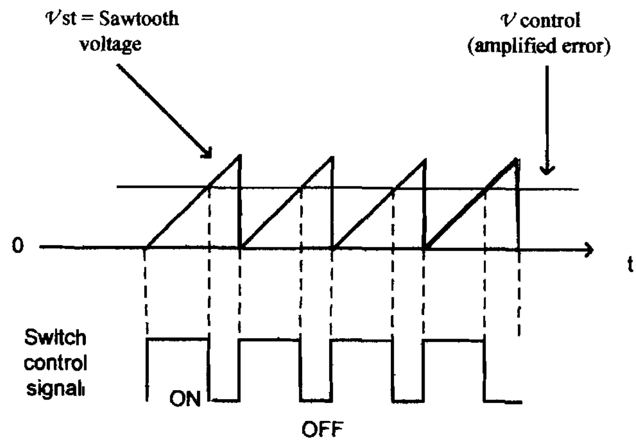


Figure 2.5 : Pulse width modulator comparator signal

2.3 FAST RECOVERY DIODES

The fast recovery diodes have low recovery time, normally less than 5μs. They are used in dc – dc and dc – ac converter circuits, where the speed of recovery is often critical importance. These diodes cover current ratings of voltage from 50V to around 3kV, and from less than 1A to hundreds of amperes.

For voltage rating above 400V, fast recovery diodes are generally made by diffusion and the recovery time is controlled by platinum or gold diffusion. For voltage ratings below 400V, epitaxial diodes provide faster switching speeds than those of diffused diodes. The epitaxial diodes have a narrow base width, resulting in a fast recovery time of as low as 50ns.

2.4 SCHOTTKY DIODES

The charge storage problem of a pn – junction can be eliminated (or minimized) in a Schottky diodes. It is accomplished by setting up a " barrier potential " with a contact between a metal and a semiconductor. A layer of metal is deposited on a thin epitaxial layer of n – type silicon. The potential barrier simulates the behavior of a pn – junction. The rectifying action depends on the majority carriers only, and as result there are no excess minority carriers to recombine. The recovery effect is due solely to the self-capacitance of the semiconductor junction.

The recovered charge of a Schottky diode is much less than that of an equivalent pn- junction diode. It is due to the junction capacitance, it is largely independent of the reverse di / dt. A Schottky diode has relatively low conduction voltage drop.

The leakage current of a Schottky diode is higher than that of pn – junction diode. A schottky diode with relatively low conduction voltage has relatively high leakage current, and vice versa. As a result, the maximum allowable voltage of this diode is generally limited to 100V.

The current ratings of Schottky diodes vary from 1 to 400 A. The Schottky diodes are ideal for high current and low voltage dc power supplies. However, these diodes are also used in low current power supplies for efficiency.

2.5 CONTROL CIRCUIT

Varying the duty cycle , D can control the output voltage of a converter. There are commercially available PWM integrate circuit (IC) controllers that have all the features to build a PWM switching power supply using a minimum number of components.

A PWM controller consists of four main functional components : an adjustable clock for setting the switching frequency , an output voltage error amplifier, a sawtooth generator for providing a sawtooth signal that is synchronized to the clock, and a comparator that compares the output error signal with the sawtooth signal. The output of the comparator is the signal that drives the power switch. Either voltage – mode control or current – mode control is normally applied.

2.6 PULSE WIDTH MODULATION

Pulse-width modulation control works by switching the power supplied to the switch on and off very rapidly. The DC voltage is converted to a square-wave signal, alternating between fully on (nearly 12v) and zero, giving the motor a series of power.

If the switching frequency is high enough, the switch runs at a steady speed due to its fly-wheel momentum. By adjusting the duty cycle of the signal (modulating the width of the pulse, hence the PWM) i.e. the time fraction it is on, the average power can be varied, and hence the motor speed.

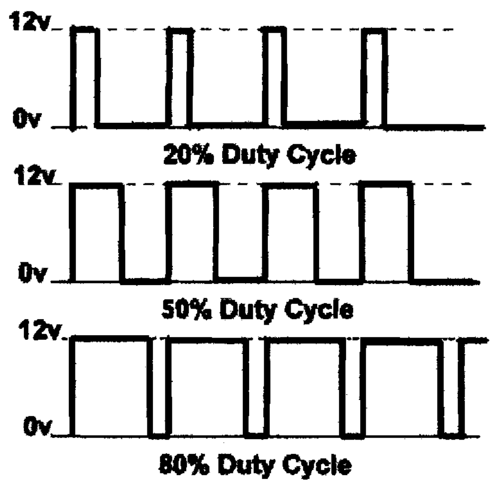


Figure 2.6 : Pulse width modulator duty cycle

Advantages of pulse width modulator are:

1. The output transistor is either on or off, not partly on as with normal regulation, so less power is wasted as heat and smaller heat-sinks can be used.
2. With a suitable circuit there is little voltage loss across the output transistor, so the top end of the control range gets nearer to the supply voltage than linear regulator circuits.

3. The full-power pulsing action will run fans at a much lower speed than an equivalent steady voltage.

Disadvantages of pulse width modulator are:

1. The 12v may be audible if the fan is not well-mounted, especially at low revs. A clicking or growling vibration at PWM frequency can be amplified by case panels. A way of overcoming this by blunting the square-wave pulse.
2. The pulsed power puts more stress on the fan bearings and windings, shortening its life.

2.6.1 How PWM working

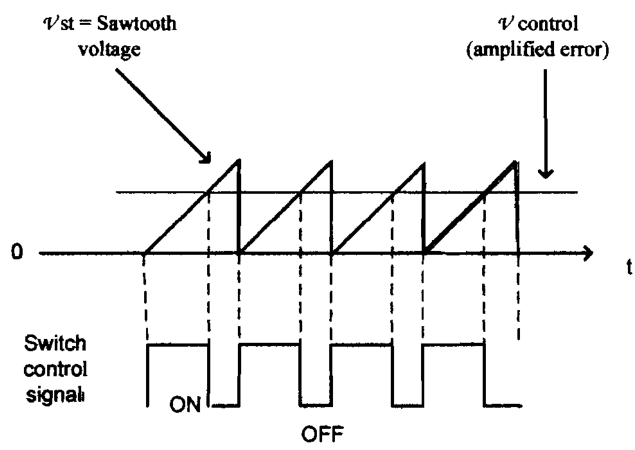


Figure 2.7 : Comparator signal

An oscillator is used to generate a triangle or sawtooth waveform (triangular line). At low frequencies the motor speed tends to be jerky, at high frequencies the motor's inductance becomes significant and power is lost. Frequencies of 30-200Hz are commonly used.

A potentiometer is used to set a steady reference voltage (straight line). A comparator compares the sawtooth voltage with the reference voltage. When the sawtooth voltage rises above the reference voltage, a power transistor is switched on. As it falls below the reference, it is switched off. This gives a square wave output to the fan motor.

If the potentiometer is adjusted to give a high reference voltage (raising the straight line), the sawtooth never reaches it, so output is zero. With a low reference, the comparator is always on, giving full power.

2.6.2 A practical PWM circuit

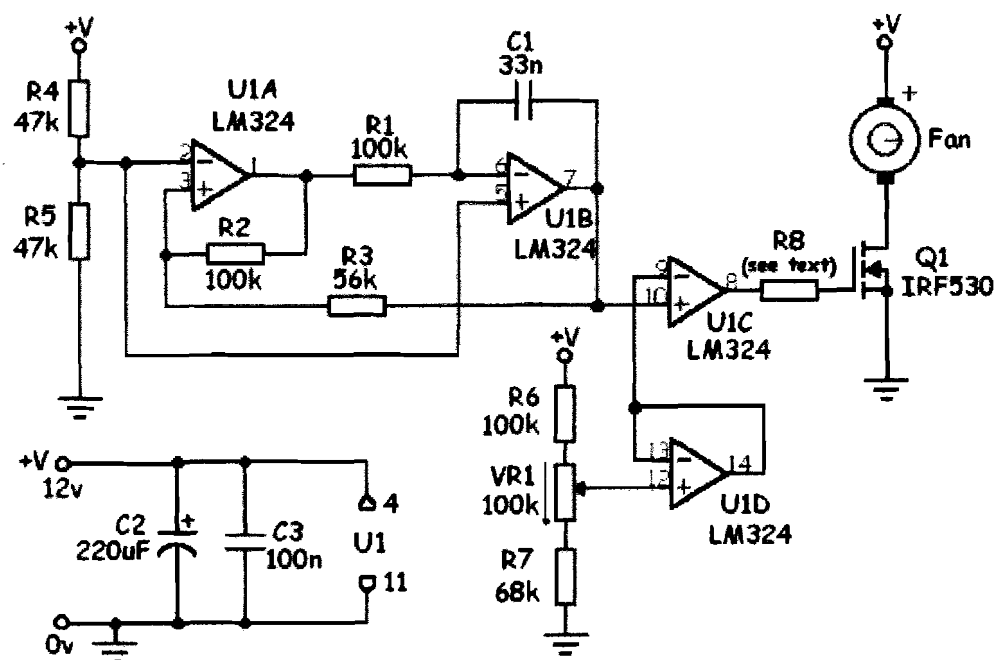


Figure 2.8 : Practical pulse width modulator circuit

This uses the LM324, a 14-pin DIL IC containing four individual op-amps and running off a single-rail power supply. The sawtooth is generated with two of them (U1A and U1B), configured as a Schmitt Trigger and Miller Integrator, and a third (U1C) is used as a comparator to compare the sawtooth with the reference voltage and switch the power transistor.

Rather than have the fourth op-amp sat there doing nothing, it's used as a voltage follower to buffer the reference potential divider. The high input and low output impedance of this draws very little current from the PD, so high value thermistors can be used in the thermal version of this controller.Here's the very neat sawtooth wave coming from the output pin on U1B. Frequency is about 130Hz with the components as shown, with the amplitude swinging between 3.5v and 9.5v on a 12v supply.

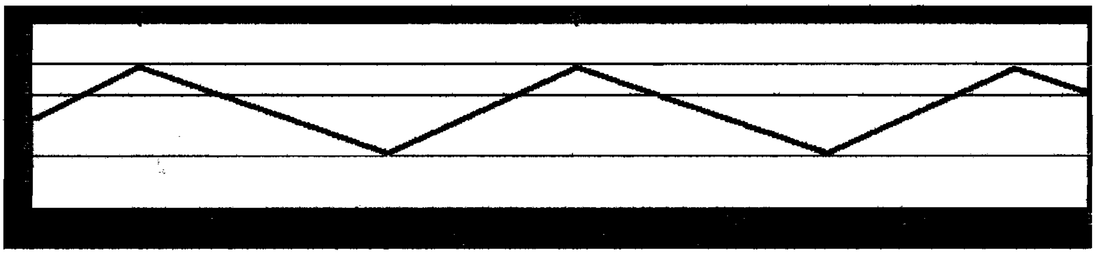


Figure 2.9 : Sawtooth signal

The reference voltage system is designed to apply a level ranging from 3v to 7.5v to the comparator. At 3v the fan is getting power all the time, at 7.5v about 30% of the time (when the sawtooth wave goes over 7.5v). Below is the pulse power applied to the fan at the minimum setting, which was just enough to keep test fan spinning.

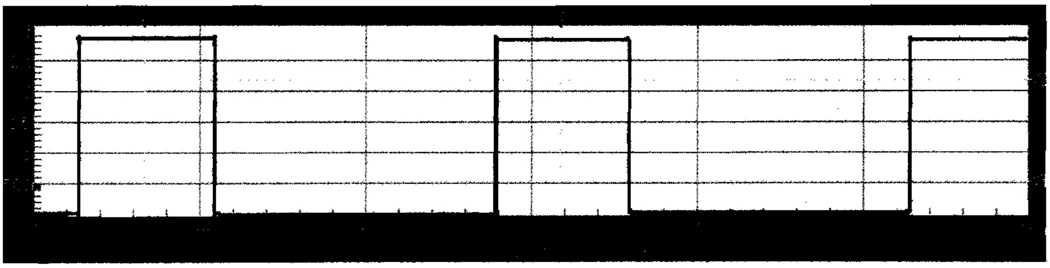


Figure 2.10 : Switch control signal

2.7 PUSH – PULL DC TO DC CONVERTER

When designing amplifier circuits that are battery powered, the need arises for generating plus and minus voltages. These voltages are usually larger than the supply voltage and must be able to provide a fair amount of power, as well as be simple and inexpensive. The circuit above uses a CMOS 555 timer to generate a clock (approx. 50KHz). The 555 drives a CMOS flip-flop which gives a 50% duty cycle clock. The Q and Q not outputs of the flip-flop are used to drive N channel FET's, which form a push pull driver to the transformer.

The output of the transformer is then rectified and filtered to provide plus and minus voltage. This configuration was set up to deliver plus and minus 25 volts at 30 watts. FET's were used in this design (as opposed to bipolar transistors) to minimize the problem of cross conduction due to storage time of the drive devices. The efficiency of the supply can be improved by using a high quality transformer core. The LC filtering on the output helps quiet the output without having to use regulators.

Figure 2.11 : Schematic for push- pull converter

2.8 PUSH PULL TOPOLOGY

The push pull topology is basically a forward converter with two primaries. The primary switches alternately power their respective windings. When Q1 is active current flows through D1. When Q2 is active current flows through D2. The secondary is arranged in a center tapped configuration as shown. The output filter sees twice the switching frequency of either Q1 or Q2. The transfer function is similar to the Forward converter, where D is the duty cycle of a given primary, that accounts for the "2X" term.

When neither Q1 nor Q2 are active the output inductor current splits between the two output diodes. A transformer reset winding shown on the Forward topology is not necessary.

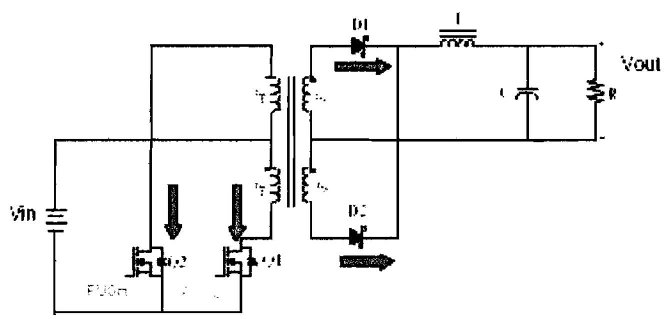


Figure 2.12 : Push – pull topology

Shown here are oscilloscope waveforms for the drain voltages of the two primary switches and the output inductor current. When a given primary is active the drain voltage is zero and the alternate switches drain is 2X the input voltage. This is due to the transformer voltage bringing reflected from the active primary to in-active primary. When neither switch is active then both drain voltages are at the input voltage.

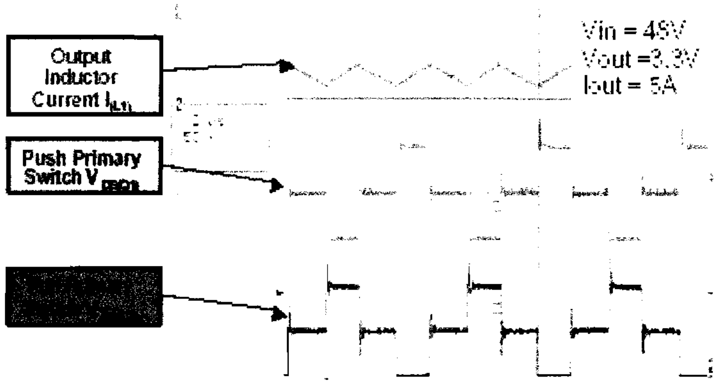


Figure 2.13 : Oscilloscope waveform

Shown here is the current for each of the two output diodes. These two current sum to form the output inductor current shown on the previous slide. Note that as discussed previously when neither of the primary switches are active, the output inductor current has a negative slope and flows half in each of the two secondary diodes.

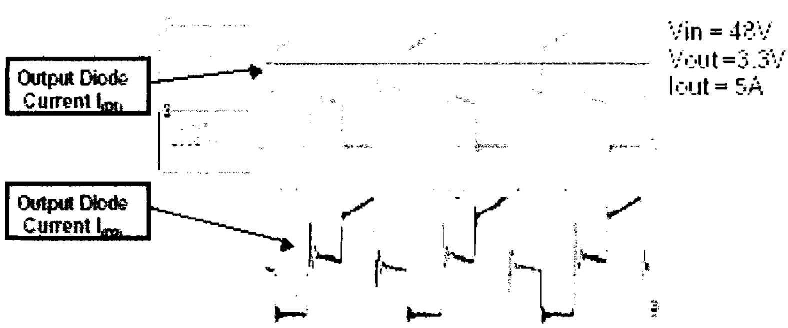


Figure 2.14 : Current waveform of output D_1 and D_2

Shown here are the transformer BH curves for the forward and the push-pull topology. The X - axis represents magnetic field intensity which is proportional to the ampere multiple with turns. The Y axis represents flux density which is proportional to the core area and the volt multiple with seconds for the winding that is active. The slope is proportional to the primary magnetizing inductance.

The forward converter operates in a single quadrant of the BH curve, moving up the curve when the switch is active and resetting during the off time. The push-pull converter operates in two quadrants of the BH curve, see-sawing back and forth as the each primary is activated. This important fact allows the maximum power capability of a push-pull transformer to be twice that of a forward transformer.

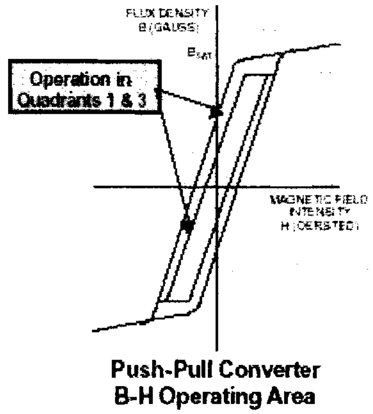


Figure 2.15 : Push – pull core utilization

The electrical isolation is switching dc power supplies is provided by a high frequency isolation transformer. Figure 2.15 shows a typical transformer core characteristic in terms of its B – H (hysteresis) loop.

Various types of dc – dc converters (with isolation) can be divided into two basic categories, based on they utilize the transformer core :

1.Unidirectional core excitation where only the positive part of the B - H loop is used.

2. Bidirectional core excitation where both the positive and the negative parts of B – H loop are utilized alternatively.

2.9 CONTROL OF DC – DC CONVERTERS WITH ISOLATION

In the single – switch topologies like the flyback and the forward converters, the output voltage V_o for a given input V_d is controlled by pulse width modulator in a manner similar to that used for their nonisolated counterparts.

In the push – pull converters, where the converter output is rectified to produce a dc output voltage V_o is controlled by using the pulse width modulator scheme as shown in Figure 2.7, which controls the interval during all the switches are off simultaneously.

2.10 PUSH – PULL CONVERTER CHARECTERISTICS

A push-pull converter is a buck type converter with a dual drive winding isolation transformer. The push – pull converter has the following characteristics:

1. Push-Pull transformers and filters are much smaller than standard forward converter filters
2. Voltage stress of the primary switches is: Vin *2
3. Voltage step-down or step-up
4. Multiple outputs possible
5. Low output ripple current
6. Lower input ripple current
7. Simple gate drive (dual)
8. Large achievable duty cycle range

2.11 METAL – OXIDE – SEMICONDUCTOR FIELD EFFECT TRANSISTORS (MOSFET)

A Metal – oxide- semiconductor field effect transistors is a voltage controlled device, that is fully on and approximates a closed switch when a gate source voltage is below the threshold value, $V_{GS(th)}$. MOSFET require the continuous application of gate – source voltage of appropriate magnitude in order to be in on state. No gate current flows except during the transitions from on to off or vice versa when the gate capacitance is being charge or discharged. The switching times are very short, being in the range of a few tens of nanoseconds to a few hundred nanosecond depending on the device type.

The on state resistance $r_{DS(on)}$ of the MOSFET between the drain and source increases rapidly with the device blocking voltage rating. On a per – unit area basis, the on state resistance as a function of blocking voltage rating BV_{DSS} can be expressed as

$$r_{DS(on)} = k\,BV_{DSS}^{2.5-2.7} \qquad (2.6)$$

where k is a constant that depends on the device geometry. Because of this, only devices with small voltage ratings are available that have low on – state resistance and hence small conduction losses.

However because of their fast switching speed, the switching losses can be small. From a total power loss standpoint, 300 – 400V, MOSFETs compete with bipolar transistors only if the switching frequency is in excess of 30 – 100 kHz. However, no definite statement can be made about the crossover frequency, because it depends on the operating voltage, with low voltage favoring the MOSFET.

Metal – oxide- semiconductor field effect transistors are available in voltage ratings in excess of 1000V but with small current ratings and with up to 100A at small voltage ratings. The maximum gate – source voltage is ± 20 V, although MOSFETs that can be controlled by 5V signals are available.

Because their on – state resistance has a positive temperature coefficient, MOSFETs are easily paralleled. This causes the device conducting the higher current to heat up and thus forces it to equitably shares it current with the other MOSFETs in parallel.

CHAPTER 3

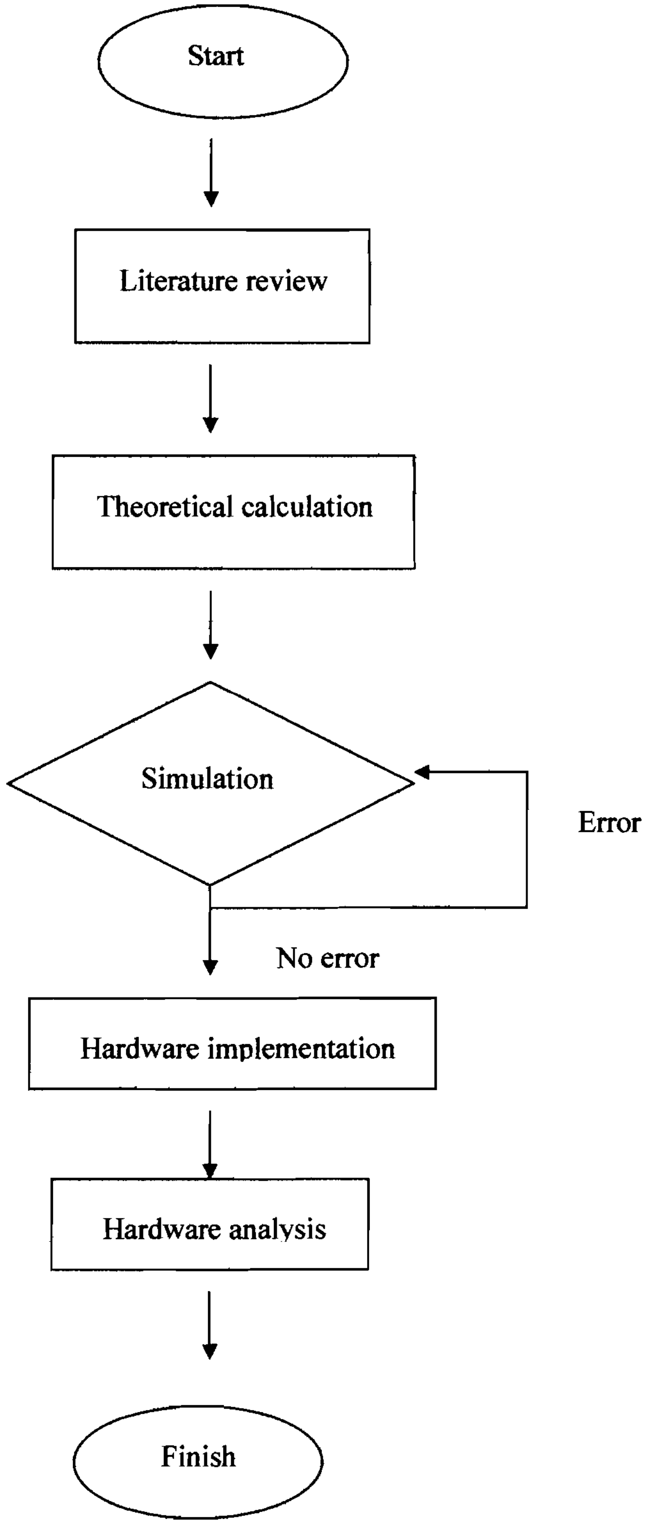
METHODOLOGY

3.1 INTRODUCTION TO THE PROJECT

The objective of this project is to design a high voltage converter. The circuit is present for conversion of voltage from 12V dc voltage to 360V dc voltage which to be used mainly for amplifiers and other utility applications. The configuration is achieved using a high frequency dc- dc push pull converter at the input side and a low pass filter at the output side. Due to simplified power stage and the application pulse width modulation technique, output voltage Total Harmonic Distortion (THD) is reduced and a relatively smaller overall inverter size is achieved. A complete circuit implementation, analysis and cost evaluation is presented a low voltage inverter has been redesign, tested and prototype to deliver a 360V dc.

This project will explore the possibility of making alternate source of energy utility interactive by means of low cost power electronic interface (dc – dc converter). The constrains towards the above scheme is the input voltage from alternate forms of energy is very rarely stable hence the design of the proposed interface has to produce a dc output, which is independent of the input fluctuations. The input voltage from the renewable forms of energy will be 12V dc with fluctuation limit of 8 – 15V dc. The output voltage will be 360 -405V dc suitable for audio applications. Since the converter is for preamplifier use, low cost, high reliability and safety are essential design issues.

3.2 PROJECT FLOW CHART



3.3 CIRCUIT AND OPERATION

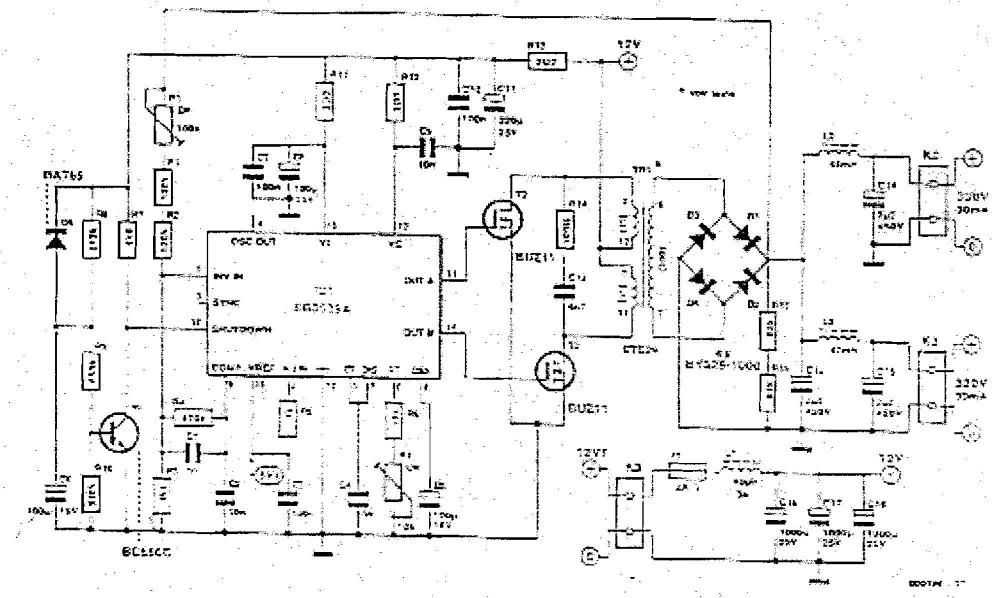


Figure 3.1 : Hardware circuit

The push pull converter use integrate circuit (IC) SG3525A (N) from Motorola which is a industry standard part that is used in many switch mode supplies. The proper description of this IC is a regulating Pulse Width Modulator (PWM) which sums up its function perfectly. A special transformer is driven with an alternating voltage by one or more switched transistors, with the driving voltage obviously limited to a safe value. By varying the pulse width of the signal, the amount of power is controlled. The output at the secondary of the transformer is rectified and feedback to the PWM regulator in order to keep the output stable. That completes the feedback loop of the regulator.

The regulator uses a reference voltage of 5.1 V. Various internal circuit use this reference: error amplifier, oscillator, PWM comparator, and the circuit source for the soft start. An extra delay circuit has been added to give valve amplifiers enough time to warm up before the high voltage supply is applied. Because valve amplifiers generally have substantial smoothing capacitors, the soft start period has been increase and the value of 100μF for C5 is a fair bit higher than usual.

A standard ETD29 type former with N27 core material for the home wound transformer. The switching frequency has been kept relatively low (30 kHz) in order to save on smoothing capacitor at the primary side. Furthermore, three of them have been connected in parallel, which splits the current between them. This design can deliver a power of about 30W.

The oscillator frequency can be set with P2 within a wide range (± 7 kHz) to compensate for the tolerance of C4 (1 nF MKT), although the exact frequency isn't critical. To facilitate maximum power transfer, the deed time has been kept to a minimum by connecting the discharge output directly to CT and by keeping the value of C4 as small as possible (refer appendix A) .

The reference voltage is decouple by C3 and fed to the non - inverting input of the error amplifier by R5. The output of the error amplifier (COMP) is also the input of the PWM comparator, which determines the pulse width. C2 limits the bandwidth and provides stability. The 330V output voltage is fed to the inverting input of the error amplifier via potential divider P1 / R1 / R2 / R3 where R4 determines the open loop gain.

P1 is used to adjust the value of the output voltage. The range has purposely been made fairly large (theoretically 270V to 370V), which gives the inverter plenty of scope for use in other applications. Slightly lower or higher output voltage can be obtained by varying the number of secondary turns proportionally (e.g. 273 turns would gives 300V). If using too many turns, the output voltage still correct, but at reduced efficiency because the output is peak – rectified. The surplus energy will then be lost and dissipated in the transformer.

The modest circuit around T1 provides a delay of about 45 seconds between the application of the 12.6V supply and taking the shutdown input low, this has to be below 0.6V to enable the inverter C6 charged slowly by the potential divider of R8 / R9 / R10, which causes the voltage at the base of T1 rise slowly and causes it to conduct. D5 causes D6 to discharge quickly when the supply is switch off.