"DESIGNING A DC CONVERTER"

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MARCH 2005

"I/we acknowledge that I already gone through this report and I/we are in the opinion that this report covers the scope and quality for the purpose of graduation in Bachelor of Engineering in Electric (Power Industry)."

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"I hereby verify that this paper work is done on my own except for the references I made which I have stated the sources clearly on the specified section."

Sign   :   _____ _____

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ABSTRACT

The purpose of this project is to design a "DC-DC Converter" which has an input of 12Vdc and the output of 340Vdc. Push-Pull Converter is used to step-up the voltage. The Push-Pull Converter used two MOSFET as a switching device. This is because MOSFET has high power rating and high switching speed. The output of each MOSFET is fed to the input if high frequency transformer. The input voltage of 12Vdc will be step-up to 340Vdc. The high frequency transformers were used due to low cost, small size and small weight. Consequently the design circuit will deliver accurate output value with low power losses. On the whole, the undertaken task would provide to understand the operation of the converter circuit practically. This is due to a "hands on" concept subjected to me in par with the requirement needed to complete my undergraduate program.

ABSTRAK

Tujuan proek ini adalah untuk merekabentuk sebuah "DC-DC Converter" yang menghasilkan voltan keluaran sebanyak 340Vdc daripada voltan masukan 12Vdc. Push-Pull Converter menggunakan dua MOSFET sebagai alat pengsuisan. Ini adalah disebabkan kadar kuasa yang tinggi dan tempoh pengsuisan yang cepat. Keluaran MOSFET dimasukkan ke input transformer berfrekuensi tinggi. Voltan input 12Vdc dinaikkan kepada 340Vdc. Berikutan harga yang murah, bersaiz kecil dan beratnya ringan transformer berfrekuansi tinggi digunakan. Litar yang direka ini akan menghasilkan keluaran dengan kehilangan kuasa yang minimum. Secara keseluruhan projek ini mendedahkan pengoperasian litar secara pratikal, serta bersesuaian dengan konsep "hands on" yang diarahkan kepada saya berasaskan kehendak untuk menjayakan program siswazah.

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CHAPTER 1

INTRODUCTION

1.1 DC-DC CONVERTERS

There are several popular DC/DC Converters such as the step down (buck) converters, step up (boost or push-pull) converter, step-down/step up (buck-boost converter), cuk converter and also the full bridge converter.

In any type of DC/DC Converter circuit, the selection of power device for a particular application not only the required voltage and current levels but also its switching characteristic. The key parameters to look for in the transistor are the switching time and current rating. These two parameters greatly affect the maximum switching frequency of the converter, and also how much current the converter can be designed for. Because switching speeds and the associated power losses are very important in the power electronic circuits. For the example, the BJT transistor is a minority-carrier device, whereas the MOSFET is a majority-carrier device which does not have minority-carrier storage delays, giving the MOSFET an advantage in switching speeds. BJT transistor switching times may be a magnitude longer than for the MOSFET. Therefore, the MOSFET generally has lower switching losses.

A DC/DC Converter is normally chosen because of its high efficiency in converting the input power to output power. A properly designed DC/DC Converter can yield an efficiency measure of greater than 90% at full load. The efficiency of a DC/DC Converter is expressed as the ratio of output power and input power.

1.2 CONTROL OF DC-DC CONVERTERS

In dc-dc converters, the average dc output voltage must be controlled to equal a desired level, if not 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}).

One of the methods for controlling the output voltage employs switching at a constant frequency (hence, a constant switching time period $Ts = t_{on} + t_{off}$) 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 ratio D, which defined as the ratio of the on duration to the switching time period, is varied.

1.3 OBJECTIVE

The objective of the undertaken project would be studying and collecting circuits regarding converters. These findings will prompt some modification into the existing circuits to obtain the required output.

Subsequently, components that need to be use for the modified circuit will be sorted out. A high frequency transformer which appears to be a part of the circuit required to be wind up to transform a 12VDC to 340VDC.

Software simulation through Pspice program needed to be handled to gain the required output value without any power losses. Finally a hardware implementation of the circuit using project board will be presented

CHAPTER 2

LITERATURE REVIEW

2.1 SMART DC-DC SWITCHING MODE POWER CONVERTER

In 1997, Lau Kwok Kit and Sung Wai Tee Electrical and Electronic student from the Hong Kong University of Science and Technology has design the "Smart Dc-Dc Switching Mode Power Converter" under their supervisor Dr. Philip Mok. In this project, a controller which can perform both PWM (PULSE-WIDTH MODULATION) and PFM (PULSE FREQUENCY MODULATION) was designed the condition for mode switching depends on the load current level. When the load current is high, PWM will be performed and this mode switching mechanism is automatic. The main advantage of using PWM as control method is that the frequency of the pulse train is fixed.

PWM is the standard scheme used in dc-dc converters where the frequency is kept constant and the width of the pulse is modulated to control the duty ratio of the synchronous switches. PFM is defined as the output voltage is sensed and compared with V_{ref+} and V_{ref-} (upper reference voltage and lower reference voltage). If it is below V_{ref-}, then a burst of fixed width pulses are supplied to the synchronous switches and V_{out} starts rising. As soon as V_{out} crosses V_{ref+} synchronous switches are switched off. V_{out} starts decreasing because of the current drainage from the load and eventually comes below V_{ref-} which against starts the burst of pulses. The cycles keep on going.

In this design, the mode of operation will automatically switch when the load current of power converter reaches a certain limit, in the case of 200mA. The students also implemented the controller for the smart Dc-Dc switching mode power converter. The

result controlled by the switch between PWM and PFM automatically as the load current changes. In this design, the power transistor is on the chip and allows us to design a simple current detection method.

But in simulation, they found out that the on chip power transistor have much larger on-resistance as compare to the components. This makes extra power loss and reduces the efficiency of the power converter. The circuit diagram is as below.
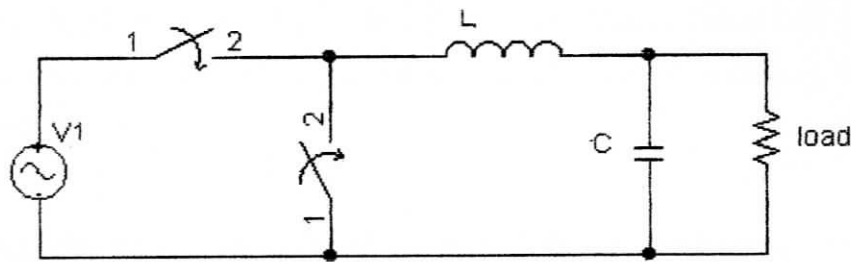

Figure 2.1: circuit diagram

A simplified block diagram of the Smart DC-DC Switching-Mode Power Converter is shown below:
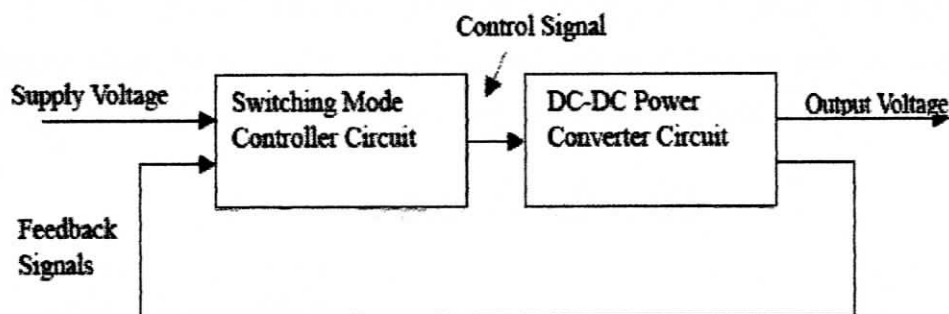

Figure 2.2: Block diagram of Smart DC-DC Switching Mode Power Converter

2.2 FULL BRIDGE DC-DC CONVERTER

In the other hand, Praveen Jain a student under Dr. Pulak Dhar has design Full Bridge Dc-Dc converter for low voltage and high current applications. In the project, full

bridge dc-dc converters are described as extensively used in medium to high power level applications.

The gating signals are such that, instead of turning-on the diagonal switches in the bridge simultaneously, a phase shift is introduced between the switches in the left leg and those in the right leg with a small delay between the switches of each leg. PSM (PULSE SKIPPING MODULATION) is used as a control technique for the output voltage regulations and the externally driven technique. High power level full bridge converters usually use IGBT switches, due to IGBT's low conduction losses and high power capability. However, IGBT is not as fast as MOSFET, and its switching frequency is hardly above 100 kHz.

They also mention about the advantage and also the disadvantage of this project. The advantage is this converter suitable for high frequency operation and the accuracy is good. The disadvantage is the circuit diagram design is complex. The circuit design as below;

The both diagram shows two typical full bridge topologies those achieve ZVS. Figure 2.3 shows ZVS is achieved by placing an inductor in series with the power transformer, while the figure 2.4 shows it is achieved by placing an inductor in parallel with the power transformer. In both topologies, a snubber capacitor is placed across each switch.
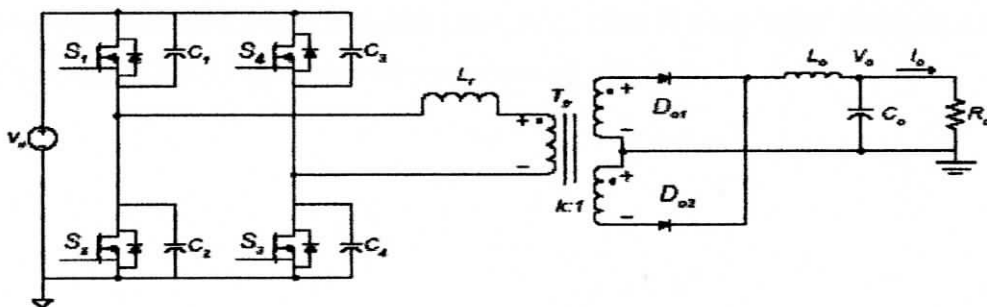

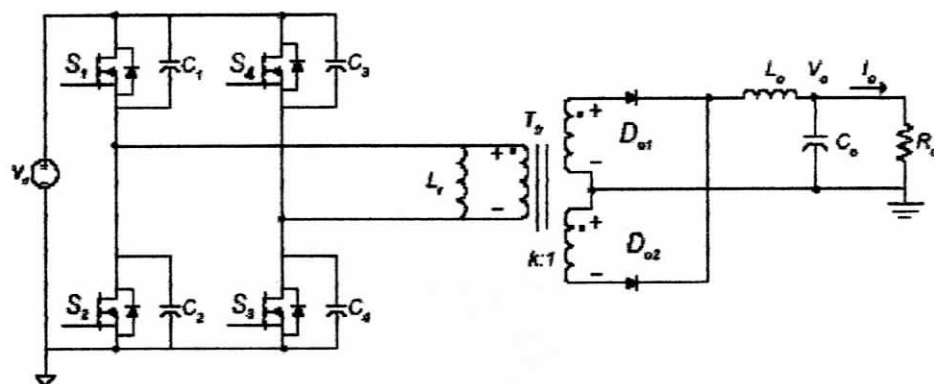Figure 2.3: ZVS topology with series inductor

Figure 2.4: ZVS topology with parallel inductor

2.3 PWM-PFM CONTROLLER

In different project, Ershad Ahmed and Syed Asif Eqmal did their 2003 Final project in Colorado. The project is "PWM-PFM Controller" for Dc-Dc Converters. The objective of the project is to design of a PWM-PFM Controller of the dc-dc converter intended for use in the portable battery operated mobile devices.

The target of this project is for portable battery operated mobile devices. In such devices the battery voltage in converted to the desired level using a buck converter and then fed to the base-band processor or other loads. The buck converter working in PWM mode shows high efficiency at higher values of the load current. As the load current falls to low values, the efficiency of the buck converter goes down to very low values. A battery operated mobile device spends most of its time in sleep mode and hence such a converter-based device will show very poor overall efficiency.
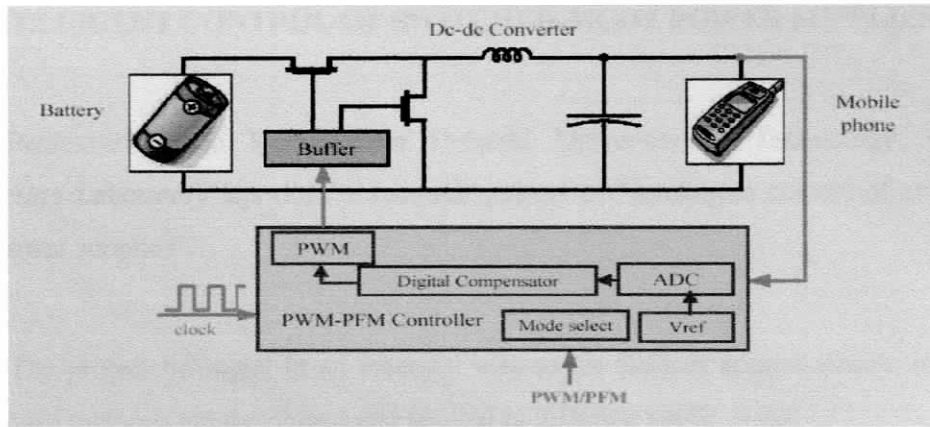
Figure 2.5: The Converter Circuit Design

A PFM mode buck converter shows high efficiency at low values of load but has other problems associated with it such as high output ripple and relatively low efficiency at high values of load current. So, to maximize the efficiency of a buck converter it is necessary to have a PWM / PFM controller which can operate in either mode as demanded by the load value. The advantage of this project is, it's a power saving method. The overall design is much faster and cheaper as compared to a pure analog design.
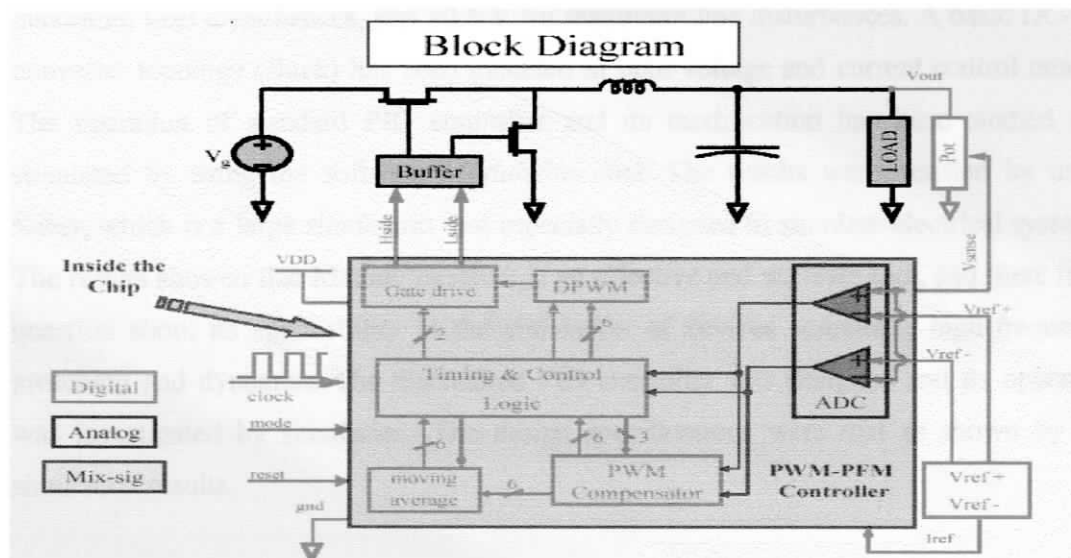

Figure 2.6: The Block Diagram

2.4 INTELLIGENT CONTROL OF SWITCHED-MODE POWER SUPPLIES

Professor Heikki Koivo from Helsinki University of Technology, Control Engineering Laboratory has done a research project of "Intelligent control of switched-mode power supplies".

The project belonged in an essential way to the field of control theory, in which new control methods are developed and applied in different applications.
The topic of the project provided a good example of how to replace analog solutions with microprocessor algorithms, which contain intelligent control strategies. The research extended new control ideas into the field of electronics and narrowed the gap between theory and practice. It also demonstrated a fast way of developing the prototype of a new product by using efficient simulation tools such as Matlab/Simulink. All this improved the cooperation between control engineers and electrical engineers.

A 500 W switching power supply was chosen as a target to study the control of the output voltage. The desired control accuracy was ±0.3 V in normal operation, ±2V for maximum load disturbances, and ±0.5 V for maximum line disturbances. A basic DC-DC converter topology (Buck) has been modeled in both voltage and current control modes. The operation of standard PID controller and its modification has been studied and simulated by using the software *Matlab/Simulink*. The results were verified by using *Saber*, which is a large simulation tool especially designed to simulate electrical systems. The results showed that Matlab/Simulink is an effective and accurate tool, and there is no question about its applicability in the simulation of devices containing high-frequency switching and dynamics. The discredited PID controller was designed and its operation was investigated by simulation. The design specifications were met as shown by the simulation results.

Troublesome operation modes like the cases with a constant power load and modified constant power load were studied both theoretically and from the control viewpoint. The theoretical problems related to these issues (e.g. regarding stability) were solved and suitable control solutions were provided. Because in the constant power load

case the control problem becomes nonlinear, a fuzzy control algorithm was designed and tested by using the software *FuzzyTech*.

The non-ideal characteristics of a real switching power supply were modeled by including equivalent series resistors (ESRs) in the model. Also the effect of line and load disturbances were studied and taken into account in the controller design to meet the design objectives. For comparison, an internal model control (IMC) algorithm was designed and tested to achieve the desired output voltage especially in the case of load disturbances. A test bench for testing the control algorithms was constructed by removing the analog control part from a real power supply and connecting a DSP board to control the output voltage.

The scientific and engineering results of the project consist of Modeling, analysis, controller design, and simulation of a DC-DC converter, by then to build a test bench to verify the operation.

2.5 SWITCHED-MODE POWER SUPPLIES

The regulated power supply technology can really be divided into two distinct forms; firstly, the linear or series regulator and, secondly, the switched-mode conversion technique. Switched-mode technology is multi-facetted with a wide variety of topologies achieving the end result of providing a regulated DC voltage.

The main differences between the linear and switched-mode regulator are in the size, weight and efficiency. The linear regulator utilizes simple techniques of controlled energy dissipation to achieve a regulated output voltage independent of line and load variation. It is, therefore, inherently inefficient, especially when a wide input voltage range has to be catered for.
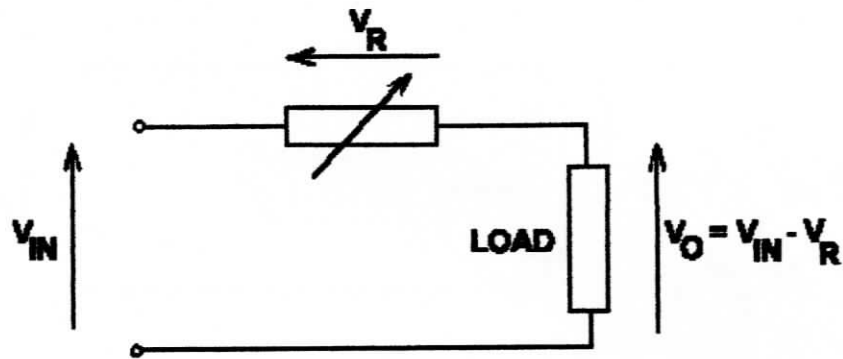
Figure 2.7: Linear Series Regulator Equivalent Circuit

A typical linear power supply is shown in Figure 2.8. The step down, low frequency mains transformer is very bulky, large heat-sinking is required to dissipate the heat generated by the regulating element and very large filter capacitors are required to store enough energy at the voltage to maintain the output for a reasonable length of time when the mains source is removed. Switched-mode techniques, on the other hand, offer the possibility of theoretically loss-less power conversion. The switched-mode regulator employs duty cycle control of a switching element to block the flow of energy and thus achieve regulation. It has the added advantage of when applied to off-line applications of giving significant size reduction in the voltage transformer and energy storage elements.
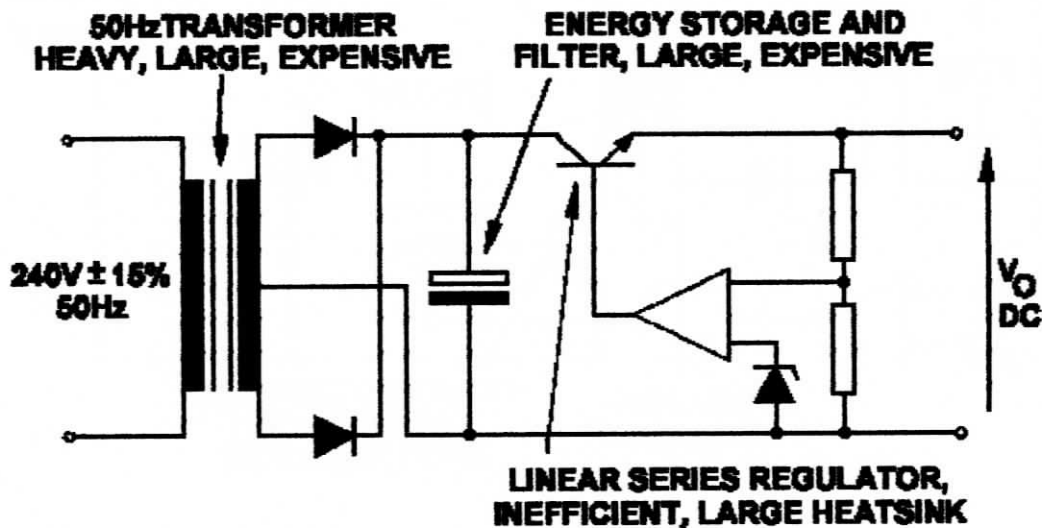

Figure 2.8: Practical Linear Series Regulator Circuit

$$V_O = \frac{1}{T} \int_0^T V_{IN}\, dT$$

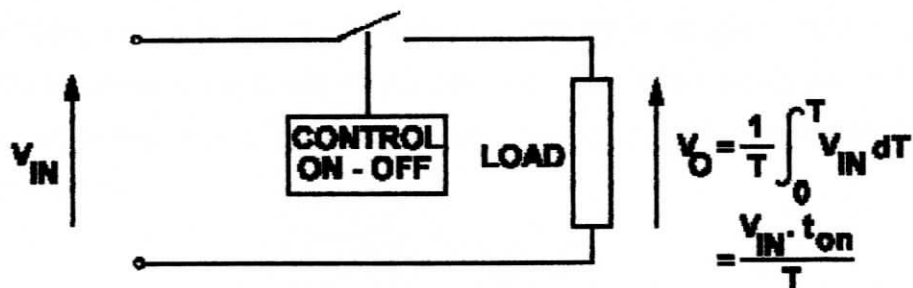$$= \frac{V_{IN} \cdot t_{on}}{T}$$

Figure 2.9: Switched-Mode Regulator Equivalent Circuit

Since a switched-mode converter can operate at significantly high frequencies, then a smaller transformer using ferrite cores can be used. Also since the high rectified mains voltage is chopped, then energy storage for hold-up can be accomplished on the primary side of the step-down transformer and so much smaller capacitors than the linear counterpart can be used. As shown in figure 2.10 below.
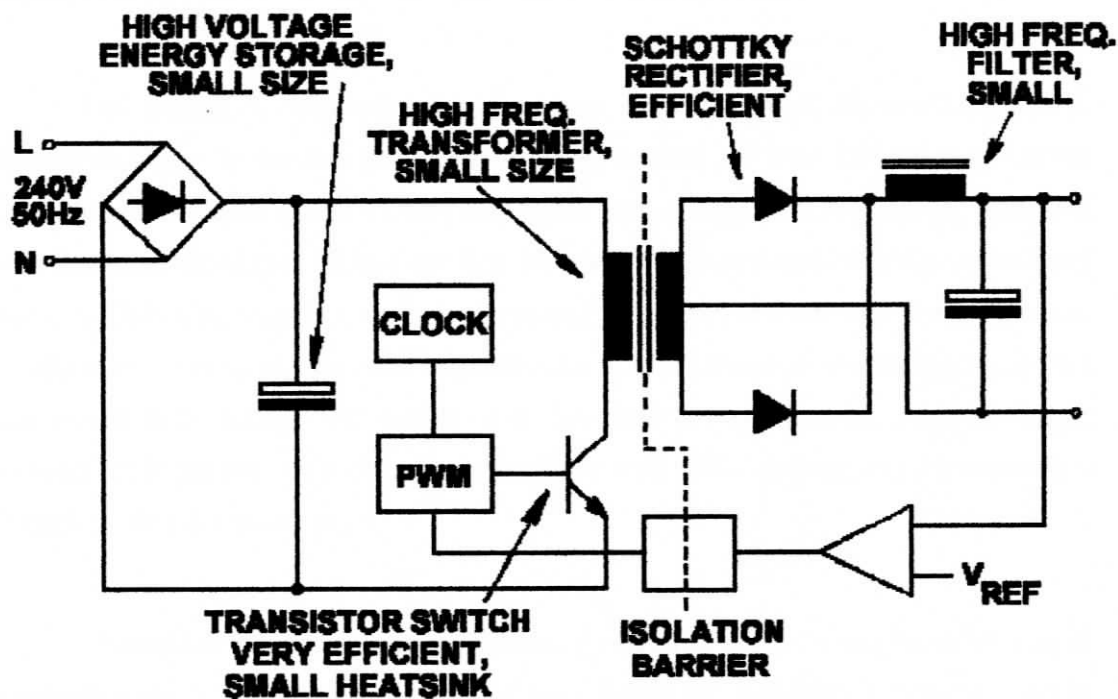

Figure 2.10: Practical Circuit of a Switched-Mode Regulator