# Chapter 1

## INTRODUCTION

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1.1 Introduction

This chapter gives an introduction to Switched Mode Power Supply (SMPS). The requirements of a SMPS and various types of DC-DC converters (isolated and non-isolated) are also discussed. The concept of resonance, quasi-resonance, hard switching and soft switching are deliberated at full length. This chapter also discusses - identified research gaps, research focus, contribution and organisation of the thesis.

1.2 Switch Mode Power Supplies

Many analog and digital electronic systems require regulated DC power supplies. These power supplies should adhere to certain requirements such as:

- Regulated Output: The output voltage must remain constant within a specified range for variations in input voltage and output load.
- Isolation: The input and the output must be electrically isolated.
- Multiple Outputs: Multi-output (positive and negative outputs) that may differ in voltage and current ratings must be isolated from one another.

Reduction in power supply size, weight and improvements in efficiency are additional requirements. Traditionally, linear power supplies were used. SMPS, as compared to linear power supplies, are smaller and much more efficient due to advancements in semiconductor
technology. The cost comparison between linear and SMPS depends on the power rating. High frequency transformer provides electrical isolation in SMPS.

### 1.3 DC-DC Converters

In general, switch mode converters can be either Isolated or Non-isolated. By isolation, it is implied as galvanic isolation so that there is no DC path from the input of the converter to its output. In order to meet the requirements of various agencies, electronic equipment operating from the AC power line needs at least one stage of isolated conversion. Non-isolated converters are Buck, Boost and Buck-boost converters. Isolated converters are Forward, Flyback, Half Bridge, Full Bridge and Push-pull converters.

#### 1.3.1 Non Isolated Converters

Buck, Boost and Buck Boost converters are basic converters, simple, with less component count and least cost. The main drawback of these converters is that the outputs are not isolated and hence are normally not preferred.

#### 1.3.2 Isolated Converters

Isolation refers to the existence of an electrical barrier between the input and output of a DC-DC converter. A separation between the applied input voltage and output voltage, which is often user accessible,
is an essential requirement as mandated by safety agencies and customers. An isolated DC-DC converter with an inbuilt high frequency transformer in the topology provides a barrier that could withstand few tens of volts to kilo volt ranges and hence are appropriate for medical applications also. The output of the isolated converters can be configured to be either positive or negative which is an added advantage. Depending on the way the transformer is utilised, isolated DC-DC converters are divided into two basic categories:

- **Unidirectional core excitation:** It is a first quadrant operation - only the positive part of B-H loop is used. Two topologies which come under this category are flyback converter and forward converter.

- **Bidirectional core excitation:** It is first and third quadrant operation - both positive and negative parts of B-H loop are utilised alternatively. Three basic topologies of bidirectional core excitation are push-pull, half bridge and full bridge.

  When output voltage needs to be isolated from main supply, flyback converter is the most commonly used SMPS circuit for low output power applications. Moreover, the overall circuit topology is simpler than other SMPS circuits. The output power of flyback type SMPS circuits may vary from few watts to less than 150 watts. The circuit can offer single or multiple isolated output voltages and can operate over wide range of input voltage variations. However, its simple topology and low cost make it popular in low output power ranges. The commonly used flyback
converter requires a single controllable switch such as MOSFET - with switching frequency in the order of hundreds of kHz. However, it suffers a few drawbacks such as - the regulation and output ripples are not as tightly controlled as in other topologies and the stress on the power switch is higher.

The forward converter is essentially an isolated version of the buck converter operating in the direct mode and the basic single switch version can be operated over a wide power range. Due to the transformer, the forward topology can be used as either a step-up or step-down converter, although the most common application is step-down conversion. Only the positive half of the core magnetization is utilized by forward converter since the magnetizing current and core flux are unidirectional. Therefore, the core is under-utilized and the size of the core is larger than a bi-directional core for the given output power. Forward topology is relied upon for its simplicity but the necessity of a tertiary winding to demagnetise the core is a setback.

Half bridge topology is used in many applications because of its wide range of power as well as good performance characteristics. Because of the capacitive voltage divider, the non-conducting FET sees only input voltage \( V_{in} \) as voltage stress. Since two power devices share the input current load and see reduced voltage stress, the half bridge is a popular choice for OFF line converters upto several hundred watts.
Most high power (>600W) off-line converters use some form of full bridge topology. The shortcomings of this topology are - increased complexity and cost.

For push-pull converters, the primary power is shared by two switch devices, each alternately conducting the primary current through each half of the split primary winding. The voltage stress on the power switches tends to limit this topology to applications with moderate input voltage levels. It is not, however, used for OFF-line converters. The benefits of using a push-pull converter are its simplicity and its ability to scale up to a higher power throughput, thereby earning them a place in industrial DC power applications. The push-pull converter magnetizes the core in both directions to utilize the core in a better way. The output ripple frequency is twice the fundamental frequency of the primary circuit; hence a smaller output filter is required to achieve the desired output ripple characteristics. Since this topology is self-resetting, a transformer reset winding is not necessary. Multiple outputs are possible with a push-pull converter. Considering all the above advantages, push-pull converters are preferred over other converters.

Table 1.1 compares the list of converters, both isolated and non-isolated, with respect to factors such as power range, efficiency and relative costs at rated supply and load [103]. From the table, it is clear that among the isolated converters, flyback and push-pull converters are
higher in efficiency and lesser in relative part costs, and hence best opted for low and medium power applications.

**TABLE 1.1 Comparison of converters efficiency [103]**

<table>
<thead>
<tr>
<th>Topology</th>
<th>Power range (W)</th>
<th>V_{in} Range (V)</th>
<th>In/Out Isolation</th>
<th>Efficiency (%)</th>
<th>Relative cost of parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buck</td>
<td>0 – 1000</td>
<td>5 – 40</td>
<td>No</td>
<td>78</td>
<td>1.0</td>
</tr>
<tr>
<td>Boost</td>
<td>0 – 150</td>
<td>5 – 40</td>
<td>No</td>
<td>80</td>
<td>1.0</td>
</tr>
<tr>
<td>Buck-Boost</td>
<td>0 – 150</td>
<td>5 – 40</td>
<td>No</td>
<td>80</td>
<td>1.0</td>
</tr>
<tr>
<td>Forward</td>
<td>0 – 150</td>
<td>5 – 500</td>
<td>Yes</td>
<td>78</td>
<td>1.4</td>
</tr>
<tr>
<td>Flyback</td>
<td>0 – 150</td>
<td>5 – 500</td>
<td>Yes</td>
<td>80</td>
<td>1.2</td>
</tr>
<tr>
<td>Push-pull</td>
<td>100 - 1000</td>
<td>50 – 1000</td>
<td>Yes</td>
<td>75</td>
<td>2.0</td>
</tr>
<tr>
<td>Half bridge</td>
<td>100 - 500</td>
<td>50 – 1000</td>
<td>Yes</td>
<td>75</td>
<td>2.2</td>
</tr>
<tr>
<td>Full bridge</td>
<td>400 - 2000+</td>
<td>50 – 1000</td>
<td>Yes</td>
<td>73</td>
<td>2.5</td>
</tr>
</tbody>
</table>

**1.4 Hard Switching**

In switch mode DC-DC converters switches are turned ON/OFF with full load current. As Fig. 1.1 shows this operation, the switches are subjected to high stresses and power loss [97 -98]. The efficiency of the converter decreases as losses increase in a linear fashion with the switching frequency of the Pulse Width Modulation (PWM). The Electro Magnetic Interference (EMI) produced from large di/dt and dv/dt is another significant drawback. At high switching frequencies the above mentioned drawbacks are further worsened. On the other hand, selection of higher switching frequencies aids in the design of compact and light weight converters.
The switching loss is given by

\[ P_s = \frac{V_o I_o f_s}{2} (t_n + t_o) \]  

(1.1)

Fig: 1.1. Generic Switching Waveforms (a) Control Signal (b) Switch Voltage (c) Switch Current (d) Instantaneous Switch power loss.

The above equation (1.1) shows that switching losses vary linearly with output voltage \((V_o)\), output current \((I_o)\), switching frequency \((f_s)\), its fall time \((t_n)\) and rise time \((t_o)\). Hence the switch mode converters are not suitable for frequencies greater than 20 kHz. A simple dissipative snubber placed across the switch can reduce the switching losses. However, the converter efficiency remains unchanged as the power loss shifts from switch to snubber.

As deduced from equation (1.1), the switching losses can be reduced by:

- Using faster and more efficient switches in which the turn ON and turn OFF delay times are reduced.
- Making the current through or voltage across the switch to be zero before turning it ON/OFF. Converters based on these concepts are called Soft Switching Resonant Converters.
1.5 Soft Switching

To obtain loss-less switching, soft switching techniques are preferred at high switching frequency [94], [98]. The advantages of soft switching are:

- High frequency operation is possible
- Reduction in the converter size
- Less EMI as switching process is not abrupt
- Parasitic capacitance energy can be recovered completely

1.6 Resonant Switch

Earlier thyristors were used in converters for wide range of power applications. The main problem with thyristor is commutation. It can be either natural or forced. One such forced commutation circuit involves a LC resonant circuit, for forcing the current to zero during the turn OFF process. This technique is a type of zero current turn OFF process. The use of a resonant circuit for achieving zero current switching or zero voltage switching has emerged as a new technology for power converters. The concept of a resonant switch replacing a conventional power switch is introduced in this section.

A resonant switch is a sub circuit composed of a semiconductor switch S and resonant elements \( L_r \) and \( C_r \). Switch S can be implemented by a unidirectional or bidirectional switch which determines the operation mode of the resonant switch.
Two types of resonant switches (depending on whether the current through or the voltage across the switch is made zero) [98] are implemented:

1) **Zero-Current (ZC) Resonant Switch**: A switch that operates with zero current switching technique has an inductor in series with it. Switch current resonates only in the positive half cycle if the switch is unidirectional; creating a half wave mode of operation. Current through the switch can flow in both directions if the diode is connected antiparallel to the unidirectional switch. In this case, the resonant switch operates in full wave mode. The switch is turned ON with zero current and the switch current oscillates due to the resonance between $L_r$ and $C_r$. This switching is used to shape the waveform during conduction and to create a zero-current conduction for the switch to turn OFF.

2) **Zero-Voltage (ZV) resonant Switch**: This technique operates with a capacitor across the switch. In a unidirectional switch, Voltage across capacitor $C_r$ oscillates both in positive and negative half cycles freely and hence the resonant switch operates in full wave mode. During the negative half cycle, resonant capacitor voltage gets clamped to zero by the diode when it is antiparallel to the switch ensuring the half wave operating mode. Voltage across the switch tends to zero, causing the switch to be turned ON with ZVS - if negative current is forced to flow through the anti-parallel diode. Switch voltage waveform during OFF time can be shaped by using the resonant circuit. This creates a zero
voltage condition for the switch to turn ON which is the sole purpose of a ZV switch.

1.6.1 Quasi-Resonant Converters

A new class of Quasi-resonant converters were introduced to overcome the drawbacks of hard switched PWM converters. Resonant tanks in converters were incorporated in order to create oscillatory (usually sinusoidal) voltage or current waveforms, so that zero voltage and current switching conditions could be created for power switches.

Quasi-resonant converters (QRCs) can be considered as a hybrid of resonant and PWM converters. The primary principle is replacing the power switch in PWM converters with a resonant switch. If the resonant elements (inductor and capacitor) are added to the DC-DC converters then the resulting converters are known as resonant switch converters.

Primarily, LC resonance can be utilized to shape switch voltage and current in switch mode converter topologies so as to provide switching of zero-voltage and/or zero current. In such topologies, there are resonant and non-resonant operating intervals in the same switching-frequency time period. Therefore, these converters have been termed as Quasi-resonant converters.

A large family of conventional converter circuits can be transformed into their resonant converter counterparts. By operating the converters in zero voltage or zero current switching mode, switching losses of devices (MOSFETs, IGBTs, etc.) can be reduced. The switch
current and/or voltage waveforms are forced to oscillate in a quasi-sinusoidal manner instead of square-wave in DC-DC or DC-AC PWM converters so that ZCS or ZVS can be achieved.

Advantages of the Quasi-resonant converters are:

- Switching losses are reduced
- Circuits can be operated at comparatively higher frequencies than that of PWM converters
- Less cost and compactness of circuit makes it more economical since operating frequency is high
- EMI problems are less severe
- Higher efficiency

Broadly, quasi-resonant converters can be classified in the following switching topologies:

- Zero-Current Switching (ZCS topology)
- Zero-Voltage Switching (ZVS topology)

Both ZCS-QRCs and ZVS-QRCs have half wave and full wave modes of operation [94 – 101].

**1.6.1.1 Zero-Current Switching (ZCS) topology**

The switch turns - ON and OFF at zero current. Fig. 1.2 shows the two switch types namely L and M type. ZCS can also be either half wave (unidirectional) or full wave (bi-directional) as presented in Fig. 1.2(b) and (c) for L and M types respectively[94], [98].
As shown in both types, the circuit consists of a switch, inductor and a capacitor; the inductor $L_r$, limits $di/dt$ of the switch current, and $L_r$ and $C_r$ constitute a series resonant circuit. When the switch current is zero, current $i = C_i dV_T/dt$ flows in the internal switch capacitance $C_i$ (the capacitances measured between collector to emitter terminal with gate of switch $S$ (IGBT) shorted [94]) due to a finite slope of the switch voltage ($V_T$) at turn-OFF. Switching frequency is limited because the high current flow causes power dissipation in the switch.
1.6.1.2 Zero-Voltage Switching (ZVS) topology

Here, the switch turns ON and OFF at zero voltage. The two types of ZVS circuit as per the position of the resonant capacitor, namely L and M type are as shown in Fig. 1.3(a) and (b) respectively.

In L type, Capacitor \( C_r \) is connected parallel to switch S in order to achieve ZVS. When internal switch capacitance \( C_j \) is added to the resonant capacitance value, it affects only the resonant frequency but does not contribute to the power dissipation in the switch. Voltage transients appear across the switch since some amount of energy gets trapped in inductor \( L_r \) of M-type configuration while switch is turning OFF; therefore, L type is preferred over M type configuration. The ZVS can also be either half wave (unidirectional) or full wave (bidirectional) type.
1.7 Comparative Analysis

The comparison, merits, demerits and limitation of ZVS and ZCS techniques [94 – 100] are discussed in this section.

1.7.1 Limitations of ZCS

Switching losses at turn-OFF can be eliminated and those at turn-ON can be reduced in a ZCS converter. During resonance, converter operation is insensitive to diode’s junction capacitance as a relatively large capacitor is connected across the output diode. Energy stored in the capacitance of device will dissipate when power MOSFETs are switched ON by zero current method. This capacitive turn-ON loss is proportional to the switching frequency. A considerable rate of change of voltage can be coupled to the gate drive through Miller Capacitor, thereby increasing the switching losses as well as noise during turn-ON condition.

Moreover ZCS switches are under high current stress so the conduction loss shoots up high. However, ZCS is particularly effective in reducing switching loss for power devices (such as IGBT) with large tail current in the turn-OFF process.

1.7.2 Advantages of ZVS over ZCS

Zero-voltage switching is a more appropriate control strategy for high frequency resonant switch mode converters than zero-current
switching control since this system has more advantages as mentioned below:

- Switching losses and stresses can be eliminated in the semiconductor devices. The switching losses being eliminated include the loss internal to the device due to the discharging of junction capacitances when the device is turned ON. In ZVS, the parasitic switch capacitance dissipates its energy into the load - if there were no ZVS this parasitic capacitance would dissipate as heat which lowers the efficiency of the system. When the switching frequency exceeds 1MHz in a PWM converter or a conventional resonant converter, the internal losses becomes significant. Thus, ZVS eliminates the capacitive turn ON losses; making it suitable for high frequency operations.

- Elimination of dv/dt noise due to device switching. The noise is often coupled into the drive circuit by means of the Miller effect and is one of the primary limiting factors for designing at very high frequencies.

- The peak current through the semiconductor devices is small as compared to PWM system.

- The EMI is reduced during transition.

- High efficiency.

- It can withstand short-circuit conditions.
• System can incorporate parasitic circuit components like inductance and capacitance.

1.8 ZVS Types

As discussed above, ZVS is preferred over ZCS especially in high frequency applications. The two types of ZVS, viz, half wave and full wave modes are discussed in detail in this section. The same types are applicable for ZCS also.

1.8.1 Half Wave Mode ZVS-QRC

In half wave mode ZVS-QRC [98] shown in Fig 1.4(a), switch S carries output current $I_o$ when it is turned ON. The supply voltage $V_i$ reverse-biases the diode $D_f$. Output current flows through the resonant capacitor $C_r$ when switch is turned OFF at zero voltage (ZV). When the resonant capacitor voltage $V_{Cr}$ is equal to $V_i$, $D_f$ turns on; starting the resonant stage. Anti-parallel diode turns ON, when $V_{Cr}$ equals zero. Resonant inductor $L_r$ is connected to the supply through the switch diode since the resonant capacitor is shorted by the later. Fig. 1.4(b) shows a linear increase in resonant inductor current $I_{Lr}$ until it reaches $I_o$ where $D_f$ turns OFF. In order to achieve ZVS, switch S should be triggered when the anti-parallel diode begins to conduct.
1.8.2 Full Wave Mode ZVS-QRC

Apart from the fact that resonant capacitor voltage $V_{cr}$ can swing between positive and negative voltages, the operation of full wave ZVS converters is similar to that of operation in half wave mode. The circuit diagram and the theoretical waveforms are as displayed in Fig.1.5 (a) and (b) respectively [98]. Energy stored in the output capacitance of the switch dissipates during turn ON as the series diode limits the direction of the switch current. Hence, the full wave mode has the problem of capacitive turn-ON loss and is less practical in high-frequency operation. High efficiency (due to less circulating energy) and simple structure (secondary rectifier diodes are the blocking devices providing half wave operation) also adds to the advantages of half wave operation. So ZVS-QRCs are usually operated in half wave mode rather than in full wave mode.
1.9 ZVS with Clamped Voltage

Clamped voltage technique overcomes the problem due to high voltage stress in single switch configuration with ZVS. The peak switch voltage can be clamped to the DC supply rail, thereby reducing the switch voltage stress. Moreover, series transformer leakage and circuit inductance can form parts of the resonant path. Although these parasitic components are undesirable in hard switched converters, they are useful in ZVS. The OFF-state voltage of the switches will not exceed the input voltage during resonance as they will be clamped to the supply rail by the anti-parallel diode of the switches.

1.10 Research Gaps

The research gaps identified in resonant push-pull and flyback converters are detailed in this section. As deliberated at the outset, the downsides of hard switched PWM converters are alleviated by incorporating resonant switches. But the introduction of resonant
switches results in high voltage stress across the switches. Furthermore
the rectifier diodes in the secondary of the transformer are subjected to
switching losses at high frequencies and high voltage stress due to the
energy stored in the transformer leakage inductance.

Moreover the use of multi-output push-pull and flyback DC-DC
converters to obtain compactness in aerospace applications results in
poor output regulation and lesser voltage conversion ratios due to
saturation problems. Analog controllers employed for addressing the
regulation problems demand extra power supplies and isolation circuits,
which in turn increases the cost factor. Additionally the selection of
controller IC for a particular application is a tedious job.

1.11 Research Focus

Considering the knowledge gained from the research gaps
identified, the research focuses to:

- reduce the switching losses
- increase the compactness of the converters
- reduce the switch voltage stress in ZVS
- reduce the cross regulation effects
- implement fuzzy controller
- increase the efficiency of the converters
1.12 Main Contribution Of The Thesis

This thesis is concentrated on exploring the possibilities of finding the new techniques for improving the line regulation, load regulation, reduction in switch voltage stress, reduction in switching losses, increasing number of outputs from a single unit thus improving the performances of the SMPS used for low voltage applications like telecommunication, set top boxes, decoders and to power the diverse subsystems such as drives, tuners, audio stages and complex processor and logic circuits with voltage/current ranges of 5V/0.5A, 3.3V/0.33A, etc.

A. ZVS Technique

Hard switching topologies have the disadvantages of switching ON/OFF at high load current/voltage. This increases the switching losses and reduces the efficiency. Hence hard switched converters are nowadays replaced by Quasi-resonant converters. This work implements ZVS topology for reducing the switching losses. Unlike ZCS converters they also have reduced switch current stress.

B. Multi-Output Topologies

To reduce the size of converters and to provide multiple isolated outputs from a single unit - multi-output topologies are used. These isolated multi-output converters occupy the same area as a single output converter and hence are preferred in applications like satellite payload, telecommunication power supplies, etc. where different voltage ranges
are required for powering different networks. Single output topology is commonly implemented for powering low power motors for robotic applications.

C. Voltage Doubler on the Secondary

To obtain a higher voltage at the load, a voltage doubler is introduced on the transformer secondary. The features of voltage doubler are higher voltage conversion ratio, reduced current/voltage stress in the secondary devices, less reverse recovery losses in rectifier, reduced switching losses in the secondary diodes and it eliminates the RC snubber across the diodes.

D. Active Clamp Circuit For Primary Switches

Voltage stress across the ZVS switch in the resonant flyback and push-pull converter is too high. To overcome this shortcoming, an active clamp flyback converter is added to the basic converter topology. Incorporation of active-clamp circuitry into the flyback topology serves to recycle transformer leakage energy while minimizing switch voltage stress. The active clamped switch introduced is turned ON at zero voltage; this action discharges energy from active clamp capacitor to transformer leakage inductance that is then used to discharge the capacitor across the switch thus bringing down voltage across the switch to zero before turn ON. The capacitor also acts as clamp that avoids excessive voltage ringing across the switches. ZVS also limits the turn-
OFF $\frac{di}{dt}$ of the output rectifier, reducing rectifier switching losses, and switching noise due to diode reverse recovery.

**E. Enhanced PID Controller (EPID)**

PWM technique is generally used for controlling switched mode power supplies. The conventional linear controllers like P, PI and PID are deployed for implementing the above said technique. These proportional, derivative and integral constants chosen react on the present error, cumulative errors and rate of change of error respectively. The controller output is the weighed sum of all these three actions. The controller output is variable in nature which in turn varies the pulse width of the PWM thus controlling the switch. Enhanced constants are introduced to the integral and derivative parts aids in improving the performance of the controller by reducing the peak overshoot, peak time and settling time of the output without affecting the PI parameters. They enhance the dynamic response of the system by reducing the error at a faster rate without any major alterations to the conventional systems. Owing to the advantages enumerated above EPID (conventional PID with enhanced constants) is employed for push-pull converter to reduce the settling time and to obtain faster response.

**F. Analog Controller**

Regulated outputs for line and load transients are achieved with the closed loop operation of the converters. Two IC were deployed to
obtain the same, IC SG3525 and UC3825. The differentiating factor here, being the accuracy of the latter. UC3825 has a wide range of switching frequency up to 1MHz which is approximately 2.5 times greater than the switching frequency generated by the general purpose IC SG3525. It also has better advantages like higher gain bandwidth error amplifier, very low rise and fall time - in the order of tens of nano seconds, fixed frequency pulse width modulation control, high current output of 2A and less noise voltage levels.

SG3525 is positioned in current fed push-pull converter and a ZVS flyback converter (single and multi-output) as it is cost effective and a generic lab purpose IC. Whereas, UC3825 is best suited for applications where tight regulations and accuracy are required, and so is positioned in multi-output hard switched flyback converters and active clamp ZVS flyback converters (single and multi-output). For aerospace applications, UC3825 is replaced by UC1825 which meets the standard requirements of aerospace while its operations and technical specifications remain the same as UC3825. The working of UC3825 IC is analysed by positioning it in multi-output hard switched flyback converters and active clamp ZVS flyback converters (single and multi-output).

**G. LDO Post Regulator**

Multiple output switching power converters are widely used in various sectors. However, one of their major drawbacks is the poor regulation. Hence a linear regulator controller, a Low Drop Out (LDO)
post regulator (UC1834) which has low power dissipation, good line and
dynamic load regulation, is used for achieving tight output regulation.
This IC is compatible with voltage and current mode topologies for
practical operation with switching frequency varying upto 1MHz.

**H. Fuzzy Implementation**

To improve the speed of response, a fuzzy controller is integrated to
the active clamp ZVS multi-output secondary voltage doubler flyback
converter. Fuzzy controllers are simple and robust. They are faster in
response, cost effective and are well suited for large load and line
variations, since the variations can be regulated with change in fuzzy
code without disturbing the hardware set up.

The concepts of ZVS, active clamp, multi-output and voltage
doubler used in this research work are referred from various individual
topologies designed for high power applications (1kW and above).
Extensive search into the papers referring to these concepts and
topologies involved indicates that there is no research work reported
regarding the same for low power applications (less than 100W). This
research work concentrates on combining these concepts into a single
topology for low power applications like setup boxes, TTL logic circuits,
CMOS circuits, power supplies for space crafts and communication
circuits. The contributions in the thesis are substantiated with the help
of simulation results obtained using MATLAB and PSIM simulation
environment and are experimentally validated.
1.13 Organisation of the Thesis

The organization of this thesis is in the following order:

In **chapter 1**, various resonant techniques used in SMPS are discussed. The state of art assessment of ZVS based full wave and half wave mode converters are provided. The performance issues of the ZCS based converters are also highlighted.

**Chapter 2** presents a detailed literature survey on the performance issues of the state of the art DC-DC converters.

**Chapter 3** presents the implementation of hard switched push-pull topology. To analyse the hard switched topology, multi-output hard switched converter was implemented and the implementation details are discussed in detail in this chapter.

**Chapter 4** contains the implementation details of multi-output push-pull converters, ZVS single and multi-output topologies with and without voltage doublers. Hard switching is replaced by ZVS and, to improvise further, voltage doubler circuit is incorporated in the load side. Experimental validation of single and multi-output is presented in this chapter.

**Chapter 5** deals with hard switching, ZVS, voltage doubler for single and multi-output flyback converters. Closed loop implementation of the topology is also explained. The impact of variation on supply voltage and load, and adaptability of converters to variations for obtaining a regulated output are also discussed in this chapter.
Chapter 6 explains the concept of active clamp in multi-output ZVS flyback topology. It also highlights the fuzzy logic based implementation of active clamped ZVS multi-output secondary voltage doubler. The results obtained for line and load variations are also analysed.

Chapter 7 is devoted to the summary and conclusions of the present research work, along with a note on the future scope.

1.14 Conclusion

Push-pull and flyback converters have better efficiency, cost effective, less voltage and power stress across the switches, for the low power level as discussed in Table 1.1, and hence are selected for implementation. The operation of basic converters is highlighted in this chapter. Analysis and design methodology of soft switching converters are more complex than hard switched PWM converters. Such soft switching converters have the attractive operational features like compactness, high efficiency and low EMI. Hence soft switching converters have taken up an appreciable share of the SMPS market. In the following chapters the single and multi-output ZVS push-pull and flyback Quasi-resonant converters are discussed. Operation, design methodology and results are presented in the subsequent chapters. High switch stress in ZVS converters are also addressed in the modified converter with clamping techniques.