CHAPTER I

INTRODUCTION

1.1 Power Devices

In many applications it is desirable to control a power converter using a microcontroller or a digital signal processor (DSP) for the implementation of sophisticated control schemes such as fuzzy control renewable energy sources control etc. The block diagram of such a configuration is depicted in Fig 1.1. A set of sensors, used to measure the power converter signals of interest, such as the output current or voltage, output frequency, etc [31]. These are interfaced through an Analog to Digital (A/D) converter to a microcontroller or DSP unit [8].

Fig.1.1. General block diagram of implementations of Digital power converter control using a Microcontroller or DSP units.
The measured parameters are input to a digital controller in order to adjust the duty cycle value of the PWM signals, which further control the power converter operation, according to the desired control law, such as fuzzy logic control, PID control, and neural networks control. Since it is desirable to integrate all operations in a single IC for reduction of the total system rate, each PWM signal is usually generated using an on-chip PWM generator [14].

The study of Conversion techniques is a major research area in the field of power electronics. The equipment for conversion techniques are applied in industry, research and development, government organizations. This equipment can be divided in four technologies [18] and [75]:

1. AC/AC transformers
2. AC/DC rectifiers
3. DC/DC converters
4. DC/AC inverters

According to incomplete statistics, there have been more than 500 prototypes of DC/DC converters developed in the past sixty years. All existing DC/DC converters were designed to meet the requirements of certain applications. They are Buck converter, Boost converter and Buck-Boost converter, zero current switching (ZCS) and zero voltage switching (ZVS) converters. Large number of DC/DC converters had not been evolutionarily classified until 2001[36].

The types of converters are classified into six generations according to the characteristics and development process. This classification grades all DC/DC converters and categorizes new prototypes. Since 2001, the DC/DC converter has been built and this classification has recognized in all over the world. Now it is easy to sort and allocate DC/DC converters and assess their technical features. DC/DC converters are essential in
variety of applications including power supplies such as personal/laptop computers, cellular phones, office equipment’s, spacecraft power systems, and telecommunication equipment’s, as well as solar systems where input/output voltage ranges overlap. PWM generation is considered the more important in the Converter design and several multicarrier techniques have been developed to reduce the distortion in level converters based on the classical with triangular carriers [38]. A DC/DC converter is an electronic circuit which converts a source of direct current (DC) from one voltage level to another. It is a class of power converter [73].

**Power Converter**

Power conversion is converting electric energy into another form. One way of classifying power conversion systems having the input and output are either alternating current or direct current [39].

**Classification of converter:**

1. DC to DC
2. AC to DC
3. DC to AC
4. AC to AC

1.1.1 DC to DC converter

a) *Types of dc to dc converter*

1. **Buck converter:** A buck converter is a step-down DC/DC converter. This design is similar to the step-up boost converter and like the boost converter it is a switch mode power supply (SMPS) that uses two switches (a transistor and a diode), an inductor and a capacitor [60].

2. **Boost converter:** A boost converter (step-up converter) is a DC/DC power converter with an output voltage greater than its input voltage. It is a class of SMPS containing at least two semiconductor switches (a diode and a transistor) and at least one energy
storage element which is capacitor, inductor, or the two in combination. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

3. **Buck–boost converter** is an one type of DC/DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude [3].

4. **The Cuk converter** (pronounced Chook) is a type of DC/DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude [40].

   The non-isolated Ćuk converter can only have opposite polarity between input and output. It uses a capacitor as its main energy storage component, unlike most other types of converters which use an inductor. It is named after Slobodan Ćuk of the California Institute of Technology, who first presented the design [61].

5. **Fly back converter**

   The fly back converter is used in both AC/DC and DC/DC conversion with galvanic isolation between the input and any outputs. More precisely, the fly back converter is a buck-boost converter with the inductor split to form a transformer, so that the voltage ratios are multiplied with an additional advantage of isolation. When driving for example a plasma lamp or a voltage multiplier the rectifying diode of the buck-boost converter is left out and the device is called a fly back transformer [42].

b) **Advantages of Dc to Dc converter**

1. Wide operating temperature range
2. Wide input range for world-wide use
3. Mechanical stability for highest demands
4. Can be used directly in industrial and railway environments
5. Compact design and high power density
6. Protected against short circuit, overloads and no load operations.

1.1.2 Principle of PWM generation

PWM generation is considered very important in the Converter design and several multicarrier techniques have developed to reduce the distortion in level converters based on the classical with triangular carriers. Some of the methods use carrier disposition and others use phase shifting of multiple carrier signals [43]. The sine wave is used as a reference to generate PWM. The DC source ($V_{cd}$) is used as a carrier signal. This DC source carrier signal is compared with a sinusoidal reference signal. The crossover points are used to determine the switching instants such as $V_{reference}$ is greater than $V_{carrier}$, then output is high otherwise, the output is low. PWM is mainly used to allow the control of the power supplied to electrical device especially to inertial loads such as motors. The main advantage of PWM is that power loss in the switching devices is very low [15].
1.2 Historical Review

DC/DC conversion technology is a major subject area in the field of power engineering and drives, and has been under development for six decades. DC/DC converters are widely used in industrial applications and computer hardware circuits. DC/DC conversion techniques have developed very quickly. In addition to its higher growth rate, the DC/DC converter market is undergoing dramatic changes as a result of two major trends in the electronics industry: high power density and low voltage. From
this investigation it can be seen that the production of DC/DC converters in the world market is much higher than that of AC/DC converters [55] and [62].

The DC/DC conversion technique was established in the 1920s. A simple voltage conversion, the simplest DC/DC converter is a voltage divider, but it only transfers output voltages lower than input voltage with poor efficiency. The multiple-quadrant chopper is the second step in DC/DC conversion. Much time has been spent trying to find equipment to convert the DC energy source of one voltage to another DC actuator with another voltage, as does a transformer employed in AC/AC conversion [20] and [63].

Some preliminary types of DC/DC converters were used in industrial applications before the Second World War. The Research was blocked during the war, but applications of DC/DC converters were recognized. After the war, communication technology developed very rapidly and required low voltage DC power supplies. This result is the rapid development of DC/DC conversion techniques. Preliminary prototypes can be derived from choppers [21].

1.2.1 Development of DC/DC Conversion Technique

According to incomplete statistics, there are more than 500 existing prototypes of DC/DC converters. The main purpose is vital importance for future development of DC/DC conversion techniques. The basic classification of DC/DC converters are

1. First generation (classical/traditional) converters
2. Second generation (multi-quadrant) converters
3. Third generation (switched-component SI/SC) converters
4. Fourth generation (soft-switching: ZCS/ZVS/ZT) converters
5. Fifth generation (synchronous rectifier SR) converters
6. Sixth generation (multiple energy-storage elements resonant MER)
1.3 Buck–Boost Converter

The buck–boost converter is a type of DC/DC converter that has an output voltage magnitude that is either greater than or lesser than the input voltage magnitude. Two different topologies are called buck–boost converter. Both of them can produce a range of output voltages, from an output voltage much larger (in absolute magnitude) than the input voltage, down to almost zero [58]. The buck-boost is a popular non-isolated, inverting power stage topology, sometimes called a step-up/down power stage. Power supply designers choose the buck-boost power stage because the output voltage is inverted from the input voltage, and the output voltage can be either higher or lower than the input voltage [4].

The topology gets its name from producing an output voltage that can be higher (like a boost power stage) or lower (like a buck power stage) in magnitude than the input voltage. However, the output voltage is opposite in polarity from the input voltage. The input current for a buck-boost power stage is discontinuous or pulsating due to the power switch current that pulses from zero to $I_L$ every switching cycle. The output current for a buck-boost power stage is also discontinuous or pulsating. This is because the output diode only conducts during a portion of the switching cycle. The output capacitor supplies the entire load current for the rest of the switching cycle [22].

1.3.1 The inverting topology

The output voltage is of the opposite polarity than the input. This is a switched-mode power supply with a similar circuit topology to the boost converter and the buck converter. The output voltage is adjustable based on the duty cycle of the switching transistor. One possible drawback of this converter is that the switch does not have a terminal at ground; this complicates the driving circuitry. Neither drawback is of any consequence if the power supply is isolated from the load circuit (if, for example, the
supply is a battery) because the supply and diode polarity can simply be reversed. The switch can be on either the ground side or the supply side [5].

A buck (step-down) converter followed by a boost (step-up) converter the output voltage is of the same polarity of the input, and can be lower or higher than the input. Such a non-inverting buck-boost converter may use a single inductor which is used for both the buck inductor and the boost inductor.

1.3.2 Conceptual overview

Like the buck and boost converters, the operation of the buck-boost is best understood in terms of the inductor's "reluctance" to allow rapid change in current. From the initial state in which nothing is charged and the switch is open, the current through the inductor is zero. When the switch is first closed, the blocking diode prevents current from flowing into the right hand side of the circuit, so it must all flow through the inductor.

However, since the inductor does not like rapid current change, it will initially keep the current low by dropping most of the voltage provided by the source. Over time, the inductor will allow the current too slowly increase by decreasing its voltage drop. Also during this time, the inductor will store energy in the form of a magnetic field [29].

When the switch is then opened, the inductor will be cut off from the input voltage supply, so the current will tend to drop to zero. Again, the inductor will fight such an abrupt change in current. To do so, it must now act like a voltage source to the rest of the circuit, which it can do using the energy it stored while charging. Since current was previously flowing "down" the inductor and so the voltage that it provides will be inverted relative to input supply. During this time, the inductor will discharge through the load and the rest of the circuit, which will cause its voltage to decrease over time. Also
during this time, the capacitor in parallel with the load will charge up to the voltage presented by the inductor [72].

When the switch is once again closed, the diode is reversing biased by the input supply, cutting the load off from the left hand side of the circuit. During this time, the capacitor will discharge into the load, providing energy and voltage to it. By cycling the switch fast enough, the inductor can be allowed to charge and discharge only slightly in each cycle, maintaining a relatively steady voltage to the load. Similarly, the capacitor will only need to discharge slightly while the switch is closed before it has a chance to recharge again while the switch is opens [59].

The voltage presented by the inductor to the load depends on how long the switch is opened and closed. When the switch is closed and the inductor is charging, the current through the inductor is ramping up linearly. The longer the switch is closed, the higher the current will get. When the switch is then opened, it is the end current that the inductor will try to maintain by acting like a voltage source. The higher this current is, the more voltage the inductor will need to provide in order to produce it [73].

1.4 Zeta Converter

A Zeta converter is a fourth-order DC/DC converter made up of two inductors and two capacitors and capable of operating in either step-up or step-down mode. Compared with other converters in the same class, such as Cuk and SEPIC converters, the Zeta converter has received the least attention. Several types of AC/DC converters have been introduced to achieve the demanded power conversion, and the less problems on harmonic and power factor. Among all converters, the zeta converter, which is originally the buck-boost type, can be regarded as a fly back type when an isolated transformer is incorporated. An isolated zeta converter has some advantages including safety at the output side, and flexibility for output adjustment [7].
A Zeta converter performs a non-inverting buck-boost function similar to that of a SEPIC. But in application which implies high power, the operation of a converter in discontinuous mode is not attractive because it results in high rms values of the currents causing high levels of stress in the semiconductors [74]. An active power factor correction (PFC) is performed by using a Zeta converter operating in continuous conduction mode (CCM), where the inductor current must follow a sinusoidal voltage waveform. This method provides nearly unity power factor with low THD [30].

1.5 Protection of Converters

Power electronic converters often operate from the utility mains and are exposed to the disturbances associated with it. Even otherwise, the transients associated with switching circuits and faults that occur at the load point stress converters and devices. Consequently, several protection schemes must be incorporated in a converter. It is necessary to protect both the Main Terminals and the control terminals. Some of these techniques are common for all devices and converters. However, differences in essential features of devices call for special protection schemes particular for those devices [28].

The IGBT must be protected against latching, and similarly the GTO's turn-off drive is to be disabled if the Anode current exceeds the maximum permissible turn-off-able current specification. Power converters devices are commonly protected against:

1. Over-current;
2. di/dt;
3. Voltage spike or over-voltage;
4. dv/dt;
5. Gate-under voltage;
6. Over - voltage at gate;
7. Excessive temperature rise;
8. Electro-static discharge;
All types of Semiconductor devices exhibit similar responses to most of the stresses, however there are marked differences. The SCR is the most robust device on practically all counts. That it has an $I^2t$ rating is proof that its internal thermal capacities are excellent. A HRC fuse, suitably selected, and in co-ordination with fast circuit breakers would mostly protect it. This sometimes becomes a curse when the cost of the fuse becomes exorbitant [76].

All transistors, specially the BJT and the IGBT is actively protected (without any operating cost!) by sensing the Main Terminal voltage. This voltage is related to the current carried by the device. Further, the transistors permit designed gate current waveforms to minimize voltage spikes as a consequence of sharply rising Main terminal currents.

Gate resistances have significant effect on turn-on and turn-off times of these devices - permitting optimization of switching times for the reduction of switching losses and voltage spikes. Protection schemes for over-voltages - the prolonged ones and those of short duration - are guided by the energy content of the surges. Metal Oxide Varistors (MOV's), capacitive dynamic voltage-clamps and crow bar circuits are some of the strategies commonly used. For high dv/dt stresses, which again have similar effect on all devices, R-C or R-C-D clamps are used depending on the speed of the device.

These 'snubbers' or 'switching-aid-networks', additionally minimize switching losses of the device - thus reducing its temperature rise. Gates of all devices are required to be protected against over-voltages (typically $\pm 20$ V) especially for the voltage driven ones. This is achieved with the help of Zener clamps - the Zener being also a very fast-acting device. Protection against issues like excessive case temperatures and ESD follow well-set practices. Forced-cooling techniques are very important for the higher rated converters and whole environments are air-cooled to lower the ambient.
1.6 Features of VLSI

Considerable research over the past two decades focused on the design of parallel machines and many valuable research contributions were made. The mainstream computer market, however, was largely unaffected by this research. Most computers today are uniprocessor and even large servers have only modest numbers (a few 10s) of processors.

It is again to anticipate an exponential increase in the number of devices per chip. However, unlike 1979, there are few opportunities remaining to apply this increased density to improve the performance of uniprocessor. Adding devices to modern processors to improve their performance is already well beyond the point of diminishing returns. There are few credible alternatives to using the increased device count other than to build additional processors. Because the chip area of contemporary machines is dominated by memory, adding processors (without adding memory) boosts efficiency by giving a large return in performance for a modest increase in total chip area. To realize the potential of such fine-grain machines to convert VLSI density into application performance we must address challenges of locality, overhead, and software.

In 1979, anticipated scaling of VLSI technology favored the development of regular machines that exploited concurrency and locality and that were programmable. The expectation is to bring more than a thousand fold increase in the number of grids, and hence the number of devices that could be economically fabricated on a chip. Clearly concurrency (parallelism) would need to be exploited to convert this increase in device count to performance.

Locality was required because the wire bandwidth at the periphery of a module was scaling only as the square root of the device count, much slower than the 2/3 power required by Rent’s rule. Also, even in 1979 it was apparent that wires, not gates, limited the area, performance, and power of many modules. The issue of design complexity
motivated regularity and programmability. Designing an array of identical, simple processing nodes is an easier task than designing a complex multi-million transistor processor. A programmable design was called for so that the mounting design costs could be amortized over large numbers of applications.

In the first conferences, many of the hard problems of parallel machine design have been solved. The design of fast and efficient networks to connect arrays of processors together and mechanisms that allow processors to quickly communicate and synchronize over these networks have been developed.

1) A grid is an intersection of a horizontal and vertical wire. Hence the number of grids on a chip is the square of the number of wiring tracks that fit along one edge of a chip. As VLSI chips are limited by wiring, not devices, the number of grids is a better measure of complexity than the number of transistors.

2) The key here is to match the design of the network to the properties of the implementation technology rather than to optimize abstract mathematical properties of the network. Odds of programming parallel machines have been demonstrated. Research machines were constructed to demonstrate the technology, provide a platform for parallel software research, and solve the engineering problems associated with its realization. The results of this research resulted in numerous commercial machines that form the core of the high-end computer industry today.

3) MIMD machines are preferable to SIMD machines even for data-parallel applications. Similarly, general-purpose MIMD machines are preferable to systolic arrays, even for regular computations with local communication. Bit-serial processors loose more in efficiency than they gain in density.
4) A good general-purpose network (like a 3-D torus) usually outperforms a network with a topology matched to the problem of interest (like a tree for divide and conquer problems). It is better to provide a general-purpose set of mechanisms than to create a specialized machine for a single model of computation.

While successful at the high end, parallel VLSI architectures have had little impact on the main stream computer industry. Most desktop machines are uniprocessor and even departmental servers contain at most a few 10s of processors. Today’s mainstream microprocessor chips are dense enough to hold 1000 of the 8086s or 68000s of 1979, yet we use all of this area to implement a single processor. By many objective measures this would clearly be a more efficient architecture.

There are three main reasons for this course of events:

a) There was considerable opportunity to apply additional grids to improve the performance of sequential processors

b) Software compatibility favored sequential machines

c) High-overhead mechanisms used in early parallel machines motivated a coarse granularity of both hardware and software.

1.7 FPGA

The most common FPGA architecture consists of an array of configurable logic blocks (CLBs), Input / Output blocks and reconfigurable matrix of interconnects CLBs are used for realization of main logic in FPGA. It typically consists of 4-input Lookup Tables (LUT), multiplexors and flip-flops. LUT is used for realization of combinational logic. It is a 16-bit configurable memory which is capable to realize all 4-input combination logical functions. The output of the LUT can be registered to realize sequential functions.
In modern FPGAs are also CLBs with more than 4 inputs integrated. Multiplexors in CLB can be also used for realization of logic function with more than 4 inputs, they allows combine outputs of LUTs CLBs are used for realization of main logic in FPGA. It typically consists of 4-input Lookup Tables (LUT), multiplexors and flip-flops.

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On the other hand SRAM memory does not remember the configuration without the power, thus the configuration must be loaded to the SRAM before the start of the FPGA function. It increases boot-time and power consumption.

Nonvolatile FPGAs use antifuses or some type of nonvolatile memory (FLASH, EEPROM). This solution provides the advantages of lower power consumption and higher resistance to radiation.

Beside basic blocks described above, there are also some others block integrated in most of the FPGAs. Delay-Locked Loops are used for clock signal generation. They synchronize clock signal in whole FPGA a can be also used as clock divider or multiplier. In some application is necessary to use a lot of memory. In these cases, there are Block RAMs integrated in FPGA. Block RAM is usually a dual-port RAM with independent control signals for each port.
Because FPGAs is widely used for DSP applications, there are multipliers, adders with Carry chain architecture, MAC units etc. integrated in some FPGAs to increase speed of computation.

The main advantage of DSP processor in comparison with FPGA is a simple implementation. DSP processor can be program in assembler or C language. On the other hand the computation performance is still limited by the architecture of DSP processor and program realization.

1.8 Advantages of FPGA

Any technique can prove its success if and only if it is been implemented in real-time. In order to have a successful hardware implementation, the various constrains viz. availability of equipment, durability for completion and viability of commercial transactions should be overcome. Field programmable Gate Arrays (FPGA) are found to be the most cost-effective and least time consuming with simple solutions for designers to implement their findings in real-time environment. FPGAs are future-oriented building blocks, which allow perfect customization of the hardware at an attractive price even in low quantities.

FPGA components available today have usable sizes at an acceptable price. This makes them effective factors for cost savings and time-to-market when making individual configurations of standard products. A time consuming and expensive

Re-design of a board can often be avoided through application-specific integration of our desired circuit in the FPGA - an alternative for the future, especially for very specialized applications with only small or medium volumes. FPGA technology is indispensable wherever long-term availability or harsh industrial environments are involved. Another important aspect is long-term availability. Many component
manufacturers do not agree on any long-term availability. This makes it difficult or impossible for the board manufacturer to support his product for more than 10 years.

The remarkable advantage of FPGAs and their nearly unlimited availability lies in the fact that, even if the device migrates to the next generation, the code remains unchanged. This is in accordance with norms like the (European standards) EN 50155 which prescribes that customized parts like FPGAs must be documented to allow reproduction and that the documentation and the source code must be handed out to the customer. In order to have a customized function, normally a device is programmed and is connected to the logic blocks through the transistors as interconnectors. The major benefit of using FPGA has two fold, one is flexibility in design and the other one is fast time in completion of the task.
1.9 Thesis Organization

A brief outline of the various chapters of the thesis is as follows.

**Chapter 1:** Provides information about the converters, PWM and SPWM. It gives the fundamental information based on power converters. It deals with DC/DC converters like Buck Boost converter and Zeta converter, types and real time application of DC/DC converters, features and challenges in VLSI and advantage of FPGA.

**Chapter 2:** Deals with review of literature survey about the generation of PWM and power converters. It gives detailed studies of work before done and it reviews the PWM and SPWM to be applied in various DC/DC converters.

**Chapter 3:** Provides information about The FPGA Implementation of Pulse Width Modulation, and analysis the area and power for different architectures.

**Chapter 4:** Design and Analysis of Various PWM Techniques for Buck boost Converter. PWM pulse and SPWM pulse are given as triggering input for Buck Boost converters and also provide analyzed results. Generation of SPWM using FPGA.

**Chapter 5:** Discussion about the Design of Sinusoidal Pulse Width Modulation (SPWM) Techniques for Zeta Converter is presented. SPWM pulse is given as triggering input for the Buck Boost and Zeta converter. Performances of converters were analyzed. Then Generation of proposed SPWM using FPGA.

**Chapter 6:** It deals with the results and discussions of all the methods.

**Chapter 7:** Concludes the overall work, which has been done. It provides highlights on thesis work and suggestions for future work.