# Analysis and Design for a Full wave Zero Voltage Switching Boost Converter using Sliding Mode Control

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***Abstract*—** DC–DC converters are nonlinear systems and they have a big challenge for control design. The classical control method are design at one operating point they are not able for varied operating point and load disturbance. The boost type DC-DC converters are used in where output voltage is greater than source voltage. But the control input appears both in voltage and current equation because the difficulties in the control of boost converter. The power converter also operates at high switching speed which results in inductor and transformer core losses, excessive switching losses and electromagnetic interference (EMI) noise issues. The ZVS is most applied and most efficient technique all the resonant converters family. But there is a problem of switching stress and nonlinearity in the system output because of load and line variations. As switching converters constitute a case of variable structure systems, the sliding mode (SM) control technique can be a possible option to control this kind of circuits. SMC is an effective technique to control the nonlinear higher order complex systems.

A Conventional Boost Converter with and without Sliding Mode control is design on MATLAB v8.1 (R2013a) and a Full Wave ZVS Boost Converter with and without SMC is also simulated on the same software. The result of both converters with and without SMC is compared and the increased efficiency of the proposed converter is confirmed. The ZVS Boost Converter with sliding mode controller shows acceptable performance than the conventional. The sliding mode controller improves the non-linearity and un-stability. The converter with SMC has better steady state and dynamic performance and also reduces the excessive switching losses, inductor and transformer core losses, and electromagnetic interference (EMI) noise issues.

**Index Terms-** Zero voltage switching(ZVS) , Sliding mode controller(SMC) and Electromagnetic interference (EMI

## Introduction

Power Electronics is the branch of Electrical Engineering which belongs partly to Power Engineering and partly to Electronics Engineering. Power Engineering is the mainly concerned with the generation, transmission, distribution and utilization of electric energy at high efficiency. Electronics Engineering also deals with the reception of data, signal of very low power level and distortion less production. In addition, apparatus associated with power engineering is based mainly on electromagnetic principles whereas that in electronics engineering is based upon physical phenomenon in vacuum, gases/vapors and semiconductors.

Applications of Power Electronics are as follows:

1) Aerospace- Space shuttle power supplies, satellite power supplies, aircraft power systems
2) Commercial- Advertising, heating, air conditioning, central refrigeration, computer equipment, elevators, light dimmers and flashers, uninterruptible power supplies.
3) Industrial- Blowers and fans, pumps and compressors, textile mills, rolling mills, cement mills, welding, arc and industrial furnaces.
4) Residential- Air-conditioning, cooking, lighting, refrigerators, dryers, fans, vacuum cleaners, washing and sewing machines.
5) Telecommunication- Battery charger , power supplies, signal transmission.
6) Transportation- Battery chargers, traction control of vehicles, trolley buses, subways, railways.

Power Electronics system consists of more than one power converters. This converter is made up of semiconductor devices that convert the power from the form available source to the required load. The load may be ac or dc, single phase or three phase. The source may be dc or ac (single phase or three phase), a battery, solar panel, electric generator or commercial supply. Power Electronic converters can be classified into following categories:

1) Diode Rectifiers- converts ac input into a fixed dc voltage.
2) AC-DC Converters- converts constant ac input voltage to variable dc output voltage.
3) DC-DC Converters (Choppers) - converts fixed dc input voltage to controllable dc output voltage.
4) DC-AC Converters (Inverters)- converts fixed dc voltage to a variable ac output voltage
5) AC-AC Converters- converts fixed ac input voltage to variable ac output voltage.

## 1.2 DC-DC CONVERTER (CHOPPERS)

DC-DC Converters or Choppers is a static device that converts the fixed DC input voltage to variable DC output voltage which is required in many industrial applications such as, subways, trolley buses, battery charging etc. DC-DC converter can be classified according to their output as follows:

1) Buck Converter- the output voltage is lower than the input voltage
2) Boost Converter- the output voltage is higher than the input voltage
3) Buck-Boost Converter- the output voltage is either greater than or lower than the input voltage
4) Sepic Converter- the output voltage is either greater than, less than or equal to input voltage

DC-DC Boost converter also termed as step up converter is a power converter that provides output voltage greater than the input voltage and output current lower than input current. It is circuit having two semiconductor switches (a diode and power switch such as, IGBT, MOSFET) and an energy storage element. Filters generally made up of capacitors are added to the output circuit reduce the ripples in output voltage.

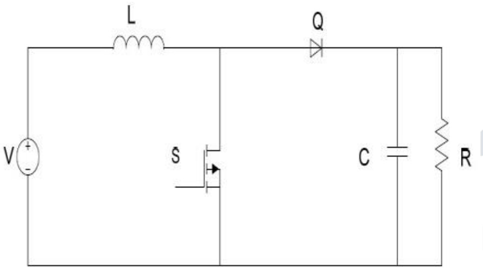

Fig.1.1- Basic Boost Converter

When the switch is ON the inductor is charged and when the switch is OFF the stored energy of the inductor is transferred to the output capacitor through diode. The ratio of output voltage to input voltage is given by,

$$\frac{Vo}{Vin} = \frac{1}{1-D} = \frac{I\,in}{Io} \qquad (1.1)$$

Where,
$V_o$= output voltage,
$V_{in}$=input voltage
$I_o$= output current
$I_{in}$= input current
D= Duty ratio i.e., the ratio of the on time of the switch to the total switching period

The circuit has inductor and capacitor which accounts mostly for its overall size. These components are used to store and transfer energy as a part of power conversion process. As a converter's switching frequency is increased, the component values of its energy storage elements decrease, due to the shorter time they are required to store voltage or current and hence the size of the components. As a result, the higher the switching frequency a converter operates with, the smaller its energy storage elements will be and smaller the size will be[6] thus the switch cannot operate at high frequency. Whenever a switch changes its state from on to off or vice versa, there is overlap between the voltage across it and current flowing through it. As power is dependent on voltage and current the overlapping between switch transition results in power losses termed as switching losses. The frequent ON and OFF of switch also results in electromagnetic interference (EMI) and noise. Thus the overall efficiency of circuit is low.

### Zero Voltage Switching(ZVS)

ZVS techniques are techniques that force the voltage across a switch to be zero just before it is turned on or off and to keep this voltage zero while a switching transition occurs. All the MOSFETs and most of the IGBTs have anti-parallel diodes that are built into the body of each device that allows the current to flow from source to load in a MOSFET and from emitter to collector in an IGBT. A ZVS turn-on in MOSFETs and IGBTs is therefore done by forcing current through the body-diode of the devices just before they are turned on. This clamps the voltage across the device to a single diode drop (which is a negligible voltage) during a switching transition so that turn-on switching losses are greatly reduced. A ZVS turn-off is achieved by slowing down the rate of voltage rise across a switch when it is turned off by adding some capacitance across the switch; this limits the overlap between voltage and current during the switching transition.

During turn on of a ZCS a high rate of change of voltage appears in the gate drive circuit due to the coupling through the capacitor resulting in the increase in switching losses and noise. The switches are under high current stress resulting in high conduction losses. By the nature of ZCS, the peak switch current is much higher. In addition, a high voltage becomes established across the switch in the off state after the resonant oscillation. When the switch is turned on again, the energy stored in the output capacitor becomes discharged through the switch, causing a significant power loss at high frequency and higher voltages. This switching loss can be reduced by using ZVS. All the losses of ZCS can be eliminated by ZVS. ZVS eliminates capacitive turn on losses and is suitable for high frequency operation. Without any voltage clamping, the switches may be subjected to excessive voltage stress which is proportional to the load and the output voltage can be achieved by varying the frequency.[1] Thus ZVS is used over ZCS.

The full wave ZVS is attained by modifying the basic boost technology to achieve zero voltage transition across the switch. The resonant circuit L-C is added to achieve ZVS condition. The resonant capacitor produces the zero voltage condition at which the switch can be turned ON or OFF.

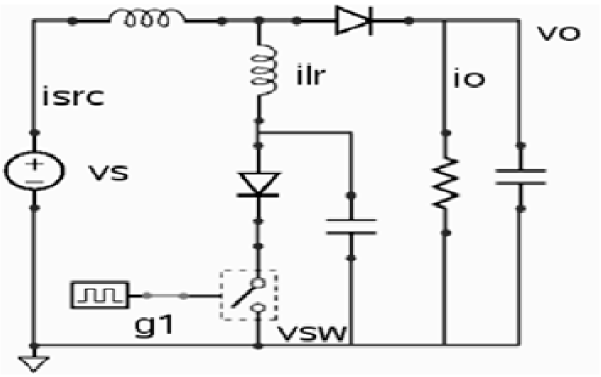

Fig.1.2- Full wave ZVS Boost Converter

The ratio of output voltage to input voltage is given by,

$$\frac{Vo}{Vin} = \frac{1}{1-D} = \frac{Iin}{Io} \qquad (1.2)$$

Where,
$V_o$= output voltage
$V_{in}$=input voltage
$I_o$= output current
$I_{in}$= input current
D= Duty ratio i.e., the ratio of the on time of the switch to the total switching period

The voltage ratio of full wave ZVS is same as that of conventional boost converter. The only difference is ZVS operates at zero voltage condition, which makes it better than conventional circuit. Having so many advantages ZVS have some disadvantages. It suffers from high peak voltage or current stress. They need to be implemented with higher voltage or current rated switches. Thus they are expensive to implement. Non-linear components in the converters changes value nonlinearly with disturbance or load variation. The major disadvantage of ZVS techniques is that they require variable frequency control to regulate the output. This is undesirable since it complicates the control circuit under wide load variations.[26]

## 1.3 SLIDING MODE CONTROL (SMC)

The Sliding Mode Control (SMC) technique is known as one of the efficient method to design robust controllers for complex high order nonlinear dynamic plant operating under uncertainty conditions. The phenomenon, " sliding mode" may appear in dynamic systems governed by ordinary differential equations with discontinuous state functions in the right hand side.[27] SMC design involves two steps:

1) Selection of state hyper planes in state/error space on which motion should be restricted known as switching function.
2) Designing of control law which addresses the converter dynamics to the sliding surface.

The SMC provides robust, good dynamic performance and easy implementation for large load supply and load variations. It is low sensitive to plant parameters and disturbances thus eliminate the necessity of exact modeling. Sliding mode control implies that control actions are discontinuous state functions which may easily be implemented by conventional power converter with "ON-OFF" as the only admissible operation mode.

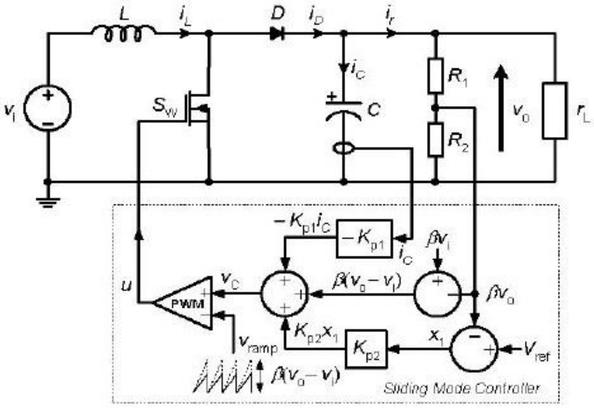

Fig.1.3- Full wave ZVS Boost Converter with SMC

## Principle of Sliding Mode Control

Consider a control law to obtain asymptotically stable system,

$$u(t)=\begin{cases}-k1y(t) & if\ y\dot{y}<0\\ -k2y(t) & otherwise\end{cases} \qquad (2.1)$$

where,
u(t) = control input
y(t) = output
$k_1$ and $k_2$ = positive scalar and $0<k_1<1<k_2$.

The eq. 3.24 can be written as follows,

$$u(t)=\begin{cases}-1 & if\ s(y\dot{y})>0\\ +1 & if\ s(y\dot{y})<0\end{cases} \qquad (2.2)$$

where, the switching function is defined by,

$$s(y\dot{y}) = ky + \dot{y} \qquad (2.3)$$

Where, $k$ is a positive scalar. As the function given in eq. 2 is used to decide which control structure should be used at any point $(y,\dot{y})$ in the phase plane, it is termed as switching function.

Eq.2. 3 can also be written as

$u(t)$ = -sgn(s(t)) (4)

where, $sgn(.)$ is signum function.

Eq. 2.2 is used to control the double integrator. For large values of $\dot{y}$ the phase portrait is shown. The dotted line in the figure represents the set of points for which $s(\, y, \dot{y}\,) = 0$ ; in this case a straight line through the origin of gradient $-k$.

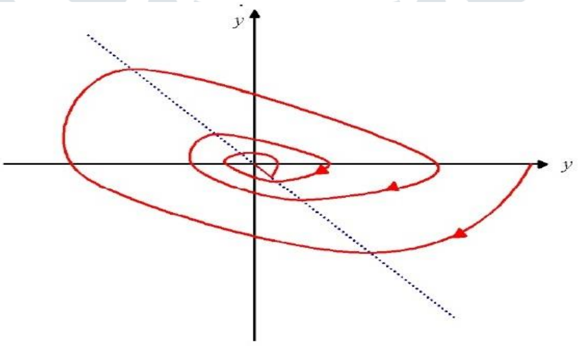

Fig. 1.4- Phase portrait for the large value of $\dot{y}$

However, for values of $\dot{y}$ satisfying the $k|\dot{y}|<1$, then

$$\begin{cases}\lim\limits_{s\to 0+}\dot{s}<0\\ \lim\limits_{s\to 0-}\dot{s}>0\end{cases}$$

When,

$k|\dot{y}|<1$, the system trajectories on either side of the line point towards the line

$$\sigma(s)=\{(y,\dot{y}) : s(\, y, \dot{y}\,)\} \qquad (2.4)$$

In which different phase portraits intercepting the same point on the line $\sigma(s)$from different initial conditions.

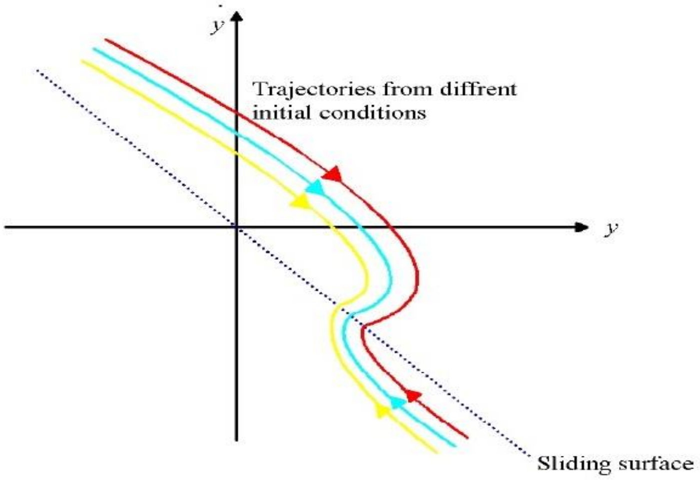

Fig. 1.5-Phase portrait of the system.

If different switching frequency is possible then the motion will be trapped to remain on the line $\sigma(s)$. the motion when confirmed to the line $\sigma(s)$ satisfies differential equation obtained by rearranging $s(y, \dot{y}) = 0$, i.e., $\dot{y}(t) = -ky(t)$ (2.5)

This represents first-order decay and the trajectory will slide along the line $\sigma(s)$ to the origin, as shown in fig. 1.6. Such a dynamical behavior is described as ideal sliding mode or an ideal sliding motion and the line $\sigma(s)$ is termed as sliding surface.

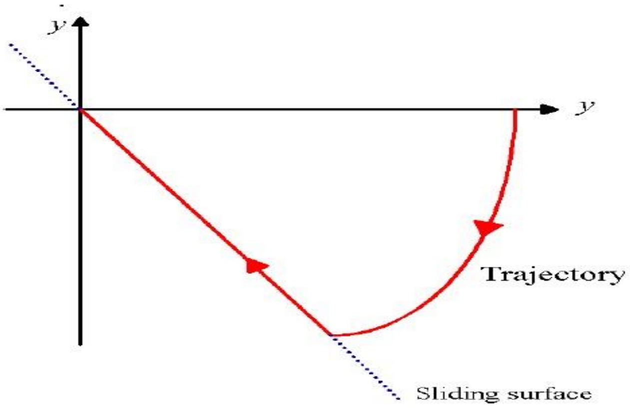

Fig. 1.6- Phase portrait of SMC

During sliding motion, the system behaves as a reduced order system that is apparently independent of the control. The control action ensures that the conditions in eq. 3.29 are satisfied and ensures that the trajectory move toward the sliding surface $\sigma(s)$ and guarantees that $s(y, \dot{y}) = 0$

## DESIGN AND ANALYSIS OF SMC BASED ZVS BOOST CONVERTER

The above section shows that the ripples and settling time have reduced but they vary with the load. In this section, I have designed SMC based ZVS boost converter to overcome the present variations have and analyzed different waveforms. The SMC based ZVS Boost Converter is designed and simulated on MATLAB/Simulink as shown in fig. 1.7 The proposed converter shown in fig. 1.7 consists of a ZVS boost converter which is as same as shown in fig. 4.8. and the rest of the circuit represents SMC. The component parameters are given in table 4.3. The performance parameters are studied.

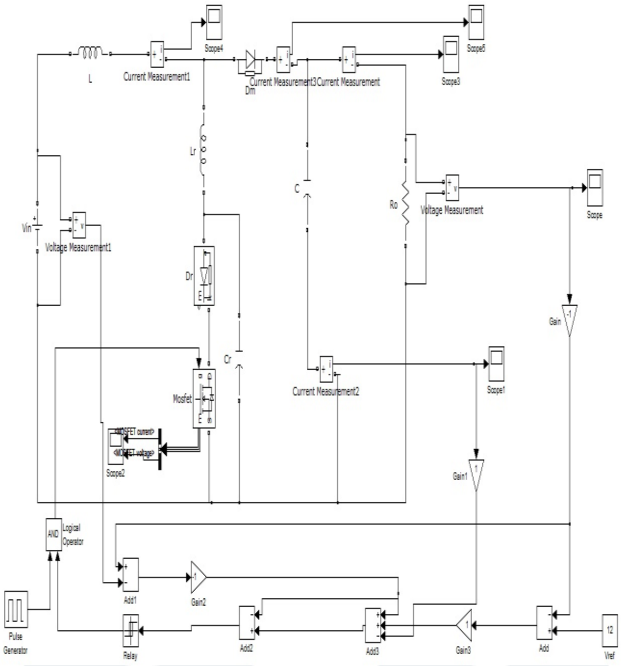

fig.1.7 smc based zvs boost converter

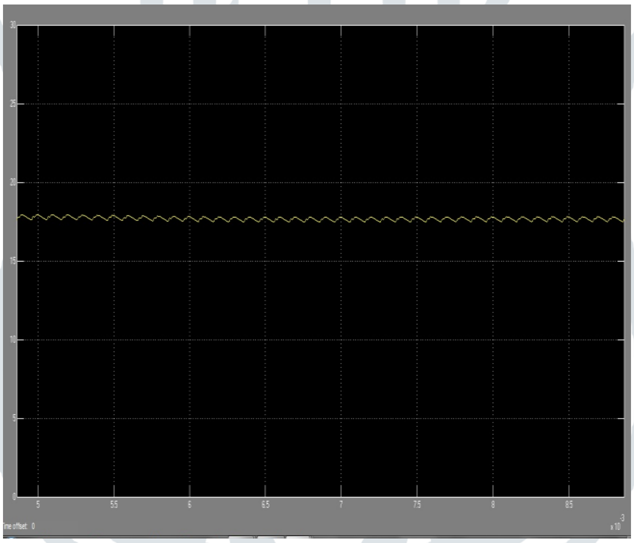

Fig 1.7 Output voltage ripples for SMC based ZVS boost converter

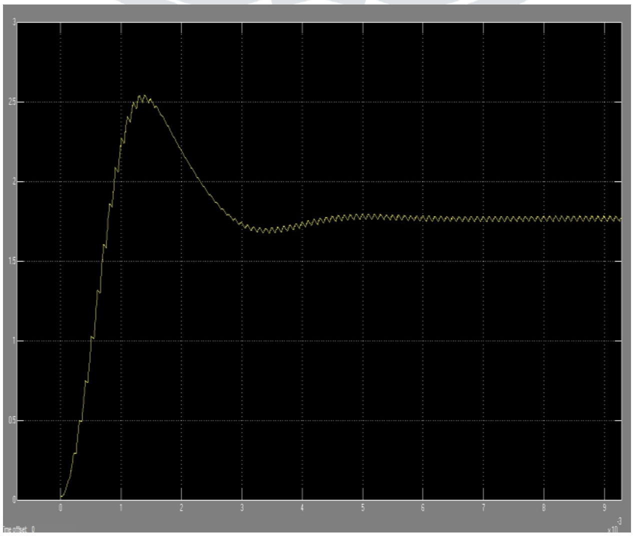

Fig.1.8 Output current waveform of SMC based ZVS boost converter.

| **Components** | **Value** |
|---|---|
| Input Voltage, Vin | 10 V |
| Inductor, L | $200X10^{-6}$ H |
| Capacitor, C | $300X10^{-6}$ F |
| Load Resistance, Ro | 1, 3 Ω |
| Resonant Inductor, Lr | $10X10^{-6}$ H |
| Resonant Capacitance, Cr | $1X10^{-6}$ F |
| Expected Output Voltage, Vo | 20 V |
| Duty Ratio | .5 |
| Switching Frequency | 1000 Hz |
| Gain , Gain 2 | -1 |
| Gain 1, Gain 3 | 1 |

## CONCLUSION

Keeping in mind the growing requirement of the power, there is need of the power supply giving continuous power and having high efficiency and low losses. The DC-DC boost converter provide output greater than the input and difficult to control than other converters of its family. In this work, I have studied the theory of DC-DC boost converter. The mathematical analysis is also studied and concluded it is one of the tool trying to meet the growing need. But still the control system is not as efficient as desired. Thus, various control systems have been applied and many modifications have been done to get the desired output. The resonant converters are the recent development which has overcome many problems. ZVS is commonly applied technique. ZVS in detail has been studied. Its operation and circuit analysis has been studied. After applying ZVS in the converter nonlinearity exists in the system due to load and line variations. To remove this many modification in ZVS technique have been done but are not fully efficient. Sliding mode control (SMC) is the technique that is used in nonlinear systems to control it and it reduces nonlinearity and provide robust control. The theoretical and mathematical study of SMC has been done. The SMC based boost converter is also studied with its mathematical equations and it is concluded that SMC can also be applied to resonant converter. Till now, SMC has been applied to boost converter or resonant buck converter. As boost converter is difficult to control application of SMC to ZVS boost converter has not been carried out. In this work, the model of boost converter, ZVS boost converter, boost converter with SMC and ZVS boost converter with SMC is simulated in MATLAB/Simulink. The results obtained are studied and analyzed. It is found that SMC can be successfully applied to ZVS boost converter and it gives desired output. The results show that SMC improves efficiency and removes nonlinearity and instability. Furthermore, it is found that SMC is less affected by disturbances. Thus it is concluded that SMC gives desired output not only from theoretical point of view but also in practical applications.

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