COMPARATIVE STUDY OF GRID CONNECTED ZERO VOLTAGE SWITCHING INVERTER WITH VARIOUS CONTROLLERS

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Abstract—This paper presents the comparative study of zero voltage switching full bridge inverter with various controller schemes. The switching waveform of the MOSFET produced by various controllers like PI controller, PID controller, DSP Controller, fuzzy logic controller etc. to obtain maximum output voltage and efficiency. Soft-switching techniques have been applied in the design of inverters, in order to achieve superior performance, maximum efficiency with variation of load. A significant number of new techniques for different applications have been presented. This paper is an attempt to classify the soft-switched dc-ac topologies in a simple and generic way with various controller schemes. The technique classifications are based on the location of the resonant network, the characteristic of switching waveforms (zero-voltage switching or zero-current switching), and the type of resonance (series or parallel). Operating principles, performance, and design limitations are discussed. The ZVS condition achieve for switches presented in circuit for large range of power to obtain maximum efficiency.

Keywords— Digital Signal Processor (DSP), Metal Oxide Semiconductor Field Effect Transistor (MOSFET), Proportional Integrator (PI), Proportional Integral Derivative (PID), Pulse Width Modulation (PWM), Zero-current switching (ZCS), Zero-Voltage switching (ZVS).

1. INTRODUCTION

The demand of power increases day by day and researchers are continuously providing efforts to fulfill the demand. The power converters are designing in such a way which reduces the losses of power therefore the Soft switching techniques have recently been applied in the design of DC to DC power converters as well as DC to AC power converters, in order to get better performance, maximum efficiency and maximum power density at low power loss conditions. The inverter used switching devices like diodes, BJTs, MOSFETs and IGBTs. IGBT and MOSFET are mostly used in basic DC to AC converter devices. The conduction losses if there should arise an occurrence of MOSFET are a result of its temperament of going about as a resistor when it is fully turned on. R_{ds} is the resistance between drain to source of MOSFET switch. In the case of IGBT, the conduction loss depends on the current passing through the device during turn-on condition and voltage, sat offered across collector and emitter junctions. Practically, the voltage or current in the switch do not drop to zeros when it is instantly turned on or off. So, there is a period term in which both current and voltages presents, so we can explain there is a covering terrain of voltage and current curve of switching devices. Thus, this overlapping of curves causes power loss. Furthermore, as average power is proportional to the frequency, so higher switching frequency will produces more loss.

Fig. 1.1 Loss of Power During Hard Switching

One more discernible is the presence of EMI on account of sharp and sudden advances. As it is clear from a symbol of devices that both IGBT and MOSFET are having anti-parallel diodes but MOSFET has a higher value of capacitance between drain and source as compared to the capacitance between collector and emitter of IGBT.

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Therefore, MOSFET devices are mostly used in power converters. In case of MOSFET C_{ds} is charged with off stage voltage subjected to it and in case IGBT current tailing is observed even after turn off condition. As we can observe that main loss for MOSFET are because of charging and discharging of the capacitance but for IGBT it is tailing current. The losses occurs in this cases are called hard switching losses. The losses are shown in Fig. 1.1. The problems arises in hard switching like switching losses, EMI, current and voltage stresses which can be reduced by using the soft-switching method. The term "soft-switching" is used to gradual transitions of switch current and voltages. There is no overlapping area between current and voltage curves of the switching device. ZVS and ZCS are the two switching techniques. As in the case of MOSFET, it consists of capacitance C_{ds} which is actually a combination of internal capacitance with additional external capacitance. MOSFET can be turned on when it is sure that voltage across the switch just before the turned on is zero and MOSFET can turn off with ZVS because of C_{ds} which prevents an abrupt rise in the voltage as the device is turned off. Fig. 1.2 shows ZVS implementation using MOSFET and its switching waveforms.

Fig. 1.2 ZVS MOSFET Implementation at Turn Off

In the circuit, the input system provides the supply to the zero voltage switching inverter which is controlled by the controller circuit which is connected to the load. The output of ZVS inverter fed to the load, the load voltage and current feedback to the controller which compares with the reference values which produces the switching waveforms to operate and achieve the zero voltage switching condition.

Fig.1.3 Block Diagram of ZVS Inverter With FLC

2. DESIGN OF PID CONTROLLER

In the PID controller, it is desired to track a given reference voltage command with minimum tracking error in transient response and minimum THD in steady state response. The purpose of the digital PID controller is to minimize voltage error. The voltage error is defined as: $V_e = V_s - V_o$

Where V_s the desired voltage and V_o is the measured output voltage. A PID controller is used to produce the required control voltage V_c according to V_e . The equation describes the PID system is

$$V_c = K_p V_e + K_i \int V_e dt + K_d dV_e/dt$$

Where K_p is the Proportional gain K_i is the Integral gain, K_d is the Derivative gain. The tuning of the parameters K_p , K_i , and K_d is achieved by using the conventional method. The values of the PID parameters were as follows.

The value of the proportional gain:

$$K_p = -R_p^2 / R_p^1$$

The value of the integral gain:

$$K_i = -1 / R_i C_i$$

And the value of derivative gain:

$$K_d = -R_d C_d$$

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Fig. 2.1: Architecture of PID Controller

The zero voltage switching inverter is controlled with PID controller is shown in fig. 2.2. This shows that the zero voltage switching condition is achieve with PID controller.

Fig. 2.2: Model of ZVS inverter with PID controller

3. DESIGN OF PI CONTROLLER

The structure of discrete PI controller is as shown in Fig. 3.1. In the figure, T_s is the sampling time while m and n are defined as

$$M = K_i (K_p/K_i + T_s/2)$$

$$N = K_i (T_s/2 - K_p/K_i)$$

Fig. 3.1: Structure of discrete PI Controller

4. DESIGN OF DSP CONTROLLER

The configuration of the proposed new ZVS-PWM inverter using a simple auxiliary commutation pole is illustrated in fig. 4.1. The proposed inverter can be divided into two parts, in which, the first part is a conventional PWM half-bridge inverter and the second part is the ZVS-PWM auxiliary commutation pole. The conventional PWM half-bridge inverter consists of two active switches, S1 and S2, two capacitors, CA and CB, a filtering capacitor Cf, and a filter inductor Lf. The components of the ZVS-PWM auxiliary commutation include two active auxiliary switches, Sa1 and Sa2, a matching transformer Ta, a resonant inductor Lr, two resonant capacitors, Cr1 and Cr2, a diode Da1, and two body diodes, D1 and D2. The auxiliary switches of the

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ZVS- PWM auxiliary commutation are synchronous with the active switches of the conventional PWM half-bridge inverter. The design strategy to generate the appropriate switching signals for two active switches (S1 and S2) and two active auxiliary switches (Sa1 and Sa2) is based on the principle of ZVS-PWM and the duty cycle controlled by the proposed DSP controller.

Fig. 4.1: Structure of ZVS-PWM inverter controlled by DSP

5. DESIGN OF FUZZY LOGIC CONTROLLER

The fuzzy logic controller is used to control primary and secondary side of linear transformer to perform control action on both input and output side. This fuzzy controller is better than PI controller since it is very robust and can be modified with the multiple input and output sources. It is very cheap and quick to implement. Fuzzy logic system is one of the types of intelligence based system whose work based on Linguistic language and Boolean logic. The fuzzy logic control structure is depends on four steps. The four main steps are:

5.1 Fuzzification

This step is used to match the input variables to fuzzy sets with the help of membership functions. or With the help of membership functions, the linguistic/ crisp input variables are converted into fuzzy sets.

5.2 Inference Mechanism

The inference mechanism is framed upon the rules, along with the fuzzified membership function.

5.3 Rules and Database

The rules are framed with either AND/ OR logic operations to specify the multiple number of input with their membership functions. The membership functions from database using the fuzzy rules in the fuzzy sets.

5.4 Defuzzification

The defuzzification is used to determine crisp output with the aid of converting the output of fuzzy to a crisp output using the membership functions. Defuzzification is used as the centroid output functions.

Fig. 5.1 Fuzzy Controller Block Diagram

In this proposed work, the seven triangular membership functions is used with 49 rules during logical AND operations. At the end of defuzzification, the crisp output is determined and also pulse signal is generated to the power semiconductor switches on the ZVS boost converter and single phase full bridge inverter. The fuzzy rule base table is shown in Table-2.1 which is easy to use and understand the fuzzy logic.

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Table-5.1 Fuzzy Logic Controller Rule Viewer

Change Error \ In Error	NP	NM	NS	Z	PS	PM	PP
NP	NP	NP	NP	NP	NM	NS	Z
NM	NP	NP	NP	NM	NS	Z	PS
NS	NP	NP	NM	NS	Z	PS	PM
Z	NP	NM	NS	Z	PS	PM	PP
PS	NM	NS	Z	PS	PM	PP	PP
PM	NS	Z	PS	PM	PP	PP	PP
PP	Z	PS	PM	PP	PP	PP	PP

6. DESIGN OF ZVS INVERTER WITH NOVEL SPWM SCHEME

The reverse recovery of the body-diode is a major problem in the MOSFET inverter, which produces during the commutation process from the body-diode to the MOSFET. There are two types of such commutation process in the MOSFET inverter. For unipolar SPWM topology and double-frequency (DF) SPWM topology the commutation appears at only one phase leg, the commutation process at both phase legs when bipolar SPWM topology is used. The simplified switching waveforms in express that the MOSFET (S1) suffers not only the load current (i_o) but also the high reverse recovery current (i_{rr}) of the body-diode (D4) during the hard-switching turn-on process, which not only makes maximum turn-on losses, but also cause high current stress to the switch.

In Fig. 6.1, an auxiliary branch is connected between the dc bus and the inverter. It is composed of an auxiliary MOSFET S_a , clamping capacitor C_c , resonant inductor L_r and resonant capacitor C_{ra} . The capacitors $C_{r1} \sim C_{r4}$ are parallel capacitors to the main switches. Earlier the commutation from body-diode to MOSFET in Fig. 6.1, the auxiliary switch S_a is turned off and the dc voltage V_{dc} across the phase leg can be resonated to zero by the resonant procedure. Therefore, the main switches achieve ZVS turn-on.

Fig. 6.1 Control Diagram of ZVS grid Connected Full Bridge Inverter

The output of inverter creates a closed feedback loop using a combination of DSP controller which produces the switching waveforms of MOSFET inverter. The highest efficiency achieve in this case is 98.2%.

Table-6.1 Comparison of Various Topologies for ZVS Inverter

TOPOLOGY	AUXILIARY SWITCH	P _o	f _s	MAXIMUM EFFICIENCY
Active-clamping DC link	1	7 KW	20KHz	90.2%
ZVS DC Link	1	0.3KW	50KHz	96.0%
ZVS PWM commutation cell	2	3 KW	32KHz	94.06%
ZVS PWM coupled magnetic	4	3 KW	20KHz	98.2%
ZVS with DSP Controller	1	3KW	20KHz	98.8%

CONCLUSION

In this paper, the comparative study of zero voltage switching full bridge inverter with various controller have been presented. As the comparative study states that the output of various controllers is used to obtain the zero voltage switching condition of MOSFET switches which plays vital role in the inverter. The paper also explains the concept of hard switching and soft switching of switches connected in the inverter circuit like Diode, MOSFET, IGBT etc. The explained controllers produces various output voltage and power across the load so efficiency of the circuit is also varies but the use of fuzzy logic controller in compare to other controllers the maximum efficiency is achieved.

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