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Enhancing The Efficiency of AC-DC Converter With Sliding Mode Control Technique

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***Abstract*-This project proposes a AC-DC converter with high efficiency. The proposed converter is derived by integrating a full-bridge diode rectifier and a series-resonant active-clamp DC-DC converter with sliding mode controller. In the existing system PI controller have less stable and not easy to predict system dynamics. The proposed SMC controller provides high efficiency because of it's insensitive to certain parameter variation and unknown disturbances and it reduces system order and mathematical expressions. The active-clamp circuit clamps the surge voltage of switches and recycles the energy stored in the leakage inductance and pumps to the output. Moreover, it provides zero-voltage turn-on switching of the switches and it reduces voltage stress across the switches. Also, a series-resonant circuit of the output-voltage doubler reduces the reverse-recovery problem of the output diodes. The proposed converter provides high output and high efficiency. The performance of proposed converter is analysed in MATLAB/simulink platform.**

***Index Terms* - Active-clamp converter, Sliding mode control(SMC), Zero-voltage switching(ZVS).**

I.INTRODUCTION

GENERALLY, the AC–DC converter consists of a full-bridge diode rectifier, a DC-link capacitor and a high frequency DC–DC converter. But in this paper low-side active clamp circuit is proposed. In general, the Active clamp circuit can be categorized into two types: Low-Side Clamp and High-Side Clamp. The clamp circuit applied to either the high side directly across the transformer primary or the low side directly across the drain-to-source of the main MOSFET switch. In a low-side clamp whenever the main MOSFET, Q_1, is conducting, the full input voltage is applied across the transformer magnetizing inductance [13]. This is referred to as the power transfer mode. Conversely, whenever the auxiliary (AUX) MOSFET, Q_2, is conducting, the difference between the clamp voltage and the input voltage is applied across the transformer magnetizing inductance. This is referred to as the transformer reset period .An additional dead-time period is introduced between the turn on and turn off transitions of Q1 and Q2. During the dead-time, primary current flow remains continuous through the body-diode of either the AUX MOSFET, Q2, or the main MOSFET, Q1. This is commonly known as the resonant period in which the conditions are set for zero voltage switching (ZVS). The conventional active clamp forward converter is needed an auxiliary switch and a clamp capacitor for a forward converter and has been used widely to reduce the voltage spikes across the switching devices and the switching losses produced by the hard switching. An active clamping method was proposed to achieve ZVS of switches and to attenuate the ringing. During the off-time interval, the leakage inductance current freewheels through the auxiliary circuits. Before turning on the main switches, auxiliary switches interrupt the freewheeling path, such that the energy in the leakage inductance is released to create ZVS condition for main switches. Single-stage AC–DC converters in low power application employ single-switch DC–DC converters such as flyback or forward converters [7]. These converters are simple and cost-effective. However, they have high switching power losses because of the hard-switching operation of the power switch. Thus, to overcome the drawback by zero-voltage switching (ZVS) operation of the power switches. Sliding mode control is a nonlinear control method for power converters, which are variable structure system due to their on and off switching operation. The controller is used to increase the converter efficiency. Sliding mode control (SMC) is used in the proposed system. It is a nonlinear control technique featuring remarkable properties of accuracy, robustness, and easy tuning and implementation. SMC systems are designed to drive the system states onto a particular surface in the state space, named sliding surface [8], [14]. It is insensitive to certain parameter variation and unknown disturbances and it reduces system order and mathematical expression. In view of this, the objective of this paper is to propose the single power-conversion AC–DC converter with high power efficiency. The proposed converter provides a simple structure, a low cost, and low voltage stresses because it has only high frequency DC–DC converter. Also, the active-clamp circuit clamps the surge voltage of switches and recycles the energy stored in the leakage inductance of the transformer. Also, a series-resonant circuit of the output-voltage doubler removes the reverse recovery problem of the output diodes by zero-current switching (ZCS) operation.

II.OPERATIONAL PRINCIPLE OF THE ACTIVE CLAMP AC–DC CONVERTER

Fig. 1 shows the proposed single power-conversion AC–DC converter and the control block diagram. The high frequency DC–DC converter is used. In the proposed converter it combines an active-clamp circuit and a series-resonant circuit across the power transformer T. The active-clamp circuit is composed of a main switch S1, an auxiliary switch S2, and a clamp capacitor Cc. The switch S1 is modulated with a duty ratio D and the switch S2 is complementary to S1 with a short dead time. The active-clamp circuit serves to clamp the voltage spike across S1 and to recycle the energy stored in the leakage inductance of the transformer T. Also, it provides ZVS turn-on of S1 and S2. The series-resonant circuit is composed of the transformer leakage inductance L_{lk}, the resonant capacitors C1,C2 , the output diodes D1,D2 and its provides ZCS turn-off of the D1 and D2.

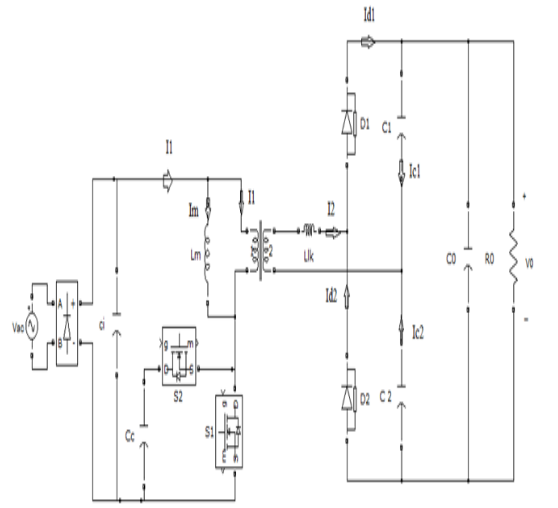


Fig.1 Proposed active clamp single power-conversion AC–DC converter.

In order to analyze the operation principle, several assumptions are made during one switching period Ts:

1) The switches S1 and S2 are ideal except for their body diodes D1,D2 and capacitances C1,C2;

2) The input voltage vin is considered to be constant because one switching period Ts is much shorter than the period of vin;

3) The output voltage Vo is constant because the capacitance of the output capacitor Co is sufficiently large, similarly, Cc is sufficiently large that is voltage ripple is negligible. Thus, the clamp capacitor voltage Vc is constant;

4) The power transformer T is modeled by an ideal transformer with the magnetizing inductance Lm connected in parallel with the primary winding Np, and the leakage inductance L_{lk} connected in series with the secondary winding Ns.

The steady-state operation of the proposed converter includes six modes in one switching period Ts. The operating modes and theoretical waveforms of the input side and the output side are shown in Figs. 2 and 3, respectively. The rectified input voltage Vi is|vin|=|Vmsinωt|, where Vm is the amplitude of the input voltage and ω isthe angular frequency of the input voltage. Prior to Mode 1, the primary current i1 is a negative direction and the secondary current i2 is zero.

Mode 1 [t0,t1]: At the time t0, the voltage vs1 across S1 becomes zero and Ds1 begins to conduct power. After the time t0,S1 is turned on. Since i1 started flowing through Ds1 before S1 was turned on, S1 achieves the ZVS turn-on. As shown in Fig. 4(a), since Vi is approximately constant for a switching period Ts, the magnetizing current im increases linearly.

During this interval, the input power is directly transferred to the output stage of the transformer. The difference between i1 and im is reflected to the secondary current i2. The secondary winding voltage v2 is

$$v_2 = nV_i \qquad (1)$$

Where the turns ratio n of the transformer is given by Ns/Np. Since Co is sufficiently large, the resonant equivalent capacitance Cr is (C1 + C2). Thus, D1 is conducting and L_{lk} resonates with Cr while the secondary current i2 flows.

The angular resonant frequency ωr and the resonant impedance Zr are given by

$$\omega r = \frac{1}{\sqrt{LlkCr}},\ Zr = \sqrt{\frac{Llk}{Cr}} \qquad (2)$$

The output current io becomes half of the output diode current iD1 by the resonant capacitors C1 and C2 as follows:

$$i_o(t)=i2(t)-ic1(t)=\frac{1}{2}iD1(t) \quad (3)$$

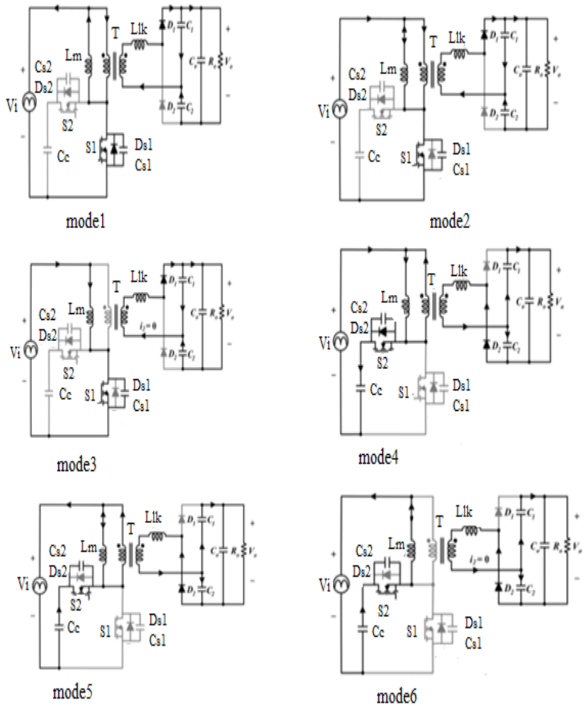


Fig.2 Operating modes of the proposed ac–dc converter.

Mode 2 [t1,t 2]: At the time t1,i1 changes its direction to positive. Llk and Cr still resonate similar to Mode1.

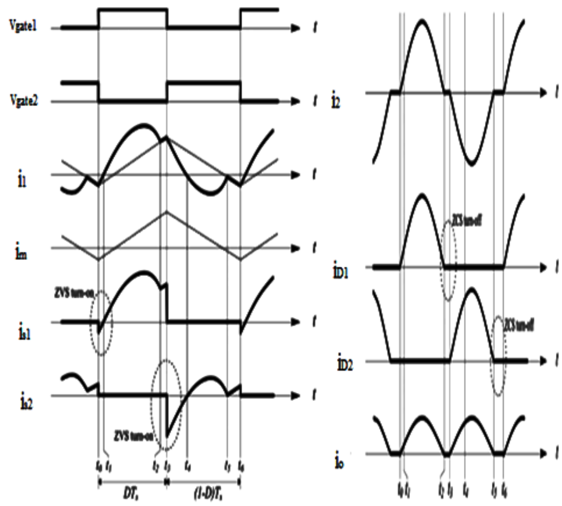
Mode 3 [t2,t 3]: At the time t2,i2 becomes zero and D1 is maintained in the on-state with the zero current. I1 and im are equal during this interval. Therefore, i1 terminates the first resonance and increases linearly as (1).

Mode 4 [t3,t 4]: At the time t3,S1 is turned off and D1 is turned off with the zero current. The ZCS turn-off of D1 removes its reverse-recovery problem. The voltage vs2 across S2 becomes zero and the body diode Ds2 begins to conduct power. After the time t3, the ZVS turn-on of the auxiliary switch S2 is achieved. Since the clamp voltages Vc is approximately constant during a switching period Ts,im decreases linearly.

During this mode, the input power is transferred to the output stage like in Mode 1. The voltage across L_{lk} is the difference between the secondary winding voltage v2 and the resonant capacitor voltage vc2. Since the equivalent clamp capacitor Cc/n2 is much larger than Cr, the resonant effect of Cc is negligible in the series-resonant network that is composed of Cc/n2,C r, and L_{lk}. Therefore, i2 begins to resonate again by L_{lk} and Cr similar to the first series resonance in Mode 1, i1 decreased by the second series resonance.

Mode 5 [t4,t5]: At the time t4,Llk and Cr still resonate similar to Mode 4. In addition, i1 may change its direction during this interval based on the designed resonant frequency fr.

Mode 6 [t5,t 6]: At the time t5,i2 becomes zero and D2 is maintained to the on-state with the zero current. i1 and im are equal during this mode. Therefore, i1 terminates the series resonance and decreases linearly.



(a) (b)

Fig.3 Theoretical waveforms of the proposed converter. (a) Input side wave- forms. (b) Output side waveforms.

At the end of this mode, D2 is turned off with the zero current. The ZCS turn-off of D2 removes its reverse-recovery problem.

With the average voltage across the primary winding Np during S2 turn-on, V1=DVi/(1 –D), from the volt–second balance law of the magnetizing inductance Lm.Where the output voltage of the converter V_o is $Vc_1 + Vc_2$.

III. SLIDING MODE CONTROL

Sliding mode control is a nonlinear control method for power converters, which are variable structure system due to their on and off switching operation. Sliding mode control (SMC) is a nonlinear control technique featuring remarkable properties of accuracy, robustness, and easy tuning and implementation. SMC systems are designed to drive the system states onto a particular surface in the state space, named sliding surface. Once the sliding surface is reached, sliding mode control keeps the states on the close neighbourhood of the sliding surface.

The principle of sliding mode control is to force the system state to S=0 for any initial condition to attain stability. For any disturbances the system state is forced back to line S=0.

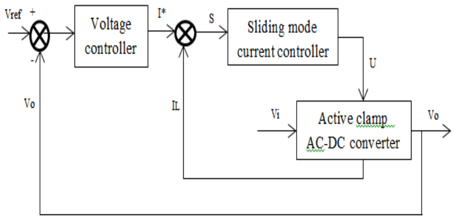


Fig.4 Controller diagram.

The system state is converter state like ON & OFF state of switch. If the switch is in ON condition S>0 and the switch is in OFF condition S<0.The former is a type of signum function and is easily realized using a switch relay.

$$e(s)=Vref - Vact \qquad (4)$$

$$X1 = Kpe(s) + \int Ki\, e(s)dt \qquad (5)$$

$$X2 = KpIc(s) + \int Ki\, Ic(s)dt \qquad (6)$$

Sliding surface "S" is given as

$$S = X1 + X2 \qquad (7)$$

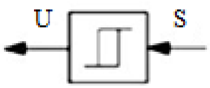


Fig.5 Diagram of hysteresis modulation

In conventional PWM control, which is also known as the duty-ratio control, the control input u is switched between 1 and 0 once every switching cycle for a fixed small duration Δ.

$$U = \begin{Bmatrix} 1 = \text{"ON"}, & when\ S > 0 \\ 0 = \text{"OFF"}, & when\ S < 0. \end{Bmatrix} \qquad (8)$$

IV. SIMULATION CIRCUIT OF ACTIVE CLAMP AC-DC CONVERTER WITH SMC

The proposed simulation is shown in the below figure 6. Simulation was applied on MATLAB/Simulink to verify the output of the proposed active clamp DC-DC converter.

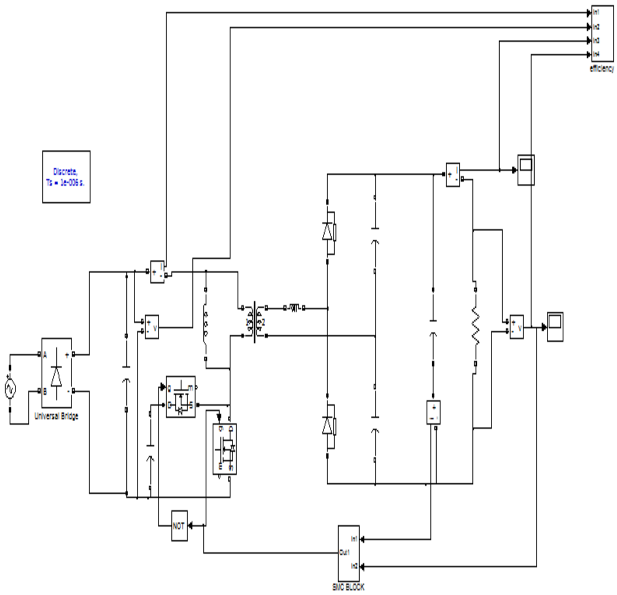


Fig.6 Simulation diagram Active clamp AC-DC converter with SMC

A.OUTPUT VOLTAGE OF PROPOSED SYSTEM

Output voltage of the proposed converter is shown in Figure 7.This Output waveform will be characterised between voltage and time magnitude and the output will be 200V.

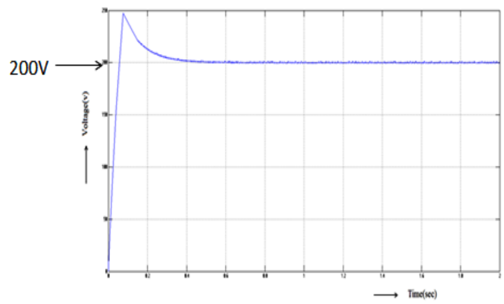


Fig.7 Output voltage of active clamp AC-DC converter with SMC

V. COMPARISON OF SIMULATION RESULTS

Simulation outputs are compared in the below table. In the active clamp AC- DC converter PI and sliding mode controllers are used and the efficiency of the system is calculated in MATLAB/Simulink.

PARAMETERS	ACTIVE CLAMP DC-DC CONVERTER WITH PI (EXISTING)	ACTIVE CLAMP DC-DC CONVERTER WITH SMC (PROPOSED)
INPUT	90V (AC Source)	90 V (AC source)
CONVERTER OUTPUT	200V	200 V
EFFICIENCY	88%	97%

Tab.1 Outputs Comparison Table

From the obtained result SMC gives high efficiency when compared with PI controller.

VI. CONCLUSION

In this paper has proposed an active clamp AC-DC converter and is controlled by using sliding mode controller, which is used to produce constant output voltage and to increase the efficiency of the system with non-linear load and also maintain system stability at all conditions. SMC controller is insensitive to certain parameter variation and unknown disturbances. By using SMC controller efficiency is high when compared to conventional controllers. Active clamp AC-DC converter provides zero-voltage turn-on switching of the switches and it reduces voltage stress across the switches. The soft switching technique of zero voltage switching (ZVS) is achieved by the use of resonant components without any additional switching devices. The proposed converter provides the high efficiency of 98%.

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