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A CONTROLLED SINGLE-PHASE SERIES RESONANT AC CHOPPER

Nikhil Mohanan[1], Jeena Joy[2], Kavitha Issac[3]
[1]*P.G.student, Mar Athanasius College of Engineering, Kothamangalam, Kerala*
[2,3]*Assistant. professor, Mar Athanasius College of Engineering, Kothamangalam, Kerala*

Abstract:- A single-phase series-resonant soft-switched ac chopper without auxiliary switches with an efficient control circuit is presented. Basic working principle is series-resonant conversion without any cycloconversion action. Auxiliary switches are absent in this topology. The presented single-phase ac chopper is producing the resonant voltage robes by the action of series resonator with the help of four bidirectional switches. A series of sinusoidal amplitude quasi-sinusoidal pulses synthesized and present at the output as purely sinusoidal waveform following the input voltage waveform. Frequency modulation with a constant-on time control technique is used in this proposed system. Waveform syntheses for the output sinusoidal voltage are clearly explained with waveforms. A typical design example of single-phase soft-switching ac chopper is simulated to assess the system performance. The power efficiency is improved by using soft switching techniques. The total harmonic distortion is well below 1%. MATLAB software is used to simulate the model.

Index Terms:- ac chopper, series resonant converter, Zero-current-switching, pi controller, THD.

I. INTRODUCTION

The importance of ac voltage regulators are increasing now a day. Disadvantages of Phase-angle control technique and Integral-cycle control technique of thyristors lead to research on new technologies in this area. The retardation of firing angle causes lagging power factor in input side and high low-order harmonic in both output and input sides are some of the disadvantages of old topologies. To reduce these problems Pulse-width modulation control technique was introduced in the ac choppers. Now a day, this is one of the prominent technologies using in any power electronics circuit. However, there still exit large electromagnetic interference (EMI) and high switching loss. As a Solution for these problems a series-resonant single-phase soft-switching ac chopper[1] is presented in this paper with a simple and compact topology, simple feedback circuit and without auxiliary circuit. This circuit is advantageous version of circuit mentioned in [2]. Zero-current-switching (ZCS) is employed for all power switches. The equal-amplitude quasi-sinusoidal pulses (QSPs) and is approximately in a form of $Vink\ (1 - cos\ \omega t)$ at the kth switching cycle is synthesized to sinusoidal output voltage waveform. The advantage of using frequency modulation with a constant-on time control strategy is better dynamic regulation characteristic, properly driving signal of the power switches and the resonant characteristic of LC tank. Simulation work done for evaluating the proposed ac chopper performance. The total harmonic distortion (THD) is well below 1%, and the power efficiency is on higher side.

II. PRINCIPLE AND WORKING

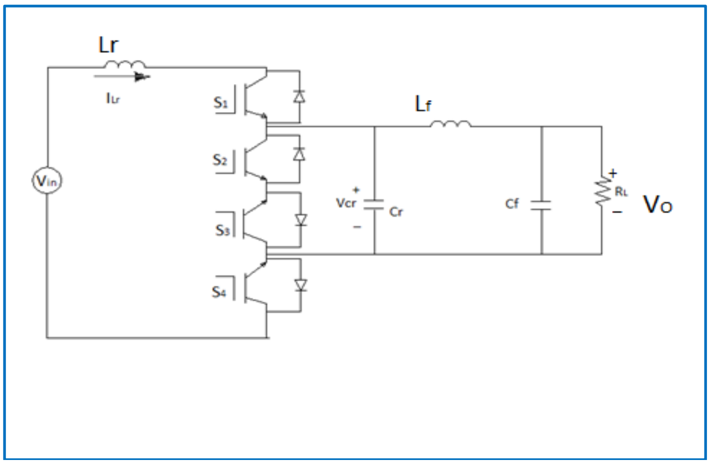


Fig. 2: Circuit diagram of proposed system

The proposed chopper circuit consists of two set of tank circuit, a resonant tank composed of an inductor Lr and a capacitor Cr, and Lf and Cf as filter circuit as shown in Fig. 1. The 4 main switches S_1, S_2, S_3 and S_4 are current bidirectional devices. The equivalent circuit in the positive (negative) half-period of the line input voltage $vin\ (t)$ is composed of S_1 (S_4), S_3 (S_2), Lr, Cr, Lf, and $Cf\ //RL$. Working in the positive and negative half-period of the line input voltage $vin\ (t)$ is more or less same; the difference is switches changing its action accordingly. Switches S_4 and S_1 reversing its action and so as S_2 and S3. In positive half period of input voltage S_2 and S_4 are always off, the switch S_3 is always on, and S_1 performs the conversion function at high frequency switching. . In negative half period of input voltage S_1 and S_3 are always off, the switch S_2 is always on, and S_4 performs the conversion function. The equivalent circuits for describing their behaviour are explained with Fig. 2. The complete synthesized resonant output voltage robes and switches drive signal are explained with Fig. 3. The output voltage $vo\ (t)$ is synthesized by resonant voltage robes with purely sinusoidal amplitude. The working states divides into 5, one linearly charging state, two resonant states, a linearly discharging state, and a freewheeling state. Remarkably, the proposed single-phase ac chopper operates in discontinuous conduction mode (DCM). For convenience some assumptions made as all devices are ideal and that the losses in Lr, Lf, Cr, and Cf are all neglected and input voltage are approximated a stairway waveform and it is approximate a constant value in one switching period. Since the circuit operation at positive line input voltage is the same as the circuit operation at negative line input voltage, only the resonant action in positive line input voltage are described here. The complete resonant robes of $VCr(t)$, and the the switching pattern is shown in Fig. 3. The working is explained with Fig. 2. In this state (positive half period of input voltage), the switch S_3 is always on and the switches S_2 and S_4 are always off, and initially switch S_1 is off. Before $= tk0$, the circuit operation is in the freewheeling mode and the current in Lf continuously delivers to the load. There are five states of resonant action in one switching cycle. They are described in the following.

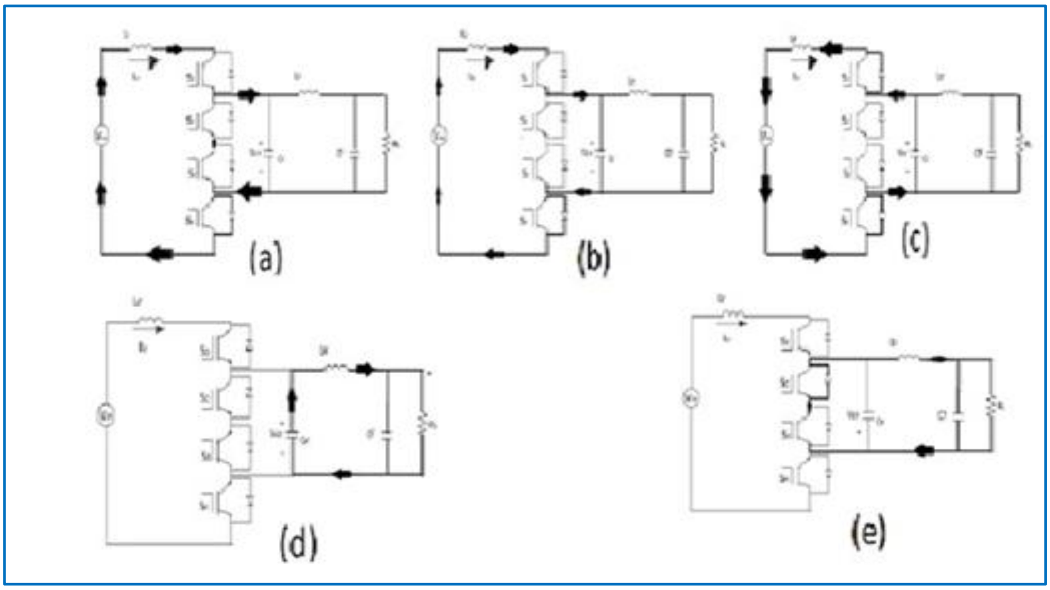


Fig 2. Equivalent circuits to explain resonant robes of vCr(t)

***Stage 1**: **The Linearly Charging State**, [$\boldsymbol{tk0} < t < \boldsymbol{tk1}$]*: Stage 1 begins with S_1 turns on with Zero Current Switching at $= t0$. The current in r , $iLr(t)$, linearly rises until reaching $ILf\ k$ .Current flows through Lr, S_1, the anti parallel diode of S_4 , and output . Design done for constant value of $ILf\ k$. The output loop is in a freewheeling state by means of anti parallel diode of S_2 is naturally turned off when $iLr\ (t)\ =\ ILf\ k$.

We have

$$vCr(t)\ =\ 0 \tag{1}$$

Stage 2 : Resonant State 1, [$\boldsymbol{tk1} < t < \boldsymbol{tk2}$]: In stage 2, S_1 is continued in conduction mode. The resonant operation is started and the resonant action proceeds through $Vink$ Lr, S_1, r , output and anti parallel diode of $S4$. The resonant voltage $vCr\ (t)$ and the resonant current $iLr\ (t)$ increase and then decrease after reaching their peak values . This state is end when the resonant current $iLr\ (t)$drops to zero. The resonant current positive peak value is

$$iLr\ peak = ILf\ k + Vink\ /\ Zo \tag{2}$$

and the resonant voltage peak value is

$$vCr\ peak = 2Vink \tag{3}$$

Thus, the maximum voltage stresses on Cr is $2Vin, max$.

Stage 3: Resonant State 2, t in [$tk2 < t < tk3$]: The resonant operation is continued in stage 3, the resonant voltage $vCr(t)$ decreases continuously. The path of resonant current $iLr\ (t)$ is Vin , Lr , the anti parallel diode of S_1 , Cr , $ILf\ k$, and S_4 . The resonant current $iLr\ (t)$ increases toward its negative peak value and then after it decreases . At that time switch S_1 is turned off with ZCS. The stage ends when the resonant current $iLr\ (t)$ stops.

The resonant current negative peak value is

$$iLr\ peak = -ILf\ k + Vink/Zo \tag{4}$$

Stage 4: The Linearly Discharging State, [$tk3 < t < tk4$]: In this state, the resonant current $iLr\ (t)$ still maintain at zero value and only the energy stored in Cr continues to discharge linearly by the piecewise constant current $ILf\ k$. When $vCr(t) = 0$, diode $D4$ is naturally turned on, and we have

$$iLr\ (t) = 0 \tag{5}$$

Stage 5: The Freewheeling State, [$tk4 < t < tk\ 5$]: When both $iLr\ (t)$ and $vCr(t)$ are zero, a freewheeling loop is formed the antiparallel diode of S_2 and $S3$ with a piecewise constant current $ILf\ k$. Thus

$$iLr\ (t) = 0 \tag{6}$$

$$vCr(t) = 0 \tag{7}$$

The simulation waveforms of $vCr(t)$ are clearly shown in Fig. 7, in which their resonant robes are clearly explored. The shadows shown on the enlarged resonant robes of $vCr(t)$ in Fig. 7 are their average value of Vok during one switching period. The criteria for achieving ZCS on S_1 , S_2 , S_3 , and S_4 are determined by the following inequalities:

$$Vin, max\ /\ Zo > ILf, max \tag{8}$$

$$\omega r\ /\ 2\pi > fs \tag{9}$$

where fs is the switching frequency, Vin, max is the maximum input voltage, and ILf, max, is the maximum average current in the filter inductor Lf .

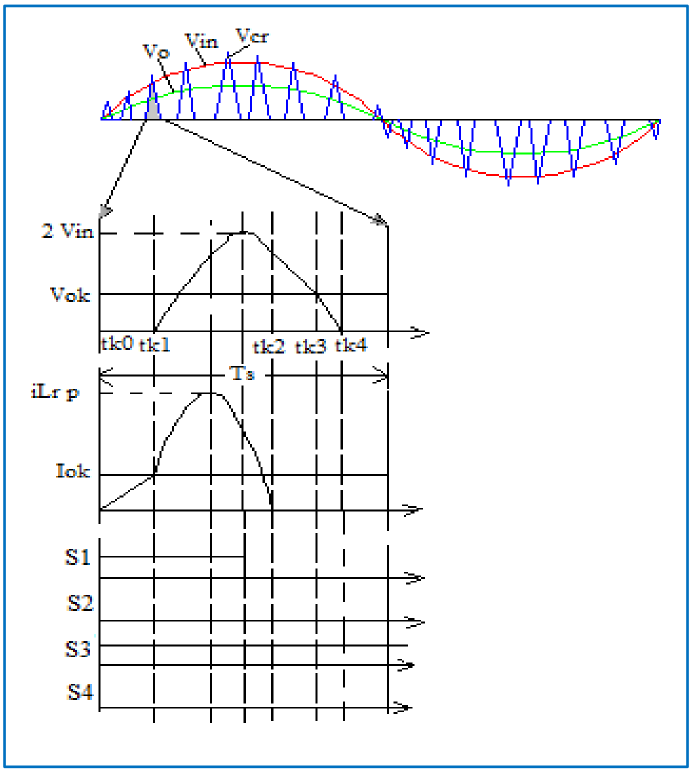


Fig 3. Waveforms to explain resonant robes of vCr(t)

III. DESIGN CONSIDERATIONS AND REALIZATION

The design procedure is described as follows:

Step 1 – Input and Output data specification

1) The input voltage $Vin(t) = Vin\,max\,sin\,wint = 310\,sin\,(2\pi \times 50t)$;
2) The output voltage $v_o(t) = V_O$ max sin $w_{in}t$ = 175 sin (2π×50t);
3) The switching frequency fs = 25 kHz
4) The maximum output power =600 W

Step 2 – calculation of maximum output current

The maximum output current , $ILf\ max = \sqrt{2}\,PO\ /\ VO\ rms$ = 6.85 A

Step 3 – calculation of resonant parameters

Let fs = 25 kHz; error voltage Vc = 0.55

The sensitivity, $Kc = 50\ kHz/V$

Resonant frequency, $f_r = (K_V V_C$ Vin max/ V_O max) = $(50\times10^3\times0.55\times310) / 175$ = 50 kHz

Thus, $w_r = 1/(\sqrt{Lr\ Cr}) = 2\pi f_r = 314159$ rad / s (10)

The inequality in (8) should be satisfied for ensuring that the main power switch turns on and off at ZCS. Hence $I_{Lf\ max}$ should be less than or equal to $Vin, max\ /\ Zo$.

$ZO = \sqrt{(Lr/Cr)} < (Vin\,max/\ ILf\ max) = 45.25\ \Omega$ (11)

The expression divided by gives

$Lr < (Vin\,max/\ 2\pi\ fr\ ILf\ max) = 144 \times10^{-6}$ H (12)

Lr is taken as 100 µH for for making ZCS property better. Lr =100 µH

Substituting value of Lr in (24) we get Cr as 101.3 nF, take Cr = 100 nF

Step 4 – calculation of the filter parameters.

Constrain for selection of filter parameters are THD value should be kept below 5%

$\%THD = \sum (V_{on}/V_{o1})^2 < 0.0025$

IV. CONTROL CIRCUIT

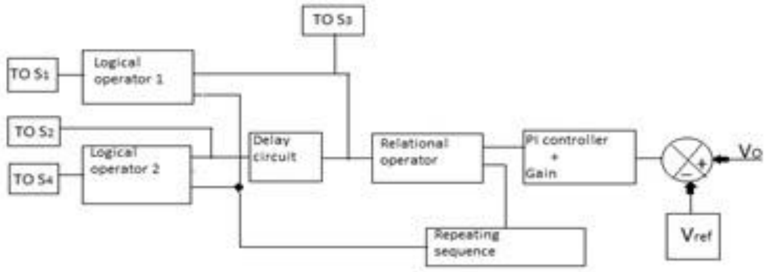


Fig 4. Proposed control circuit

Control circuit is based on frequency modulation constant on time control. Here sinusoidal output of line frequency is compare with the reference voltage (Voltage need to get at the output set as reference voltage), and its output is given to the P I Controller. P I controller output is controlled according to the controller parameter and the error signal received. Controlled output is compared with repeating sequence of desired frequency (25 kHz in this case) using relational operator and we get output pulses with line frequency. That pulses are desired pulses to switch S_3. And this line frequency pulses are delayed accordingly using a delay circuit to provide pulses to S_2. Both S3 and S2 satisfying same purpose in positive and negative half cycle of input source respectively. Line frequency pulses logically AND ed with desired frequency pulses. And its output is at desired frequency (25 kHz) given as pulses to switch S_1. And this signal is delayed and gives to Switch S_4.

Whenever a deviation happened in output voltage, pulse width of pulses to switches changes accordingly and output voltage corrected. Controlling of pulse width done by P I controller.

V. SIMULINK MODEL

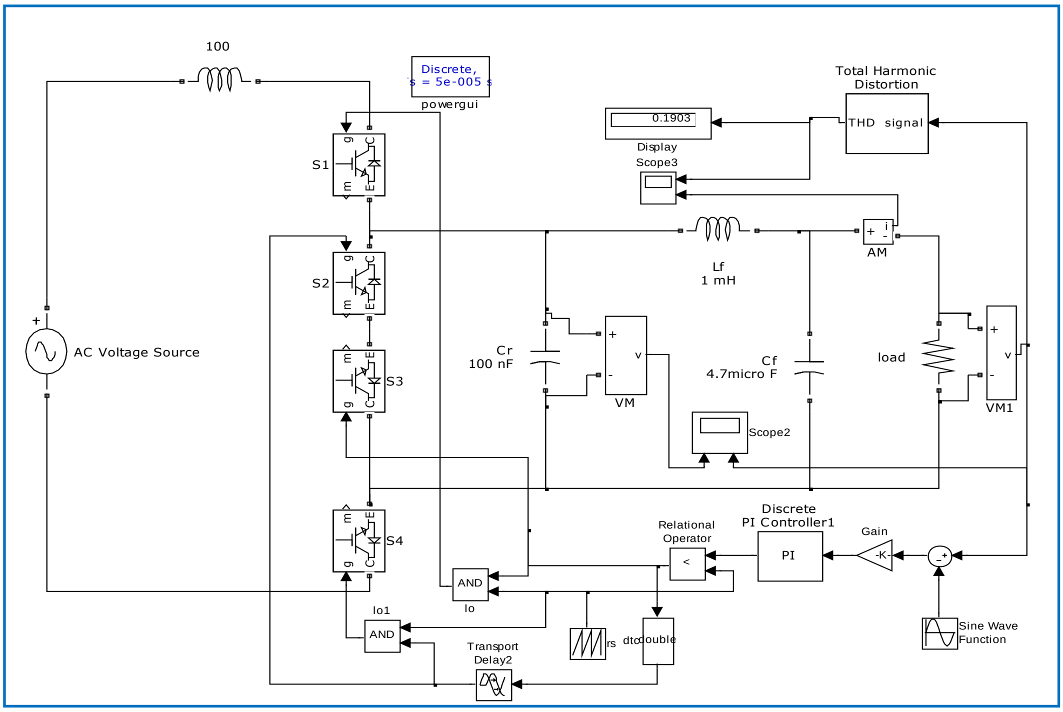
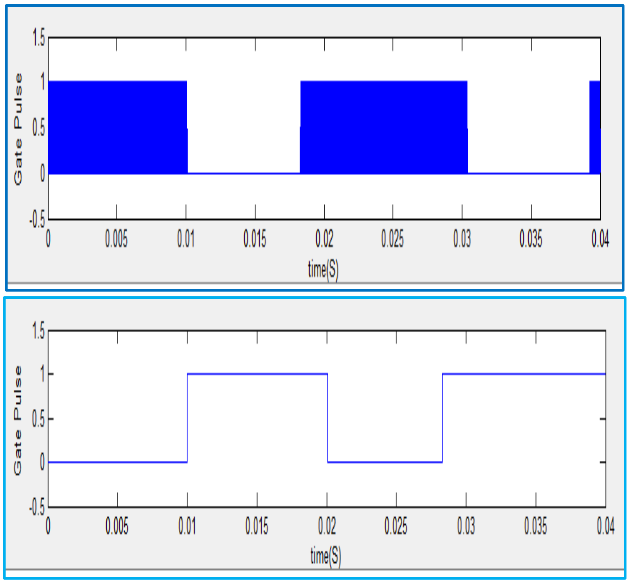


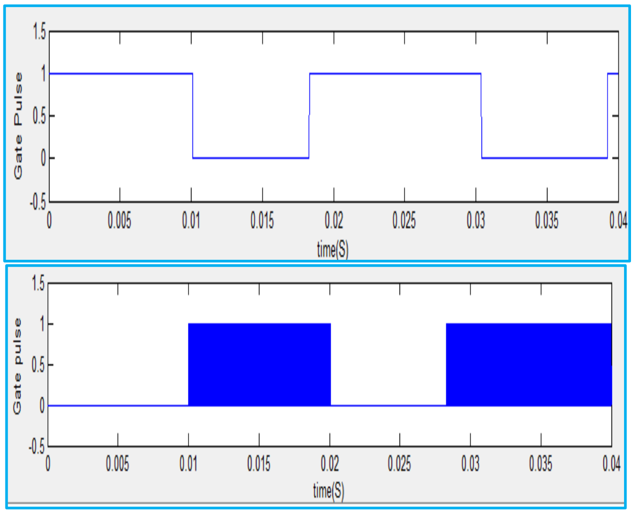
Fig 5. MAT LAB model of proposed system

VI. SIMULATION RESULTS

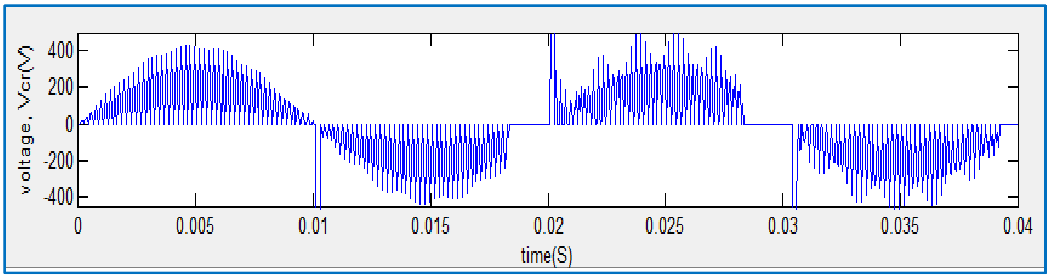
The simulation of the proposed AC series resonant chopper done with the help of MATLB SIMULINK. Fig. 6(a),(b) shows the generated gate signals for S_1,S_2,S_3 and S_4 respectively . Simulated waveforms of output voltage, current and %THD is for an input voltage of 310v with load resistance R=11.5 Ω, Lr=100 µH, Cr=100nF, Lf= 27 mH, Cf=47 µF are obtained as shown in figure 6. Resonant robes producing across the resonant capacitor have some disturbances as time goes on, because of the production of uneven pulses. Work going on to neutralize the problems occurred.



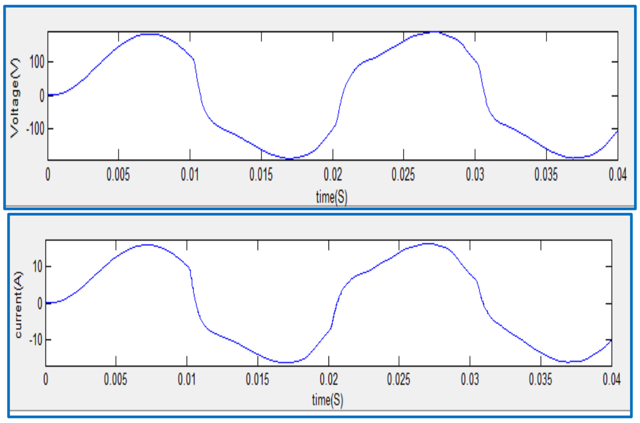
(a)



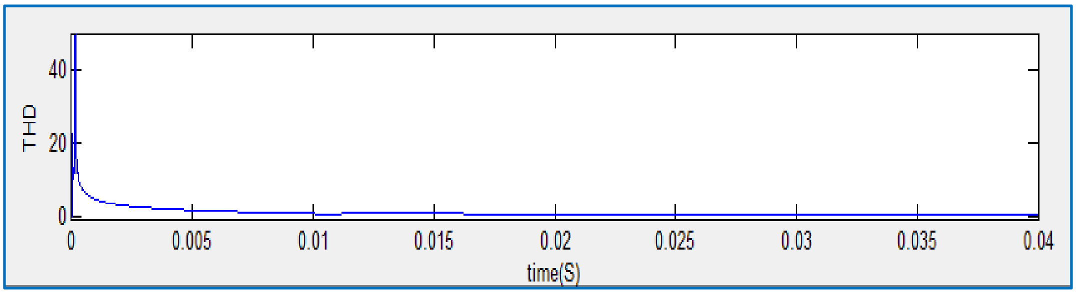
(b)



(c)



(d)



(e)

Fig.6: (a) Gate pulses, S_1 and S_2 (b) Gate pulses, S_3 and S_4 (c) Voltage across Cr (d) Output voltage, Output current (e) %THD

V. CONCLUSION

Modelling of Controlled high performance single phase ac chopper with zero voltage switching and frequency modulation is done in MAT LAB. Simulated the proposed system and different waveforms are obtained. There are some disadvantages sustained with this circuit like distorted output. Work continues on it to get the best possible output with resistive load. As future scope it can apply for other type of loads also. It also possess certain advantages like absence of Auxiliary switches, constant Frequency at input and output same as that of a transformer, Reduced number of Power Electronics components . It can avoid rectifier action, it provides Small and simple Controlling circuit. It accompanies with small amount of Switching losses, also have Improved values of THD from 0.949% to 0.19%. Power efficiency is more compared with hard switching techniques.

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