

# A Method for Suppression of Resonance Oscillation in PWM Current Source Converter

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**Abstract**— A suppression method for the resonance oscillation in the AC side of a pulse-width modulation (PWM) current source converter. The converter is operated with the PWM switching pattern. The resonance current, caused by the LC low pass filter at the step change of the pattern, can be effectively suppressed by one pulse control of the pattern. This method does not need to have the feedback loop of the current/voltage and does not offer the switching stress of the devices. The switching timing of the control is determined by pre-calculation of the off-line in consideration of the circuit constants. The circuit diagram for PWM current source converter and the PWM waveform generation circuit is drawn and simulated by using MATLAB.

**Key words:** Current Source Converter, Pulse-Width Modulation (PWM), Resonance Oscillation, Single-Phase

## I. INTRODUCTION

Use of turn-off device and application of pulse-width modulation (PWM) technique for power converter have brought distinct improvements in the characteristics. The achievement of sinusoidal wave of ac side in rectifier is an important result, and it contributes to unity power factor and reduction of harmonics in the ac power source and to low noise drives of ac motor. The converter with high performance of the power control is realized by employing powerful microprocessor. The PWM converter is classified into a voltage source type and a current source type. The former has ac inductor and dc capacitor, and the latter has LC ac filter and dc inductor. The PWM voltage source converter has been used widely because of the conversion efficiency and the installation size superior to the PWM current source converter. To achieve the sinusoidal input current, however, the voltage source converter necessitates the control loop for the switching of the devices, for instance a current regulated modulation control with hysteresis comparator.

## II. NEED FOR CURRENT SOURCE CONVERTER

In the current source converter, the sinusoidal input current can be easily obtained without addition of the control loop for the switching because it depends on the dc current. The voltage waveforms of the ac side in the voltage source converter consist of the trains of pulses of which the width is sinusoidally modulated with constant amplitude. The harmonic due to these pulse trains cause audible noise in the ac inductor. As the current source converter can directly convert the dc current into the sinusoidal current through the filter, the noise in the filter inductor is low considerably. The waveform of the ac current in the current source converter has direct relation to the PWM pattern that determines the switching timing for the devices.

The sub-harmonic modulation technique, which uses a comparison of two waves: reference modulating wave

with the identical frequency to ac source and carrier wave with high frequency, is simple in hardware logical circuit or software programming and is used widely. The sub-harmonic modulation has no need of such complex calculations as the space vector modulation implements. In the sub-harmonic modulation, it is most desirable that, among several waves, the sinusoidal wave is employed as the modulating and the triangular wave as the carrier, from a point of view of harmonics. The PWM pattern, which is generated by a comparison of the sinusoidal modulating and the triangular carrier waves, contains no harmonics, so that a sinusoidal ac current without harmonics can be obtained. The sinusoidal PWM is an effectual method as long as the converter is in steady state operation. The sinusoidal wave of the input, however, cannot be maintained in the case of the change of the dc output. The low pass filter on the ac side, which is indispensable to the current source converter circuit, generates the resonance and may cause oscillations in the supply current in the transient condition. The trigger of the resonance is due to the over-charge or the over-discharge of the filter capacitor when the width of the pulse in the PWM pattern is changed suddenly.

Fig. 6.e. gives the control times and the resonance period for constant in the case of  $R_f=0$ . The control times both increase as the LC constant increases. However, both the times  $t_1$  and  $t_2$  have the fixed rate to the period  $t_r$ . Equation (30) means that the supply current goes to the final value without the oscillation at one-third of the resonance period. This relation of the control times permits this method to be applied to the sub-harmonic modulation for the PWM converter. The time  $t_2$  does not almost change and the time  $t_1$  increases slightly according to increase of the resistance. The variation of  $t_1$  is caused by the change of the damping factor, which has relation to  $R_f$ .

### A. Block Diagram Explanation

The ac source is given to the resonant block which is the LC ac filter. Then it is given to the PWM current source converter. The PWM current source converter is controlled by the PIC Microcontroller. The PIC microcontroller gives the control signal to the driver circuit.

### B. Block Diagram

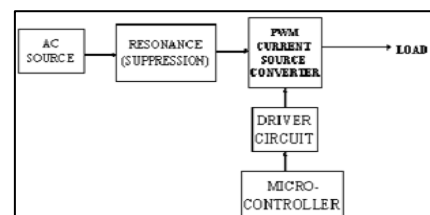


Fig. 1: Block Diagram

The oscillation is occurred in the inductor due to the resonance. This resonance oscillation is suppressed by the PWM pattern generated by the PIC microcontroller.

C. Circuit Diagram

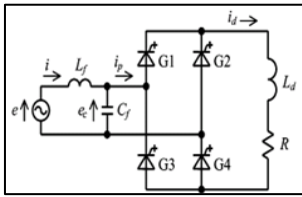


Fig. 2: PWM Current Source Converter

D. PWM Current Source Converter

The circuit configuration of the single-phase PWM current source converter is shown. The four turn-off devices gate turn offs (GTOs) can be replaced by the others metal oxide semiconductor field effect transistors (MOSFETs) or insulated gate bipolar transistors (IGBTs) etc. An inductor,  $L_f$  and a capacitor,  $C_f$  form a low-pass filter which permit the supply current to shape sinusoidal.  $L_d$  represents the dc smoothing reactor and R is the dc load.

E. PWM Waveform

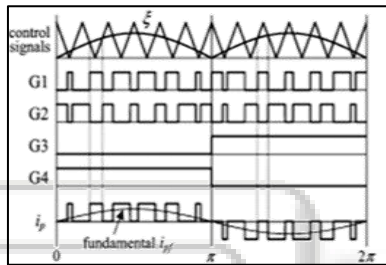


Fig. 3: PWM Waveform

1) PWM Method

The converter is operated by employing the PWM switching pattern shown in Fig. 3. The sinusoidal modulating wave, which is synchronized with the supply voltage, is compared with the triangular carrier wave. The intersection of two waves corresponds to the switching time for the devices G1 and G2. Although the input current  $i_p$  in the ac side of the converter consists of the pulse trains that are distributed sinusoidally, the fundamental of  $i_p$  flows into the supply through the LC filter. The supply current  $i$  contains the capacitor charging current which is independent of the PWM operation. The dc current  $i_d$  can be regulated by changing the dc voltage, of which the average value is in proportion to the amplitude of the modulating wave under the fixed carrier amplitude. The modulation index (MI) is defined as the ratio of the modulating amplitude to the carrier amplitude and is the only parameter for the converter control.

2) Converter Model and Suppression Method

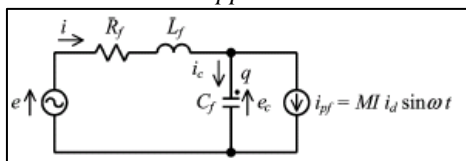


Fig. 4(a): Converter Model (for original with ac sources)

The converter can convert the dc current to the ac current with the same waveform as the modulating wave, because the dc reactor functions as the current source. Ignoring the current ripple due to the PWM switching, the model in the ac side of the converter can be represented in the equivalent circuit given by Fig. 4(a) with the ac current source  $i_{pf}$ . The current  $i_{pf}$  is the fundamental of the current  $i_p$  and its

amplitude equals to the product of the modulation index MI and the dc current  $i_d$ . Because the step change of MI brings the current  $i_{pf}$  to the discontinuous flow, the resonance, i.e., the transient oscillation of the current  $i$  and the voltage  $e_c$  is produced.

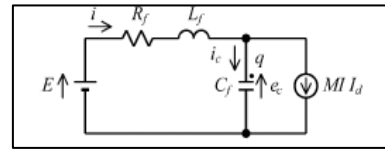


Fig. 4(b): Converter Model (for transient with dc sources)

In the current source converter, the dc inductor  $L_d$  of the output side is not always connected to the filter capacitor  $C_f$ . The connection between  $L_d$  and  $C_f$  depends on the device conduction, so that the resonance in the dc output cannot contain continuous oscillation. This results in the dc current ripple depending on the switching frequency of the device. As the value of  $L_d$  is considerably large compared with that of  $L_f$ , the dc inductor  $L_d$  does not need to be taken into the consideration for the suppression of the resonance oscillation in the ac side.

This method of the suppression makes use of the control of the modulation index only within one cycle of the resonance frequency. Assuming the instantaneous values of the supply voltage  $e$  and the dc current  $i_d$  to be fixed in the control period that is very short, the AC sources can be replaced by the dc sources as shown in Fig. 4(b).

F. Variation of MI

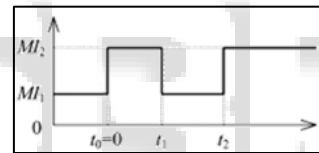


Fig. 5 Modulation Index (in current increase)

The DC model is used for the derivation of the control timing by reason of the simplification of the analysis, because the transient current is independent of the type of the source. The simple process in the change of the modulation index can achieve the suppression of the current oscillation. Fig. 5 shows the variation of MI in the case of increase of the current. The values of MI are changed at the time by the calculations obtained, between the present  $MI_1$  and the desired  $MI_2$ . The normal resonance is caused by the step change of MI in the interval  $t_0$  to  $t_1$ . However, the step down of MI at  $t_1$  causes the capacitor to be charged in reverse and permits the supply current  $i$  to be varied slowly. The instantaneous values of the current  $i$  and the capacitor voltage  $e_c$  at  $t_2$  equal to the values in the steady state with  $MI_2$ . As the conditions, the variation rate in increase or decrease, of the current  $i$  depend on the relationship between the voltages  $E$  and  $e_c$ , the MI control results in the charge control of the capacitor  $C_f$ .

G. Results obtained in DC Model

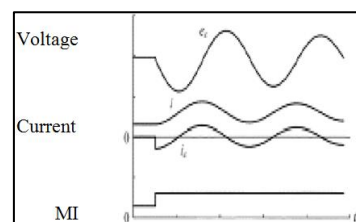


Fig. 6(a): Current Increase without Control

H. DC Model Results

The regulation of the modulation index MI results in the step change of the capacitor current. The discontinuous flow in  $i_c$  triggers the resonance and the oscillation occurs in the voltage and the current. The resonance oscillation that is caused by the single change of MI cannot be attenuated except the existence of the damping factor  $R_f$ . In the suppression control, the capacitor current  $i_c$  is controlled by the regulation of MI. As the current  $i_c$  flows oppositely in the interval  $t_1$  to  $t_2$  with the previous value of MI, no oscillation due to the resonance remains in the current  $i$ .

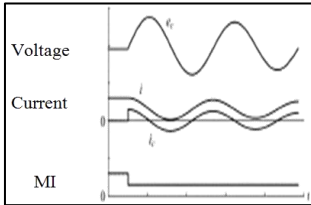


Fig. 6(b): Current Decrease Without Control

At the time  $t_2$  when MI is set to the desired value again, the capacitor voltage  $e_c$  and the supply current  $i$  reach to the values that equal to ones in the steady state condition. The results show that the resonance oscillation is perfectly suppressed. In the control times and, the identical value is used in both the current increase and decrease.

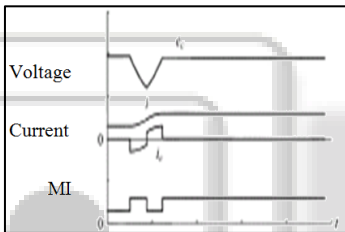


Fig. 6(c): Current Increase with Control

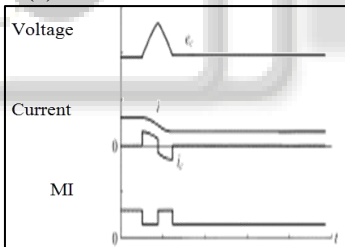


Fig. 6(d): Current Decrease with Control

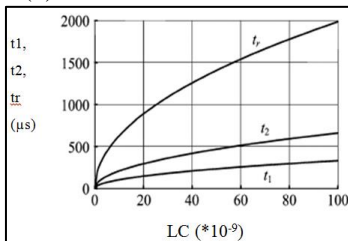


Fig. 6(e): Control Times & Resonance Period Vs LC

I. Experimental Waveforms

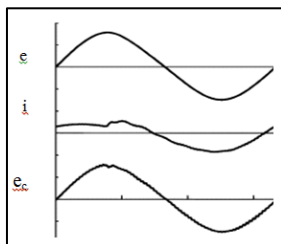


Fig. 7(a): MI Increase with Control

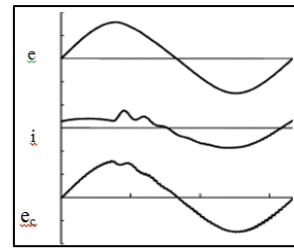


Fig. 7(b): Mi Increase Without Control

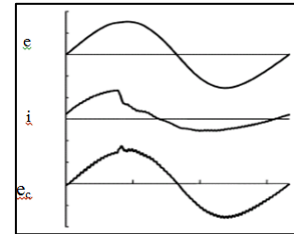


Fig. 7(c): Mi Decrease With Control

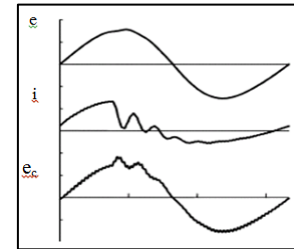


Fig. 7(d): Mi Decrease without Control

III. SIMULATION

Simulation is done by Simulink in MATLAB. A Subsystem for the PWM signal generation is drawn. From this circuit the gating signals  $G_1, G_2, G_3, G_4$  for the PWM current source converter are generated. The simulation circuit for the entire circuit diagram is drawn and then the circuit is simulated to obtain the experimental waveforms. The PWM signal, the capacitor voltage with reduced oscillation & the output waveforms are obtained and these waveforms are viewed in the scope.

A. Simulation Circuit for PWM Waveform

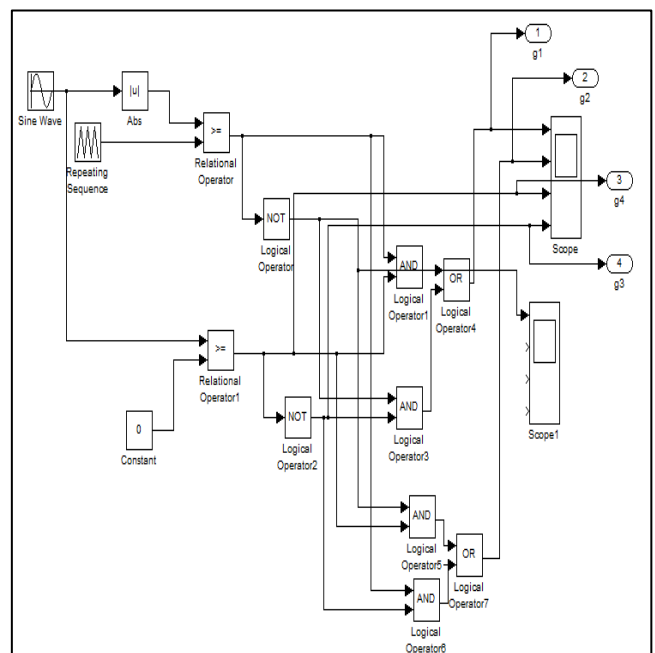


Fig. 8: Simulation Circuit for PWM Waveform

B. Simulated PWM Waveform

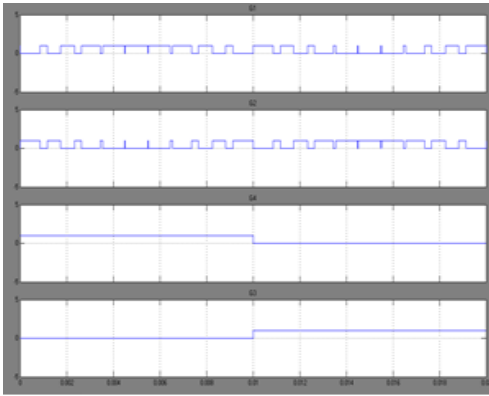


Fig. 9: Simulated PWM Waveform

C. Simulation Circuit for Entire Circuit Diagram

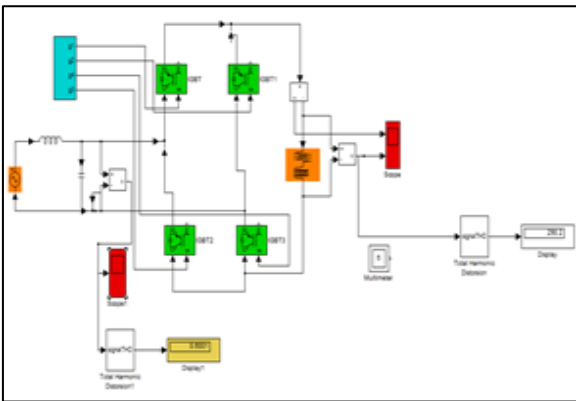


Fig. 10: Simulation Circuit for Entire Circuit Diagram

D. Current & Voltage Waveform of DC Load, R

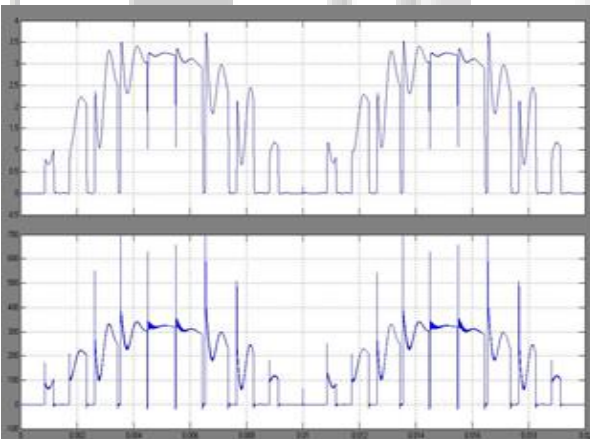


Fig. 11: Current & Voltage Waveform of DC Load, R

E. Waveform for Resonance Circuit with Oscillation

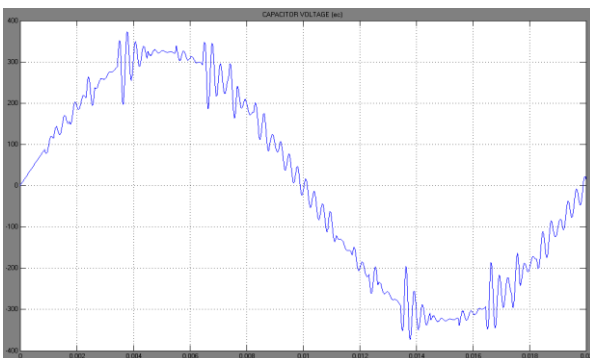


Fig. 12: Waveform for Resonance Circuit with Oscillation

F. Waveform with Reduced Oscillation

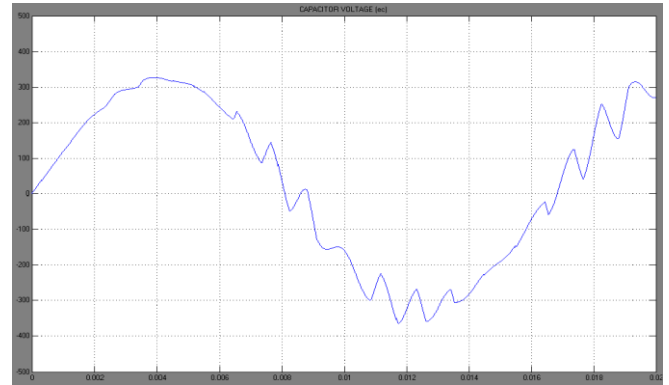


Fig. 13: Waveform with Reduced Oscillation

IV. CONCLUSION

The suppression method for the resonance oscillation in the PWM current source converter has been given and the experimental results in the have been shown. This method is effective for the suppression of the resonance oscillation. The control timing depends on the constants only in the ac side and no feedback loop is necessary to the suppression. When the carrier frequency for the generation of the PWM pulses is selected at the value corresponding to the control timing, the pulse regulation in two carrier cycles allows the oscillation to be damped.

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