Resonant Controller to Minimize THD for PWM Inverter

Atul A. Joshi [1], Ravindrakumar M. Nagarale [2]

[1]PG Student, M.B.E.Society's College of, Engineering, Ambajogai (M.S), India
[2]PG Department, M.B.E.Society's College of, Engineering, Ambajogai (M.S), India

Abstract*: In this paper, a method for minimization of Total Harmonic Distortion (THD) is proposed in case of PWM inverter. Inverters are widely used in many applications such as in the UPS and ac motor drives resulting in harmonics production. A phase compensation Resonant Controller (RSC) is proposed for 1-phase pulse width modulation (PWM) inverter using MATLAB simulation. The simulation results are then compared with State Feedback Controller (SFC) and State Vector Pulse Width Modulation (PWM) controller provided to approach the system.*
Keywords: *Total harmonic distortion (THD), Pulse width modulation (PWM) , Resonant controller (RSC), Feedback controller, State vector PWM controller etc.*

I. Introduction

Every wave shape has a Total Harmonic Distortion (THD) value [1]. The THD is the main criterion to calculate the high grade performance of PWM inverters. Output voltage waveforms of inverters are distorted by non linear loads or some uncertain conditions and hence affect the inverter output. Now days various electronic equipments are used in various fields resulting in harmonic production & which causes low power factor, electromagnetic interference, voltage distortion etc. Harmonic current occur in a facility's electrical system can cause equipment malfunction, data distortion, transformer and motor insulation failure, overheating of 11 neutral buses, tripping of circuit breakers, and solid-state component breakdown. The reduction of harmonic distortion and control of output waveforms of PWM converters have attracted many researchers' interests.

The State vector PWM technique [2-3] algorithm offers a novel method for minimizing the total harmonic distortion (THD) of the output voltage of the inverter and uses simple arithmetic for determining the sector and does not require lookup tables. However, due to the high order structure of its internal model, State space vector PWM technique is found to be very slow in removing high order harmonics in case of PWM inverter. However, State Feedback Controller (SFC) [3] is based on an accurate nominal model of the PWM inverter. In the presence of parameter uncertainties and nonlinear loads, phase compensation MRSC $R(z)$ are plugged into SFC controlled inverter to improve the tracking accuracy and eliminate the dominant harmonics. As all we know, odd harmonics in the low frequency band dominate the total harmonic distortion of the output voltage of the single phase PWM inverter with the rectifier load, especially 3rd, 5th, 7th, 9th, 11th,13th and 15th order harmonics. However, due to the parameter uncertainties, unknown delays and nonlinear loads, accurate transfer function of SFC system is different from $H(z)$.

Resonant control (RSC) [4], which is based on IMP, has infinite open-loop gain at resonant frequency, and can achieve zero steady state error control for sinusoidal signal with the frequency at resonant frequency. Since harmonics of the output voltage/current of power converters mainly concentrate within low frequency band, for example, 3rd, 5th, 7th, 9th, 11th, 13th and 15th order harmonic often dominate the harmonic distortion caused by the single-phase rectifier load. Therefore a parallel combination of multiple resonant controllers (MRSC) at dominant frequencies can be used to eliminate major harmonic distortion, and can obtain high control accuracy. Phase compensation method is proposed for RSC to achieve wider stability range. Finally, phase compensation resonant control scheme is applied to a single-phase PWM inverter to reduce its THD value. There are many techniques for harmonic reduction, such as, Using Walsh function technique By using 12 pulse transformer design, Using Input Trap filter, Using PSO - Particle swarm optimization, Using Genetic algorithms, Using Repetitive controller, By using Space vector modulation, State feedback controller, Resonant controller. Above all techniques are used for harmonic reduction in case of inverters. But the main and advantageous one is the Resonant controller. We can reduce THD through it.

II. PWM Inverter

The power circuit of a single-phase PWM inverter [5-8] is shown in Fig (1). The output signal generated by the PWM inverter is the pulse width modulated signal, having constant frequeney. It includes an insulated gate bipolar transistor (IGBT) half bridge configuration and an filter. The equivalent series resistance (ESR) of the filter capacitor is not considered because of its negligible effect on the system performance in the concerned frequency region.
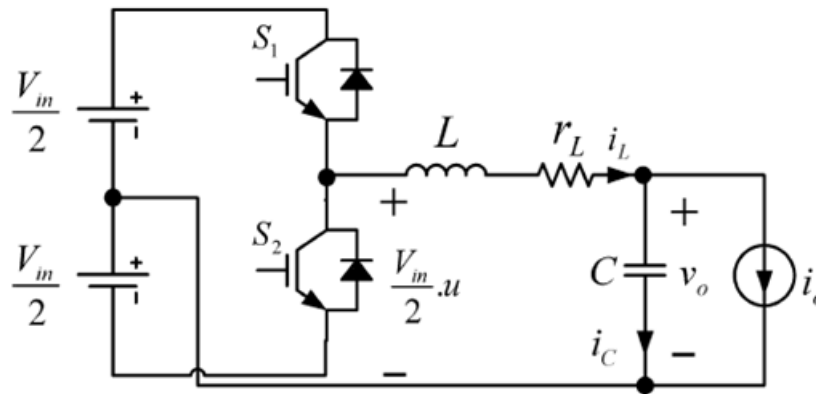
Fig. (1). Power circuit of single phase inverter

The following differential equations can be written from the power circuit shown in Fig.:

$$L\,\frac{di_L}{dt} = \frac{V_{in}}{2} - V_o - r_L i_L \qquad (1)$$

$$i_C = c\,\frac{dv_o}{dt} = i_L i_o \qquad (2)$$

In the most straightforward implementation, generation of the desired output voltage is achieved by comparing the desired reference waveform (modulating signal) with a high frequency triangular 'carrier' wave. Depending on whether the signal voltage is larger or smaller than the carrier waveform, either the positive or negative dc bus voltage is applied at the output. Note that over the period of one triangle wave, the average voltage applied to the load is proportional to the amplitude of the signal (assumed constant) during this period. The resulting chopped square waveform contains a replica of the desired waveform in its low frequency components, with the higher frequency components being at frequencies of close to the carrier frequency. Notice that the root mean square value of the ac voltage waveform is still equal to the dc bus voltage, and hence the total harmonic distortion is not affected by the PWM process. The harmonic components are merely shifted into the higher frequency range and are automatically filtered due to inductances in the ac system.

Although the SPWM [3] waveform has harmonics of several orders in the phase voltage waveform, the dominant ones other than the fundamental are of order n and n±2 where n = fc/fm. This is evident for the spectrum for n=15 and m = 0.8 shown in Fig.5. Note that if the other two phases are identically generated but 120° apart in phase, the line-line voltage will not have any triple n harmonics. Hence it is advisable to choose $\frac{f_c}{f_m} = 3k, (k \in n)$, as then the dominant harmonic will be eliminated. The dominant 15th harmonic is effectively eliminated in the line voltage. Choosing a multiple of 3 is also convenient as then the same triangular waveform can be used as the carrier in all three phases, leading to some simplification in hardware.

But high performance pulse-width modulated (PWM) inverters should accurately regulate the output ac voltage/current to the reference sinusoidal input with low total harmonics distortion (THD) and fast dynamic response. Nonlinear loads such as the rectifier loads that cause periodic distortion are major sources of THD. However, ac references and disturbances contain dominant odd-harmonic frequencies and minor even-harmonic frequencies in the PWM inverters.

III.   Resonant Controller
Resonant control (RSC), which is based on IMP, has infinite open-loop gain at resonant frequency, and can achieve zero steady state error control for sinusoidal signal with the frequency at resonant frequency [4]. Since harmonics of the output voltage/current of power converters mainly concentrate within low frequency band, for example, 3rd, 5th, 7th, 9th, 11th, 13th and 15th order harmonic often dominate the harmonic distortion caused by the single-phase rectifier load. Therefore a parallel combination of multiple resonant controllers (MRSC) at dominant frequencies can be used to eliminate major harmonic distortion, and can obtain high control accuracy. However, in practical applications, when a RSC with high-order resonant frequency (e.g., seventh, ninth, eleventh order harmonics) is plugged into MRSC, the control system is apt to become unstable. With the help of phase compensation principle for repetitive control [4], phase compensation method is proposed for RSC to achieve wider stability range. Phase compensation at each resonant frequency enables more RSCs to be added into MRSC. Therefore both stability and control accuracy of multiresonant control

system can be improved. Finally, phase compensation resonant control scheme is applied to a single-phase PWM inverter to evaluate its validity.

The phase compensation principle for Resonant controller is used for PWM inverters. In which parallel combination of multiple resonant controllers at dominant harmonic frequencies can be used to eliminate dominant harmonic distortion as follows:

$$R(s) = \sum_{n=1}^{i} g_n \frac{s \cos \omega_n T_n - \omega_n \sin \omega_n T_n}{s^2 + \omega_n{}^2} = \sum_{n=1}^{i} R_n(s) \qquad (3)$$

This principle is used to simulate the controller. Where $R_n(s)$ is a RSC with phase compensation time τ_n and gain g_n [5] . And, average phase of RSC at its resonant frequency is θ_n . Obviously, each RCS in MRSC of (3) can choose its gain and compensation phase independently. Independent phase compensation and gain for each RSC enable MRSC to achieve zero phase compensation at each dominant harmonic frequency (i.e., resonant frequency) with an optimal error convergence rate. Therefore, more RSCs can be added into MRSC to enhance its tracking accuracy. Compared with phase compensation RC, phase compensation MRSC can achieve almost the same tracking accuracy at much higher error convergence rate. Since MRSC is only comprised of RSCs at the dominant harmonic frequencies in the low frequency band, it doesn't need a low pass filter.

IV.   Resonant Controller For PWM Inverter

Fig. (2) presents a single phase PWM inverter with its resonant control scheme [4]. The control objective of the PWM inverter is to force output voltage Vc to track the reference input ref accurately. The discrete mathematical model of such a single phase PWM inverter can be expressed as:

$$\begin{bmatrix} v_c(k+1) \\ \dot{v}_c(k+2) \end{bmatrix} = \begin{bmatrix} f_{11} & f_{12} \\ f_{21} & f_{22} \end{bmatrix} \begin{bmatrix} v_c(k) \\ \dot{v}_c(k) \end{bmatrix} + \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} V_{in}(k) \qquad (4)$$

$$y(k) = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} V_c(k) \\ V_c(k) \end{bmatrix} \qquad (5)$$

Where, $f_{11} = 1 - \frac{T^2}{2 L_n C_n}$, $f_{21} = -\frac{T}{(L_n C_n)} + \frac{T^2}{(2 L_n C_n R_n C_n)}$,

$$f_{22} = 1 - \frac{T}{(R_n C_n)} - \frac{T^2}{(2 L_n C_n)} + \frac{T^2}{(2 R_n C_n R_n C_n)} ,$$

$$h_1 = \frac{T^2}{(2 L_n C_n)} , \quad h_2 = \frac{T\left(1 - \frac{T}{2 R_n C_n}\right)}{L_n C_n}$$
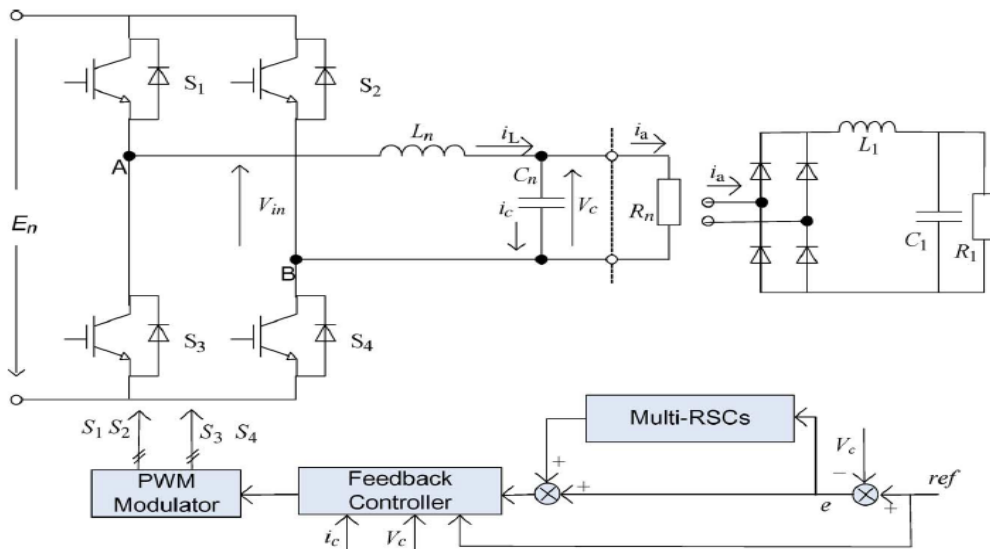

Fig. (2) - Single phase PWM inverter with Resonant control scheme.

Where E_n, L_n, C_n and R_n are the nominal value of the dc voltage, the inductance, the capacitance and the load resistance respectively, is the output voltage V_c of the inverter, T is the sampling period.

Fig. (3) presents the resonant control system [6]-[7] of the single phase PWM inverter, where ref is the reference input, e is the control error, u is the control input, d is the disturbance, $K(z)$ is the SFC of (4), $P(z)$ is the plant of (3), $R(z)$ denotes digital multiple RSCs.
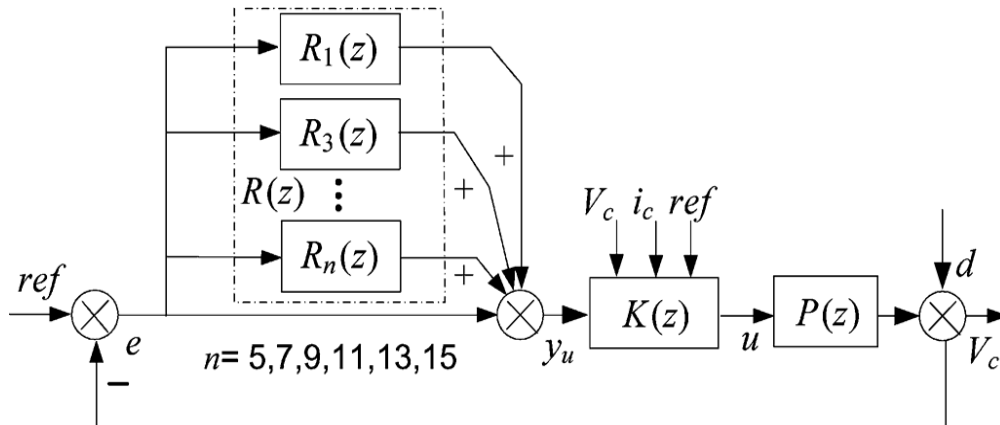

Fig. (3)- Block Diagram of Resonant Control inverter system

A state feedback controller (SFC)[4] can be employed as follows:

$$\mu(k) = -K_f x(k) + h\,ref(k) \qquad (6)$$

To control the PWM inverter, where $K_f = [K_1\ K_2]$, h is the gain of the reference input . The poles of the feedback control system can be assigned to achieve good robustness by tuning control gains K_1 and K_2.

V.   Simulation Results For THD

The simulation results can be seen on FFT analysis through discrete model. In case of PWM inverter, the harmonic reductions can be shown by the main performance index THD. The harmonic reduction is done on the selected sine wave. On that selected sine wave, to minimize the harmonics the Resonant controller is used. The THD results are shown between the magnitude and the frequency of selected signal. For different harmonic orders, we get different THD values. The bar representation of the harmonic orders are shown in fig (4).
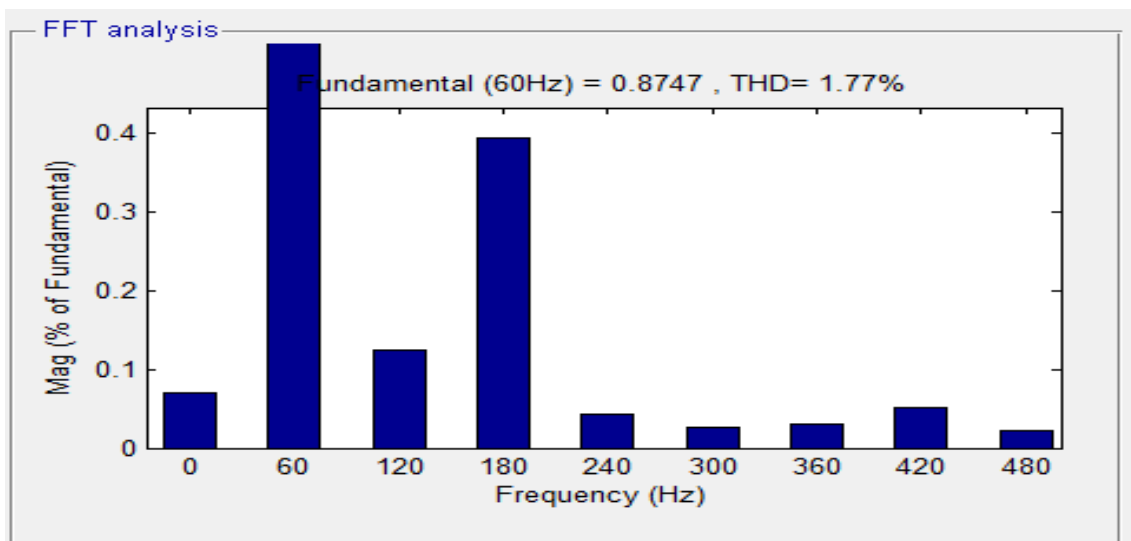

Fig . (4) - THD values for Resonant controller

The table1 shown below make sure that, among all controllers or techniques for THD minimization, the Resonant controller is the best and efficient controller.

TABLE (1) . THD values.

SN.	CONTROLLERS / TECHNIQUES	THD VALUE(%)
1	Resonant Controller	1.77 %
2	Space vector PWM technique	108.61 %
3	State feedback Controller	2.12

VI.   Conclusion

The paper proposes technique for minimization of Total Harmonic Distortion. Presently no method gives sinusoidal output waveform with zero percentage THD. The resonant controller is efficient, compared to space vector PWM controller and state feedback controller, since it gives 1.77% THD value. In this paper the phase compensation principle for RSC is developed. Phase compensation multiresonant control scheme provides a high performance control solution for PWM converter systems. A MATLAB Simulation diagram and simulation result shows that resonant controller is very efficient to minimize the THD value.

References

[1]. Yaskawa, "Minimizing Total Harmonic Distortion Values", Yaskawa Electric America, Inc, vol. 1, pp. 2-4, 2006.
[2]. Yang Yinfu, Liu Jingbo and Zhou Dangsheng, "Pulse by Pulse Current Limiting Technique for SPWM Inverters", International Conference on Power Electronics and Drive Systems, PEDS, vol. 4, July 1999.
[3]. R .Karthikeyan, "An Efficient Multilevel Inverter System for Reducing THD with Space Vector Modulation", International Journal of Computer Applications (0975 – 8887) vol. 23, pp. 2, June 2011.
[4]. Yunhu Yang, Keliang Zhou, "Phase Compensation Resonant Controller for PWM Converters", IEEE Transactions on industrial informatics, vol. 9, no. 2, May 2013.
[5]. Carlos Alberto Lozano Espinosa, "Minimization of THD and Angle calculation for Multilevel Inerters", International Journal of Engineering & Technology IJET-IJENS vol.12 No. 05 ,October 2012.
[6]. Keliang Zhou and Danwei Wang, "Digital Repetitive Learning Controller for Three-Phase CVCF PWM Inverter" IEEE transactions on industrial electronics, vol. 48, no. 4, August 2001.
[7]. Keliang Zhou, Kay-Soon Low, Danwei Wang, Fang-Lin Luo, Bin Zhang,and Yigang Wang, "Zero-Phase Odd-Harmonic Repetitive Controller for a Single-Phase PWM Inverter" , IEEE transactions on power electronics, vol. 21, no. 1, January 2006.