International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 6, Number 3 (2013), pp. 329-337

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Control of Transformerless Inverter Supplying Linear and Non-linear Loads

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Abstract

This paper discusses the design of current mode control of inverter to shape filter inductor currents along with shaping of output voltage analogous to rectifier design, for non-linear loads. The inverter chosen is a single phase half bridge transformerless inverter. The load considered is an SCR full bridge rectifier with various firing angles. The reduction in filter current harmonics helps in reducing the size of the filter. The results are validated through experimentation.

Index Terms: Current harmonics, Current mode control, SCR full bridge rectifier, transformerless inverter.

Introduction

The wide use of renewable energy sources warrants use of inverters in large extent. These sources are used for many portable applications and supply rectifier type of loads. Such loads cause distortion of the supply voltage and current waveforms. The major concern in all the inverter design has been to shape the inverter output voltage and less emphasis has been given on handling of the current harmonics. The load harmonic currents are to be supplied by the output filter components. A scheme has been introduced by [1] to supply the load harmonics by modulating the inverter switches. The load currents (three phase) are measured and transformed to synchronous reference frame and used as reference currents for the inverter. Many of the UPS applications discuss about the controller design for sinusoidal output voltage and do not provide current mode control for the inverter [2,3]. In the zero voltage

switched inverters, the emphasis has been on reducing the switching losses than reducing the inductor ripple [4,5]. Compensation for DC bus fluctuations to produce regulated output voltage is presented in [6]. Further the advantages of transformerless rectifiers and inverters have been highlighted in literature[9], transformerless circuits have reduced switching loss, increased efficiency and are smaller in size.
The output voltage control suffers due to drop in the filter inductor when the distortions in the current are high. Hence for non-linear loads, the output voltage feedback alone cannot compensate for tracking a sinusoidal reference. By incorporating a current mode controller to shape the inductor current along with the capacitor voltage, best controller action can be achieved. The controller proposed in this paper modulates the switching action of the inverter switches to relieve the filter components form the burden of supplying the harmonics. The technique proposed in this paper is simple compared to [1] as the controller can be designed in analog form.

The Transformerless Inverter Circuit

Consider the half bridge transformerless inverter as shown in Figure 1.The dynamic equations of the inverter averaged over one switching cycle with the variables marked as in Figure 1, are presented in (1) and (2).

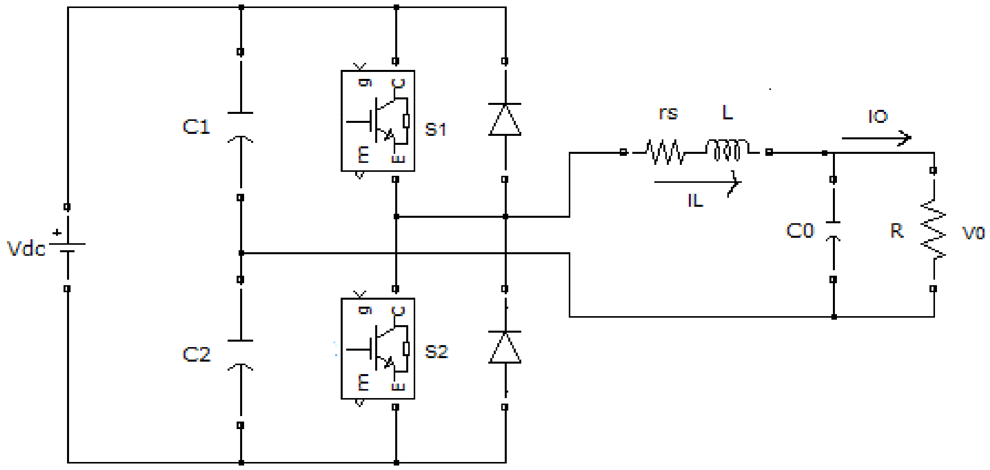


Figure 1: Half bridge Transformerless inverter.

$$L\left(\frac{di_L}{dt}\right) = dV_{c1} - V_{c2}\left(1-d\right) - V_0 + r_s i_L \quad (1)$$

$$c\left(\frac{dV_0}{dt}\right) = i_L - i_0 \quad (2)$$

Where d is the duty cycle.

The controller of the transformerless inverter can be derived easily considering volt-second balance in the output filter inductor analogous to transformerless rectifier. The only difference is that in a rectifier, the inductor current is shaped to be in-phase with the supply voltage. Whereas in the inverter it may lag the output voltage.
Let T be the switching period. Assuming a constant and high switching frequency f (1/T), d is determined from the following volt-second balance equation across the filter inductor

$$V_0 - i_s r_s = d\left(V_{C1} - V_{C2}\right) \quad (3)$$

The normal control objective is to maintain output voltage V_0 sinusoidal irrespective of the load current i_0. The second objective considered is to shape the filter inductor current to have low distortion. It is achieved by introducing an inner current loop.
The proposed control structure is shown in Figure 2.

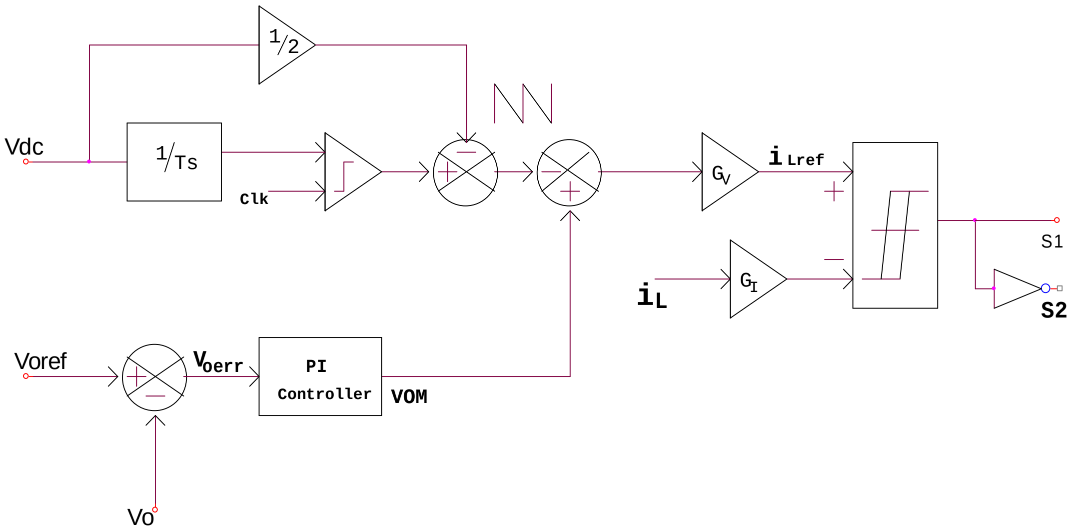


Figure 2: Proposed control scheme.

A PI controller is present in the voltage control loop to produce the current reference. This reference current is compared with the actual current to switch the devices S_1 and S_2. Let us consider two cases of loads namely.

1) Loads carrying sinusoidal load current.
2) Loads carrying non-sinusoidal load current.

When the inverter is supplying for R, RL and RLE loads which draw sinusoidal currents, maintaining the output voltage and inductor current sinusoidal is simple. In the second case the load harmonic currents are also to be supplied by the filter. Proper tuning of the controller parameters helps to meet the control objectives.

Main Results

The controller develops a ramp with the upper limit as $V_{dc}/2$ and lower limit as -$V_{dc}/2$.This ramp is amplitude modulated with the output of voltage loop PI controller(V_{OM}) as shown in Figure 2. This modulated ramp is compared with filter inductor current to produce the switching signals for S_1 and S_2.

The gain of the current loop plays a major role in shaping the inductor current and the capacitor voltage.

Let us consider the expression for capacitor current.

$$i_c = i_L - i_0$$

A sinusoidal load current i_0 can produce sinusoidal capacitor and inductor current. where as a non-sinusoidal load current has to be compensated either by the inductor current or by the distorted current / (voltage) or both. The parameters chosen for the inverter are given in table 1. The results of various control gains and the corresponding distortions on the output voltage and inductor currents are tabulated in table 2.

Table 1: Inverter parameters.

Mosfet	**Inductor**	**Capacitor**	**R**
IRF540N	1mH	47uF	50Ω

Table 2: THD of output filter inductor current and output voltage with R and RL load.

Type of Load	**Current Gain**	**Volatge Gain**	**Current THD (%)**	**Voltage THD (%)**
R	20	2.5	2.470	0.0322
	20	500	2.549	0.0346
	20	10	2.542	0.0351
	10	500	2.553	0.0359
	20	0.1	29.64	13.13
	20	0.5	36.75	15.41
R L	20	2.5	2.464	0.0320
	20	500	2.548	0.0350
	20	10	2.525	0.0349
	10	500	2.534	0.0342
	20	0.1	29.77	13.13
	20	0.5	36.91	15.41

The results show that improper tuning of the controller may lead to non-sinusoidal filter currents even for a sinusoidal load current. Improper tuning would have required a large sized inductor. In case of SCR loads, as the firing angle changes from 0° to 90°

the distortion in the current waveform increases, but tuned to their minimum levels as high-lighted in table 3. Simulation results show that it is possible to achieve pure output voltage waveforms with firing angles up to 30°. The maximum voltage THD is restricted to 4.6% (90° firing angle) but the inductor current THD increases with the firing angle. The current loop serves to limit the load current protecting from over current short circuit.

Table 3: THD of Inductor Current and Output Voltage with rectifier load with various firing angles.

Firing angle (Degrees)	Current Gain	Voltage Gain	Current THD (%)	Voltage THD (%)
10	20	2.50	6.14	1.85
	20	500	6.21	0.27
	20	10	6.28	0.28
	10	500	6.34	0.29
	20	0.10	39.64	28.38
	20	0.50	44.44	31.98
30	20	2.50	14.00	1.1
	20	500	14.70	0.58
	20	10	14.86	0.74
	10	500	14.70	0.59
	20	0.10	39.08	39.11
	20	0.50	45.14	44.93
45	20	2.50	27.29	1.89
	20	500	28.68	2.11
	20	10	28.31	1.882
	10	500	28.54	2.011
	20	0.10	39.74	47.35
	20	0.50	45.66	49.62
60	20	2.50	39.84	4.57
	20	500	42.66	3.503
	20	10	41.99	3.44
	10	500	41.68	3.158
	20	0.10	40.78	45.54
	20	0.50	47.19	46.24
90	20	2.50	80.92	5.561
	20	500	82.42	4.663
	20	10	82.65	4.972
	10	500	82.39	4.687
	20	0.10	57.75	32.11
	20	0.50	63.65	31.60

The simulation results with various loads(R and RL) are shown in Figs. 3. The simulation results with bridge rectifier load for different firing angles are shown in Figures 4. It is observed that output voltage reaches the desired value. Both the output voltage and filter inductor current maintain sinusoidal shape irrespective of type of load. The voltage regulation has been maintained for a step load disturbance and reference change as shown in Figure 5.

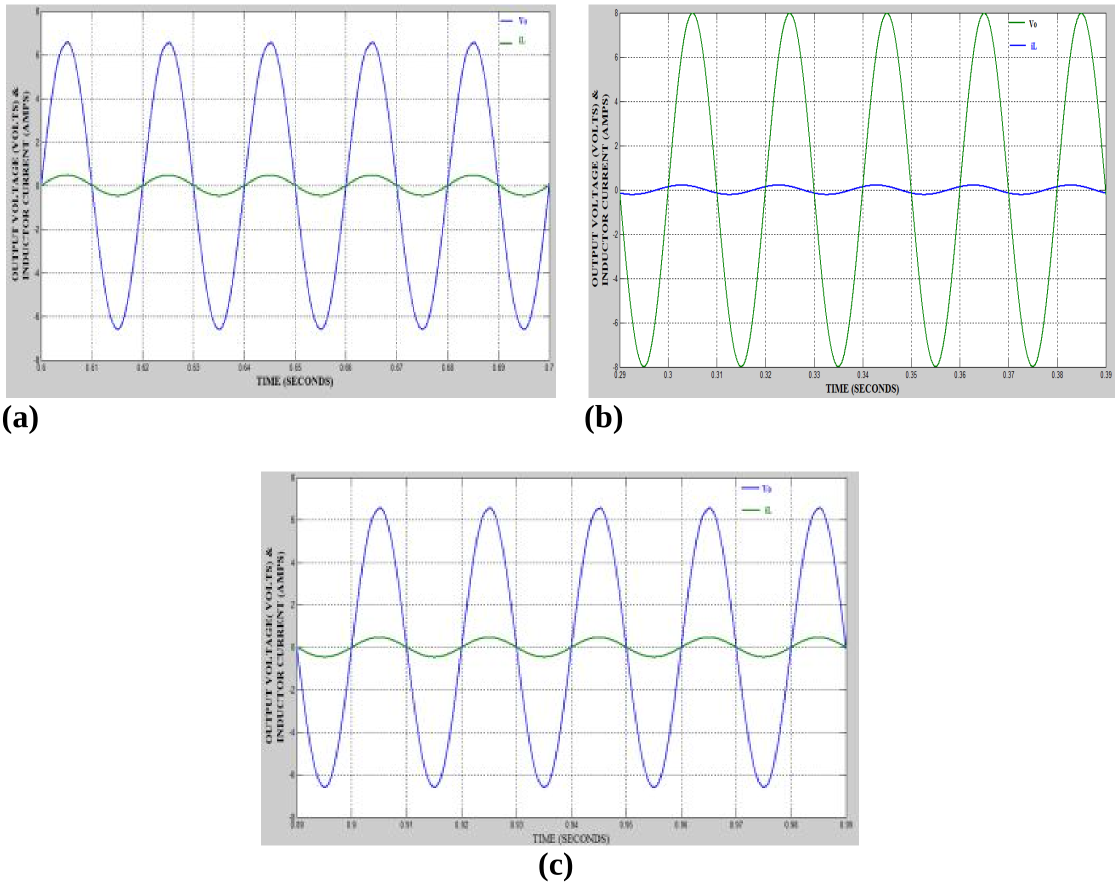
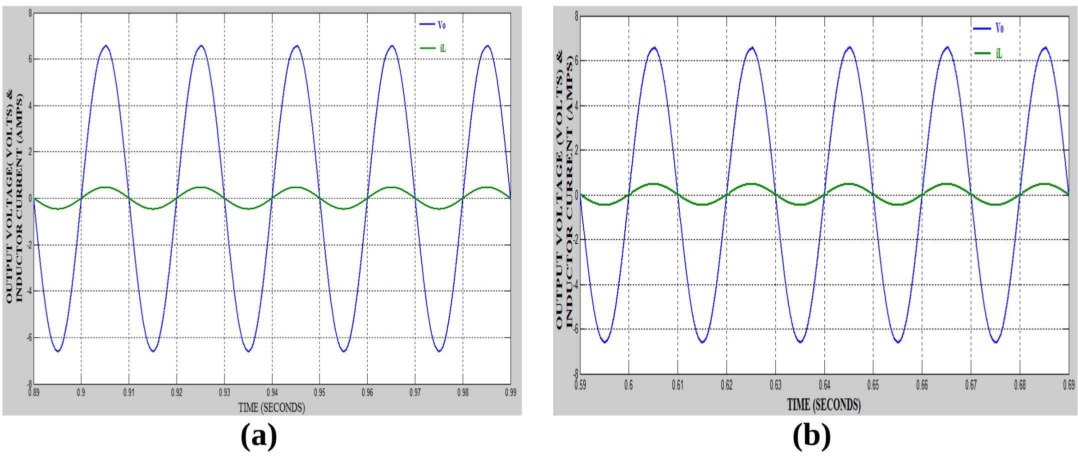
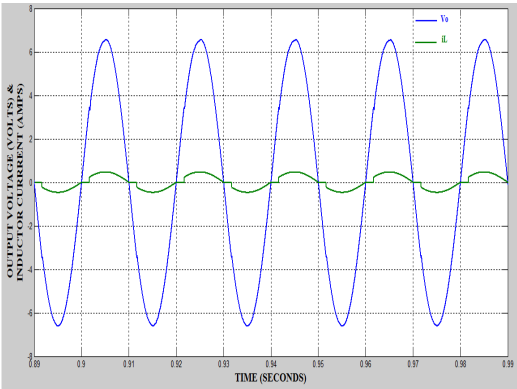
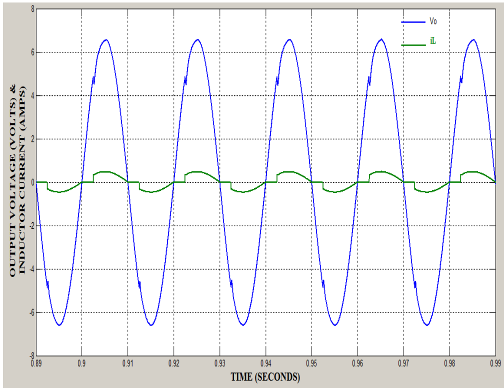


Figure 3(a-c): Output voltage and inductor current with various types of load (a)Purely resistive load (b) inductive load (c) Bridge rectifier load.

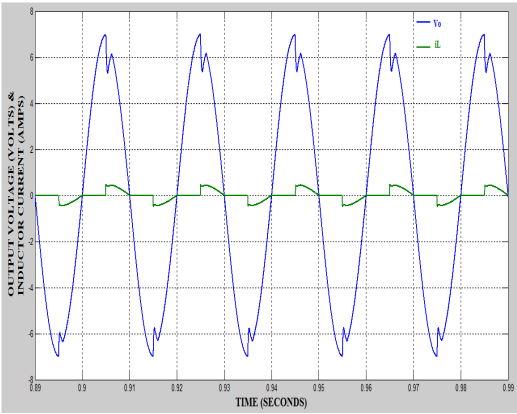




(c)



(d)



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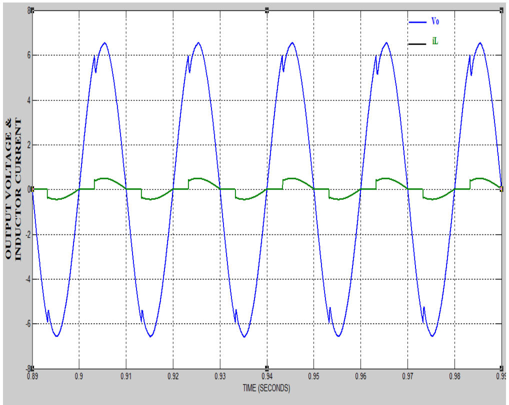
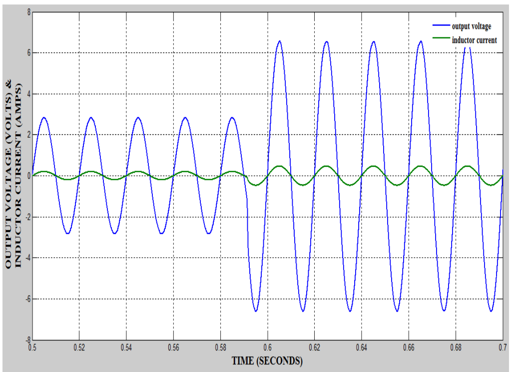
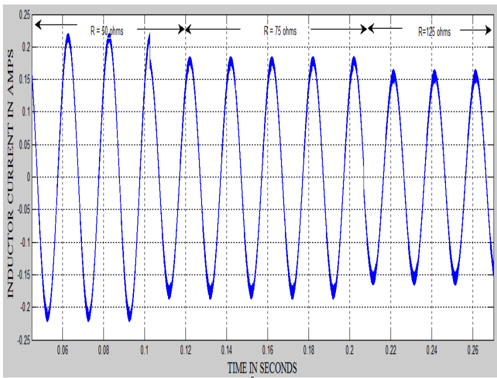


(f)

Figure 4(a-f): Output voltage and inductor current with rectifier load with different firing angles. (a) 0° (b) 10° (c) 30° (d) 45° (e) 60° (f) 90°

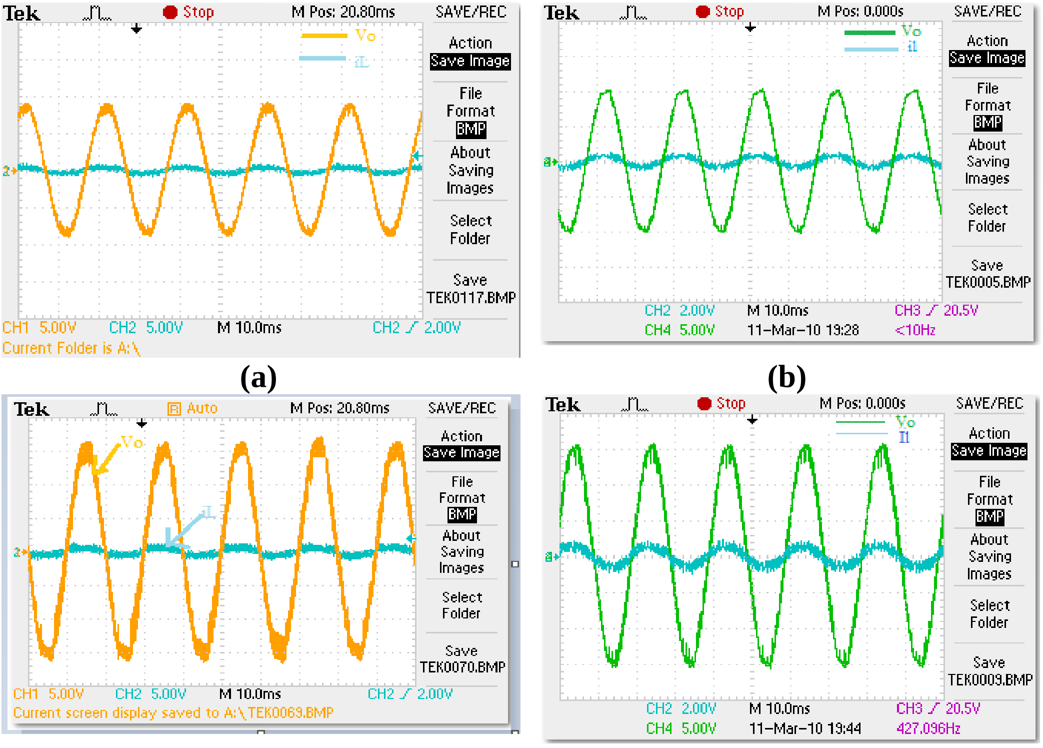


(a)



(b)

Figure 5: Response of the inverter for step change (a) Output voltage and inductor current for step change in Vo Reference (b) Inductor current for step changes in load resistance.



(a) (b)

(c) (d)

Figure 6: Hardware results.

Experimental results with various loads are shown in Figures 6(a-d)

Conclusion

Controller is designed for single phase transformerless inverter. The Control scheme modulates the half bridge inverter switches to maintain near sinusoidal filter voltage and current. The wave shapes are shown to be sensitive to loop gains. Proper choice of loop gain resulted in reduced THD of the voltage and current waveforms. Performance of the controller with various loads is validated through simulation and experimentation. Experimentation has been carried out with the controller implemented in real time workshop of MATLAB using NI data acquisition system. The output inductor current and capacitor voltage waveforms are shown in Figure 5, for restive and diode-rectifier loads. The wave shapes reveal that THD is less than 10%.

References

[1] Srinivas ponnaluri, Axel brickweddde and Rik W. De Docker, October 2001, "Overriding Individual Harmonic Current Control with fast dynamics for UPS with Non-linear loads," IEEE conference on power Electron. and drive systems, vol.2, pp 527-532.

[2] Rajesh Ghosh and G. Narayanan., January 2007 "A Simple Analog Controller for Single-Phase Half-Bridge Rectifier," IEEE trans. Power Electron., vol. 22, pp. 186-198.

[3] Carlos G.C.Branco, Cicero M.T.Cruz and Rene P.Torrico-Bascope, August 2008, "A Non isolated Single-Phase UPS Topology With 110-V/220-V Input-Output Voltage Ratings," IEEE trans. Ind. Electron., vol. 55, pp. 2974-2983.

[4] Jih-Sheng Lai, Junhong Zhang, Huijie Yu, and Heath Kouns, November 2006 "Source and Load Adaptive design for a High-Power Soft Switching Inverter," IEEE trans. Power Electron., vol.21, pp.1667-1675.

[5] Maracello Mezaroba, Denizar Cruz Martins and Ivo Barbi., October 2007 "A ZVS PWM Half -Bridge Voltage source Inverter With Active Clamping," IEEE trans. ind. Electron., vol.54, pp. 2665-2672.

[6] Matthew C. Trigg and Chemmangot V. Nayar., October 2008 "DC Bus Compensatio for a Sinusoidal Voltage- Source Inverter With Wave–shaping Control," IEEE trans. ind. electron, vol.55, pp.3661-3669.

[7] Sheng-Yuan Ou., December 2012 "Design and Implementation of a ZCS-PWM Half-Bridge Boost Rectifier with Output Voltage Balance Control," IEEE trans. ind. electron, vol.59, pp.4646-4656.