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Proceedings

IECON 2011 - 37th Annual Conference of the IEEE Industrial Electronics Society

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07 - 10 November, 2011

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The 37th Annual Conference of the IEEE Industrial Electronics Society

7–10 November 2011
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The world's industry, researchers and academia are cordially invited to participate in a wealth of presentations, tutorials, special sessions, social activities and to enjoy the fantastic and unique Australian experiences.

IECON 2011 and ICELIE 2011 (the 5th International Conference on E-Learning in Industrial Electronics) will be held concurrently. In addition, IECON 2011 will host the Industry Forum as part of the conference. Participation in both conferences just requires a single conference registration fee.

The objectives of the conference are to provide high quality research and professional interactions for the advancement of science, technology and fellowship. The main features of the conference include Plenary Speeches, Invited Talks, Regular Sessions, Special Sessions, Tutorials and the Industry Forum.

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15 April 2011

Tutorial proposals
15 May 2011

Special session proposals
[illegible] February 2011

Notification of acceptance
1 July 2011

Final submissions due
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Chairs: Peter Palensky (Austria), Armando W. Colombo (Germany), Alex Talevski (Australia)

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Chairs: Seddik Bacha (France), Gerard Ledwich (Australia), Yunyong Liu (China)

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Power Electronics and Energy Conversion

Chairs: Marco Liserre (Italy), Grahame Holmes (Australia), Udaya Madawala (New Zealand)

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Electrical Machines and Drives

Chairs: Chandan Chakraborty (India), Babak Fahimi (USA), Gerard Champenois (France)

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Sensors, Actuators and Systems Integration

Chairs: Hiroshi Hashimoto (Japan), Roberto Oboe (Italy), Yonhua Tzeng (Taiwan)

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Special Sessions

The conference will include Special Sessions on highly specialised topic areas reporting technical trends and breakthroughs within the scope of the conference. Special Sessions are organised at the initiative of one or more individuals, who must adhere to specific procedures published at the conference website.

Industry Forum

The Industry Forum is a series created by the IEEE Industrial Electronics Society to focus on industry directions and use of IES technologies in industry products. It also motivates discussion with applications of the same technologies into diverse usage areas such as automobiles, robotics in the consumer products, remote sensor control in the home, etc. IECON 2011 Industry Forum has a selection of topic sessions of particular interest to the industries in Australia as well as our IECON attendees; it will discuss product directions, industry needs and product requirements among our diverse, highly international society members.

Paper Submissions

Prospective authors are invited to electronically submit full papers in English (6 pages, 4500 words, in pdf format) following instructions available on the IEE-IES Manuscript Submission System, accessible via conference website www.iecon2011.org. Accepted and presented papers will be published in the respective conference proceedings, and included in the IEEE Xplore® online digital library and EI Compendex database.

In addition, authors of selected papers will be called upon to resubmit their papers for consideration of publication in the IEEE Transactions on Industrial Electronics and IEEE Transactions on Industrial Informatics.

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Department of Electrical Engineering, Faculty of Engineering, King Mongkut's University of Technology Thonburi Bangkok, Thailand

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ABSTRACT

This paper presents a dual output full-bridge series resonant inverter with improved asymmetrical voltage-cancellation contr appliance. The proposed control scheme can adjust the output power separately, and achieves the zero-voltage switching (improved efficiency. A laboratory prototype has been implemented on a DSPIC2010 controller. The experimental results are p the proposed control scheme.

INDEX TERMS

- **IEEE terms**

Equations , Home appliances , Power generation , Resonant inverters , Switches , Voltage control

A Dual Output Series Resonant Inverter with Improved Asymmetrical Voltage-Cancellation Control for Induction Cooking Appliance

Jirapong Jittakort[1], Saichol Chudjuarjeen[2], Anawach Sangswang[1], Sumate Naetiladdanon[1], and Chayant Koompai[1]

[1]Department of Electrical Engineering, Faculty of Engineering
King Mongkut's University of Technology Thonburi Bangkok, Thailand
[2]Department of Electrical and Telecommunication Engineering,
Rajamangala University of Technology Krungthep, Bangkok, Thailand
E-mail : jirapong2@hotmail.com, saichol@ieee.org, anawach.san@kmutt.ac.th

***Abstract*-This paper presents a dual output full-bridge series resonant inverter with improved asymmetrical voltage-cancellation control for induction cooking appliance. The proposed control scheme can adjust the output power separately, and achieves the zero-voltage switching (ZVS) condition with improved efficiency. A laboratory prototype has been implemented on a DSPIC2010 controller. The experimental results are presented to validate the proposed control scheme.**

I. INTRODUCTION

In recent years, cooking appliances using induction technology are becoming popular. A growing favorite in the restaurant kitchens and households, induction cooktops generate a high-frequency alternating current magnetic field that reacts with ferrous metal (iron or steel) in cookware to create heat. The main benefits of the induction cooking appliances are energy saving, safety, fast heat generation and no ambient heat. The requirements for induction cooking appliance are given as high frequency switching, power factor close to unity, high efficiency, low cost, wide power range and reliability.

The configuration of induction-heating cooking appliance consists of rectifier, inverter and resonant load as shown in Fig. 1. Main source is ac supply voltage. The rectifier converts ac voltage to dc voltage. A dc capacitor is used for filtering the ripple voltage. The inverter converts the dc voltage into the high-frequency ac voltage for the load. The traditional topology of inverter uses the single switch [1], the half bridge inverter [2], and full bridge inverters [3]-[5]. The series resonant load consists of a resonant capacitor connect with a cooking coil. In general, the switching-frequency control techniques of the inverter are the variable-frequency and fixed-frequency technique. However, the variable-frequency technique is not preferred for the domestic induction heating appliance because of the electromagnetic interference (EMI) and difficult control [6]. The popular techniques for the domestic induction heating appliance is fixed–frequency control, which has several techniques such as the phase shift (PS), the asymmetrical duty cycle (ADC) [8], the asymmetrical voltage cancellation (AVC) control [3]. The two conventional fixed-frequency control techniques proposed for different dc–dc or dc–ac converters are the

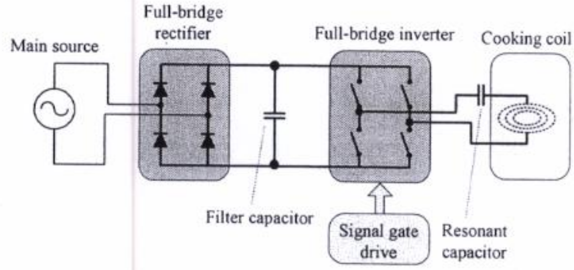

Fig. 1. A schematic configuration of Induction-heating cooking appliance.

phase-shift or clamped-mode control [2]–[3] and the asymmetrical duty-cycle or asymmetrical PWM control [4]–[5]. The recent development of the domestic induction cooking appliances has been the multi-burner induction cooker [8]-[10]. It uses the full-bridge inverter with six power switch for two outputs. However, the power switches are used for carrying both output load currents at series resonant loads. This becomes burden of the system and decreases the system efficiency.

This paper presents a dual output full-bridge series resonant inverter with improved asymmetrical voltage-cancellation control for induction cooking appliance. The purpose is to improve the efficiency by reducing switching losses. The paper is organized as follows. Section II presents the principle of AVC-control. In section III, an improved AVC-control with the operation mode of full bridge inverter for series resonant load is described in detail. The experiment and experimental results are given in Section IV and V, respectively.

II. DUAL OUTPUTS FULL-BRIDGE SERIES RESONANT INVERTER

A multi burner induction heating cooking appliances shows in Fig. 2, and the AVC control shows in Fig. 3 [8]. The dual output series resonant inverter in Fig.2 consists of the four power switches such as Q_1, Q_2, Q_3 and Q_4 for load 1 and the four power switches such as Q_1, Q_2, Q_5 and Q_6 for load 2.

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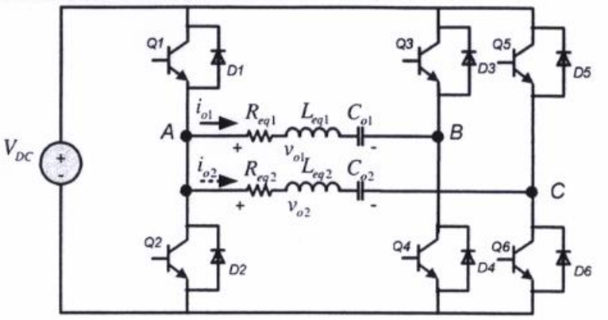


Fig. 2. The full-bridge inverter with two output series resonant loads.

The main power switches are Q_1 and Q_2. This topology used asymmetrical voltage-cancellation control technique for induction cooking appliance. The series resonant load consists of the equivalent resistance R_{eq} and the equivalent inductance L_{eq} connected with the resonant capacitor C_o. The average output power of series resonant load 1 (P_{o1}) can be controlled by adjusting the angle α_1 of the output voltage of load 1(v_{o1}). Similarly, the average output power of series resonant load 2 (P_{o2}) can be controlled by adjusting the angle α_2 of the output voltage of load 2 (v_{o2}). Using this scheme, the long operation time of power switch Q_3 and Q_5 becomes redundant.

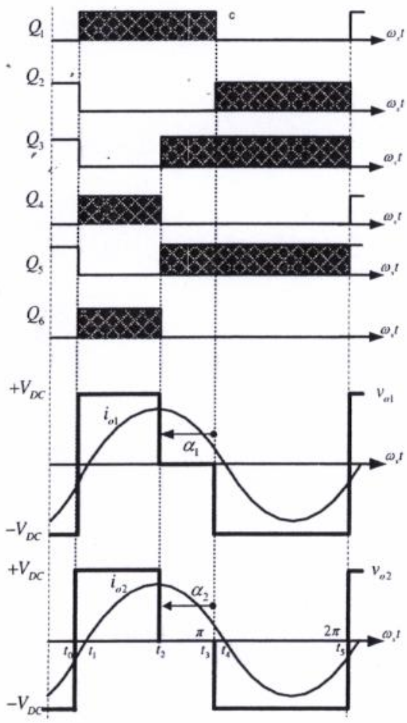


Fig. 3. The full-bridge inverter with some typical waveforms for AVC control [8].

III. The Improved AVC-control for Dual Output Series Resonant Inverter

A. Modes of Operation

By sharing the current between the power switches and free-wheeling diodes, the switching pattern of an improved AVC-control with the output current and voltage waveforms are shown in Fig. 4. An improved AVC-control scheme is operated with the switching frequency (f_{sw}) above the resonant frequency (f_o). It can achieve the zero-voltage switching (ZVS) condition at any operational modes. Fig. 5 shows the schematic circuit with the six operational modes of an improved AVC- control. The average output power for series resonant load 1 (P_{o1}) can be adjusted by the signal gate drive of Q_4 with control the output voltage waveform v_{o1}. The average output power for series resonant load 2 (P_{o2}) can be adjusted by the signal gate drive of Q_5 with control the output voltage waveform v_{o2}. The power losses on the power switch or the insulated gate bipolar transistor (IGBT) are produced by the current through the IGBT multiplying with the voltage across the power terminal Collector (C) and Emitter (E). Comparing switching pattern in Fig. 3 and 4, the less operation time of power switches can be achieved. Consequently, the efficiency of dual inverters can be improved by sharing the load current through the power switches and free-wheeling diodes.

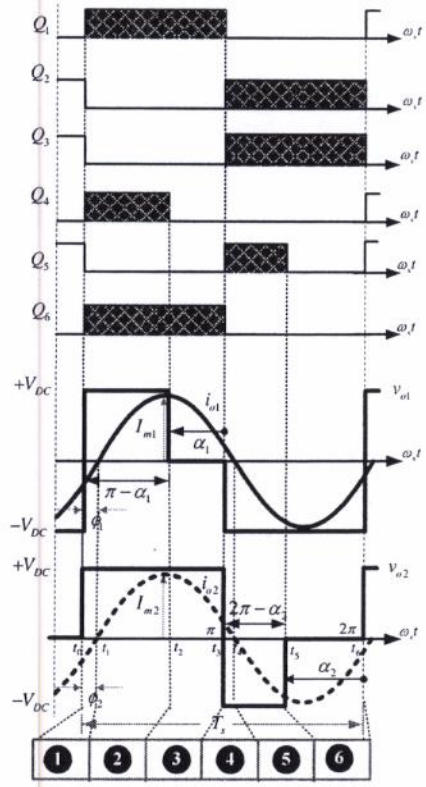
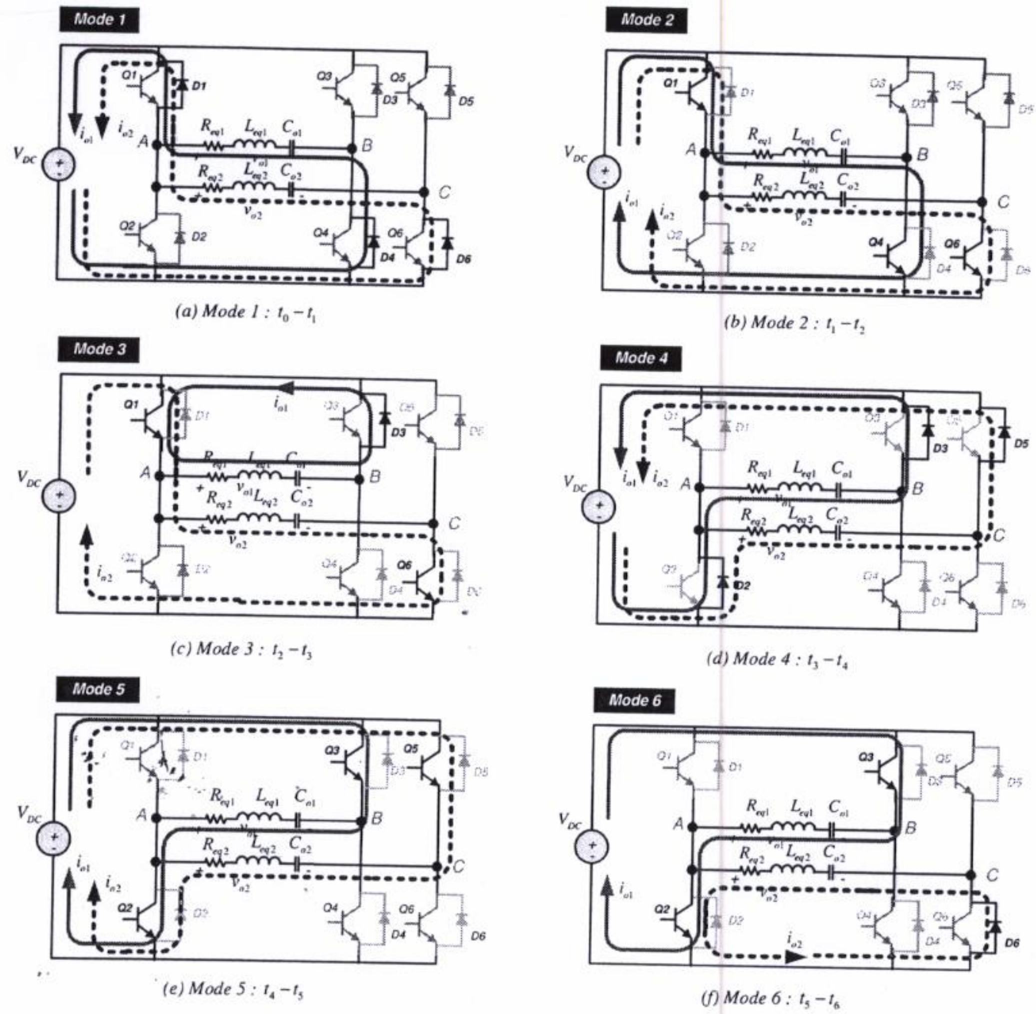


Fig. 4. Switching pattern of an improved AVC-control.



(a) Mode 1 : $t_0 - t_1$ (b) Mode 2 : $t_1 - t_2$ (c) Mode 3 : $t_2 - t_3$ (d) Mode 4 : $t_3 - t_4$ (e) Mode 5 : $t_4 - t_5$ (f) Mode 6 : $t_5 - t_6$

Fig. 5. Operation modes of an improved AVC-control.

Mode 1 : ($t_0 - t_1$)

In this mode stored energy from a resonant load is returned to dc source and operated zero voltage switch (ZVS) condition. When $t = t_0$, the power switches Q_2, Q_3 and Q_5 are turned off. The power switches Q_1, Q_4 and Q_6 are applied but they does not conduct till t_1. The anti-parallel Diodes D_1, D_4 and D_6 conduct from t_0 to t_1. The equivalent circuit is shown Fig. 5(a), while the load current i_{o1} and i_{o2} are negative and the output voltage v_{o1} and v_{o2} are positive.

Mode 2 : ($t_1 - t_2$)

This mode is powering mode. At $t = t_1$, as soon as the antiparallel diodes D_1, D_4 and D_6 are turned off, the power switches Q_1, Q_4 and Q_6 are conducted that the ZVS operation is achieved. The equivalent circuit is shown Fig. 5(b), while the load current i_{o1} and i_{o2} are positive and the output voltage v_{o1} and v_{o2} are positive.

Mode 3 : ($t_2 - t_3$)

This mode shows that the energy does not transfer for load 1 and the equivalent circuit is shown in Fig. 5(c). At $t = t_2$, the load current i_{o1} is positive when the power switch Q_1 is turned on , and anti-parallel diode D_3 of the power switch Q_3 is conducted. The output voltage v_{o1} is equal to zero. At $t = t_2$ for load 2, the load current i_{o2} is positive when the power switch Q_1 is turned on, and the power switch Q_6 is conducted. The output voltage v_{o2} is positive.

Mode 4 : ($t_3 - t_4$)

This mode is regenerative mode and shown the equivalent circuit in Fig. 5(d). At $t = t_3$, the power switches Q_1, Q_4 and Q_6 are turned off with anti-parallel diode D_2, D_3 and D_5 of the power switches Q_2, Q_3 and Q_5 are conducted. Considering for load 1, the load current i_{o1} throws the power switch Q_1 and the anti-parallel diode D_3. The output voltage v_{o1} is negative. Considering for load 2, The load current i_{o2} throws the power switch Q_1 and the anti-parallel diode D_5. The output voltage v_{o2} is negative.

Mode 5 : $(t_4 - t_5)$

This mode is powering mode and shows the equivalent circuit in Fig. 5(e). At $t = t_4$, the power switches Q_2, Q_3 and Q_5 are turned on. While the load current i_{o1} and i_{o2} are negative and the output voltage v_{o1} and v_{o2} are negative.

Mode 6 : $(t_5 - t_6)$

This mode shows energy does not transfer for load 2 and shows the equivalent circuit in Fig. 5(f). At $t = t_5$ for load 1, the load current i_{o1} is negative and the output voltage v_{o1} is negative when the power switches Q_2 and Q_3 are conducted. At $t = t_2$ for load 2, the load current i_{o2} is negative when the power switch Q_5 is turned on and the anti-parallel diode D_6 of the power switch Q_6 is conducted while the output voltage v_{o2} is positive.

B. Analysis of the average output power

The schematic of full bridge inverter with the two output series resonant load shows in Fig. 2. The aim of an improved AVC-control scheme is variable the average output power by adjusted the output voltage waveform. The series resonant load consists of the equivalent resistance (R_{eq}) and the equivalent inductance (L_{eq}) that two components are connected with the resonant capacitor (C_o), it show in Fig. 2. The impedance of series resonant is given by

$$Z_{eq} = R_{eq} + j\left(\omega_o L_{eq} - \frac{1}{\omega_o C_o}\right)$$
$$= R_{eq}\left(1 + jQ^2\left(\omega_n - \frac{1}{\omega_n}\right)\right) \tag{1}$$

The amplitude of Z_{eq} is

$$|Z_{eq}| = R_{eq}\sqrt{1 + jQ^2\left(\omega_n - \frac{1}{\omega_n}\right)^2}. \tag{2}$$

The phase of Z_{eq} is

$$\theta = \tan^{-1}\left(Q^2\left(\omega_n - \frac{1}{\omega_n}\right)\right). \tag{3}$$

The normalized switching angular frequency is

$$\omega_n = \frac{\omega_s}{\omega_o}. \tag{4}$$

The resonant angular frequency is

$$\omega_o = \frac{1}{\sqrt{C_o L_o}}$$

where $\omega_s = 2\pi f_s$ with ω_s being the switching angular frequency and f_s being the switching frequency. The load quality factor (Q) is obtained by equation (5)

$$Q = \frac{\omega_o L_{eq}}{R_{eq}} = \frac{1}{\omega_o R_{eq} C_o} = \frac{Z_o}{R_{eq}} \tag{5}$$

where $Z_o = \sqrt{\frac{L_{eq}}{C_o}}$ with Z_o being the resonant impedance. The average output power of series resonant load 1 (P_{o1}) can be calculated from the output voltage waveform (v_{o1}) as shown in Fig. 4. It can be vary by adjusted the angle α_1. The equation of v_{o1} can be obtained by the Fourier series theory in equation (6)

$$v_{o1} = V_{o1} + \sum_{n=1}^{\infty}\{a_n \cos n\omega_s t + b_n \sin n\omega_s t\} \tag{6}$$

where

$$V_{o1} = \frac{1}{T}\int_0^T v_{o1}(t)\, d\omega_s t$$
$$= \frac{(\pi - \alpha_1)V_{DC} - \pi(V_{DC})}{2\pi}. \tag{7}$$

Where $an = 0$ and

$$b_n = \frac{2}{T}\int_0^T v_{o1}(t)\sin n\omega_s t\, d\omega_s t$$
$$= \frac{V_{DC}}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\left[-\cos(\pi - \alpha_1) - \cos n\pi\right]\sin n\omega_s t \tag{8}$$

$$v_{o1} = \frac{(-\alpha_1)V_{DC}}{2\pi} + \frac{V_{DC}}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\left[-\cos(\pi - \alpha_1) - \cos n\pi\right]\sin n\omega_s t. \tag{9}$$

Where

$$V_{mo1,n} = \frac{V_{DC}}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\left[-\cos(\pi - \alpha_1) - \cos n\pi\right] \tag{10}$$

Considering, the fundamental of V_{m1} can be obtained by equation (11)

$$V_{mo1,1} = \frac{V_{DC}}{\pi}\left[1 - \cos(\pi - \alpha_1)\right] \tag{11}$$

The load current i_{o1} through the series resonant of load 1 is derived by

$$i_{o1} = I_{m1}\sin(\omega_s t - \phi_1) \tag{12}$$

Assumed

$$I_{m1} = I_{mo1,1} = \frac{V_{mo1,1}}{|Z_{eq1}|}$$
$$= \frac{V_{DC}\left[1 - \cos(\pi - \alpha_1)\right]}{\pi R_{eq1}\sqrt{1 + jQ^2\left(\omega_n - \frac{1}{\omega_n}\right)^2}} \tag{13}$$

The average output power P_{o1} can be obtained equation (14)

$$P_{o1} = I_{m1}^2 R_{eq1}$$
$$= \frac{V_{DC}^2\left[1 - \cos(\pi - \alpha_1)\right]^2}{\pi^2 R_{eq1}\left(1 + jQ^2\left(\omega_n - \frac{1}{\omega_n}\right)^2\right)} \tag{14}$$

The same as, the average output power of series resonant load 2 (P_{o2}) in Fig. 4 shows the output voltage waveform v_{o2}. It can be vary by adjusted the angle α_2 on negative voltage waveform. The equation of v_{o2} can be obtained by the Fourier series theory in equation (15)

$$v_{o2} = V_{o2} + \sum_{n=1}^{\infty}\{a_n \cos n\omega_s t + b_n \sin n\omega_s t\} \tag{15}$$

$$V_{o2} = \frac{1}{T}\int_0^T v_{o2}(t)\,d\omega_s t = \frac{\alpha_2 V_{DC}}{2\pi} \tag{16}$$

Where $an = 0$ and

$$b_n = \frac{2}{T}\int_0^T v_{o2}(t)\sin n\omega_s t\,d\omega_s t = \frac{V_{DC}}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}\{[1-\cos n\pi]-[\cos n\pi - \cos(2\pi-\alpha_2)]\}. \tag{17}$$

Where $V_{mo2,n} = \frac{V_{DC}}{\pi}\sum_{n=1}^{\infty}\frac{1}{n}(-\cos n\pi - \cos(\pi-\alpha_2))$ (18)

$$V_{mo2,1} = \frac{V_{DC}}{\pi}(-\cos(\pi-\alpha_2)) = \frac{V_{DC}}{\pi}(1-(\pi-\alpha_2)) \tag{19}$$

The load current i_{o2} through the series resonant of load 2 is derived by

$$i_{o2} = I_{m2}\sin(\omega_s t - \phi_2) \tag{20}$$

$$I_{m2} = I_{mo2,1} = \frac{V_{mo2,1}}{|Z_{eq2}|} = \frac{V_{DC}(1-\cos(\pi-\alpha_2))}{\pi R_{eq2}\sqrt{1+jQ^2\left(\omega_n - \frac{1}{\omega_n}\right)^2}}. \tag{21}$$

The average output power P_{o2} can be obtained equation (22)

$$P_{o2} = I_{m2}^2 R_{eq2} = \frac{V_{DC}^2(1-\cos(\pi-\alpha_2))^2}{\pi^2 R_{eq2}\left(1+jQ^2\left(\omega_n - \frac{1}{\omega_n}\right)^2\right)}. \tag{22}$$

IV. The Implementation

The block diagram of the proposed control strategy is illustrated in Fig. 6. The desired output power P_{o1} and P_{o2} of inverter can be controlled by variation of the phase angle α_1 through the switch Q_4 and α_2 through the switch Q_5. The proposed control algorithm is implemented on a DSPIC2010 controller to generate a high-frequency signal for gate drivers of the switches Q_1 to Q_6.

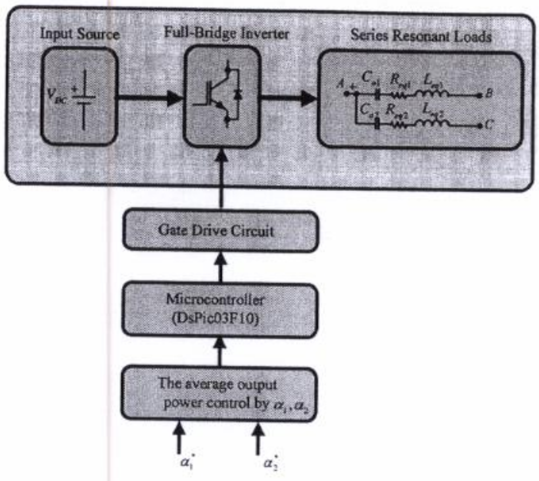


Fig.6. Block diagram of the proposed control.

In addition, all switches is operated at a high switching frequency that is above the resonant frequency to eliminate the turn-on switching loss of IGBTs and to achieve a ZVS condition in the whole power range.

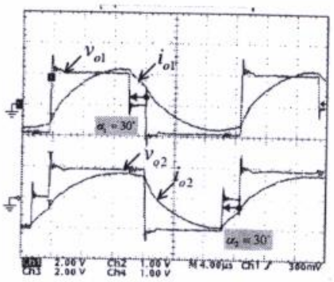
V. Experimental Results

To verify the validity of a full-bridge series resonant inverter system with the proposed control strategy, a hardware experiment is performed by using parameters in Table I.

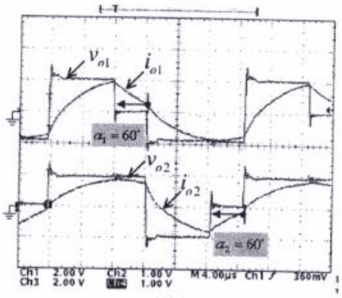
TABLE I Experiment Circuit Parameters

Item	Symbol	Value	Unit
Resonant resistance of load 1 and 2	R_{eq1}, R_{eq2}	5	Ω
Resonant inductance of load 1 and 2	L_{eq1}, L_{eq2}	64.34	μH
Resonant capacitors of load 1 and 2	C_{o1}, C_{o2}	330	nF
DC input voltage	V_{DC}	100	V
Switching frequency	f_s	41	kHz
Power switches	$Q_1 - Q_6$	IRG4PC50S	

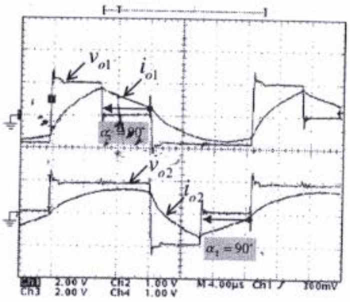
Fig. 7 show the output voltage and current waveforms from the experimental results. Fig. 7 (a) is the output voltage waveform for each load by adjusting $\alpha_1 = \alpha_2 = 30^\circ$. Fig. 7 (b) is the output voltage waveform for each loads by adjusting $\alpha_1 = \alpha_2 = 60^\circ$. Fig. 7 (c) is the output voltage waveform for each load by adjusting $\alpha_1 = \alpha_2 = 90^\circ$. Fig. 7 (d) is the output voltage waveform for each load by adjusting $\alpha_1 = \alpha_2 = 120^\circ$. Fig. 7 (e) is the output voltage waveform for each load by adjusting $\alpha_1 = \alpha_2 = 150^\circ$. The average output powers for each loads can be measured by multiplying the average output current and voltage through the oscilloscope. Fig. 8 (a) shows that the average output power of improved AVC control was higher than original control; consequently, the system efficiency can be improved as shown in Fig. 8 (b).



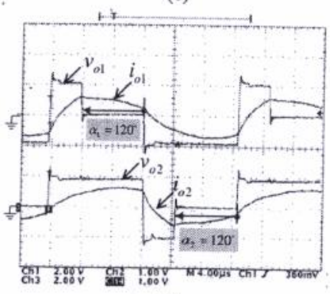
(a)



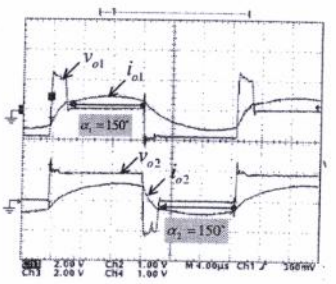
(b)



(c)

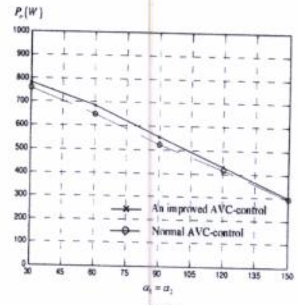


(d)

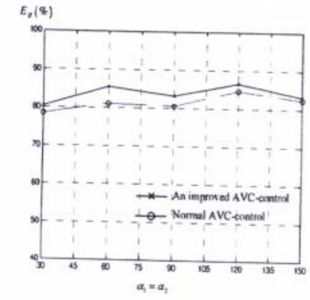


(e)

Fig.7. the experimental results waveform.



(a)



(b)

Fig. 8. The comparison of output power and the efficiency.

VI. CONCLUSION

In this paper, a dual output full-bridge series resonant inverter used an improved asymmetrical voltage-calculation control for induction cooking appliance. The experimental results are shown with different output power under operating of ZVS conditions. A performance of improved topology is better than the normal control strategy.

REFERENCES

[1] H.W. Koertzen, J. A. Ferreira, and J. D. van Wyk, "A comparative study of single switch induction heating converters using novel component effectivity concepts" in Proc. *IEEE Power Electronics Specialists Conf. (PESC'92),* Vol. 1, pp. 298–305, June 29 1992-July 1 1992.

[2] H. W. Koertzen, J. D. van Wyk, and J. A. Ferreira, "Design of the half-bridge series resonant converter for induction cooking," in Proc. *IEEE Power Electronics Specialists Conf. (PESC)*, vol. 2, pp. 729–735, June. 1995.

[3] J. M. Burdío, L. A. Barragán, F. Monterde, D. Navarro, and J. Acero, "Asymmetrical voltage-cancellation control for full-bridge series resonant inverters," *IEEE Trans. Power Electron., vol. 19, No.2,* pp. 461–469, Mar. 2004.

[4] F. P. Dawson and P. Jain, "A comparison of load commutated inverter system for induction heating and melting applications," *IEEE Trans. Power Electron.*, vol. 6, no. 4, pp. 430–441, Jul. 1991.

[5] Fernando Moiiterde., Jose M. Burdio., and Abelardo Martinez, "A New ZVS Two-Output Series-Resonant Inverter for Induction Cookers Obtained by a Synthesis Method" *IEEE conf. PESC,* pp. 1375-1380, June 2000.

[6] J. Acero, J.M. Burdío, L.A. Barragán, D. Navarro, and S. Llorente, "EMI improvements using the switching frequency modulation in a resonant inverter for domestic induction heating appliances," in *IEEE Power Electronics Specialists Conf. (PESC)*, pp. 3108-3112, June 2004.

[7] O. Lucia, J.M. Burdo, I. Millan, J.Acero and S. Llorente, " Efficiency Optimization of Half-Bridge Series Resonant Inverter with Asymmetrical Duty Cycle Control for Domestic Induction Heating" in *Power Electronics and Application, EPE conf.*, pp. 1-6, Sept 2009.

[8] José M. Burdío, Member, Fernando Monterde, José R. García, Luis A. Barragán, and Abelardo Martínez, "A Two-Output Series-Resonant Inverter for Induction-Heating Cooking Appliances" *IEEE Trans on power electronic,* vol. 20, No. 4, pp. 815-822, July 2005.

[9] Fernando Moiiterde., Jose M. Burdio., and Abelardo Martinez, "A New ZVS Two-Output Series-Resonant Inverter for Induction Cookers Obtained by a Synthesis Method" *IEEE conf.PES,* pp. 1375-1380, June 2000.

[10] J. Acero, J. M. Burdio, L. A. Barragan, D. Navarro, R. Alonso, J. R. Garcia, F. Monterde, P. Hernandez, S. Llorente, and I. Garde, "The domestic induction heating appliance: An overview of recent research," in *Proc. IEEE Appl. Power Electron. Conf. Expo.*, pp. 651–657, Feb. 2008.

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Welcome to IECON 2011, ICELIE 2011 and IES Industry Forum

On behalf of the IEEE Industrial Electronics Society (IES) we would like to extend a warm welcome to all delegates to join us to celebrate the 60th Anniversary of the Society through their participation in the three exciting events, namely, IECON 2011, ICELIE 2011, 2011 IES Industry Forum, jointly held from 7-10 November 2011 at the Crown Conference Centre in Melbourne, Australia.

IECON is the flagship annual conference of the Industrial Electronics Society. ICELIE is the event where the discussion of modern education and electronic learning methods for teaching in the field of industrial electronics will be held. IES Industry Forum is an initiative that provides an opportunity to focus on industry directions and the use of emerging technologies in industry products.
The nine technical sessions have been organised to share technological advances, educational methods and industry interests related to:

- Mechatronics and Robotics
- Factory Automation and Industrial Informatics
- Control Systems and Applications
- Power Generation and Distribution
- Power Electronics and Energy Conversion
- Electrical Machines and Drives
- Sensors, Actuators and Systems Integration
- Information Processing and Communications
- Computational Intelligence and Industrial Applications

There are also 47 special sessions organised to focus on future technology trends and 11 tutorials covering a broad spectrum of IES technical interests. Approximately 1,137 manuscripts were submitted to either IECON or ICELIE, of which 739 papers were accepted in the two final programs. On average, each paper received 2.86 peer reviews with approximately 1220 reviewers participating in the process. The overall review process was monitored and finalised by the Chairs and the respective program committees.

The IECON 2011 Technical Program is enhanced by four plenary sessions presented by the following high profile keynote speakers:

a) **Finite Alphabet Control: Applications and Reflections** (Tuesday)

Laureate Professor Graham Goodwin (FRS, FIEEE, Hon.FIEAust, FTSE, FAA), University of Newcastle, Australia and Director of Australian Research Council Centre of Excellence for Complex Dynamic Systems and Control.

b) **Field Weakening Methods for Permanent Magnet Machines - Present Status and Future Possibilities** (Wednesday)
Professor Thomas Lipo (FIEEE), Emeritus Professor at University of Wisconsin, USA.

c) **Hybrid Intelligence Optimal Control for Operation of Complex Industrial Processes** (Wednesday)
rofessor Tian-You Chai (FIEEE, FIFAC, FIEAS), Director of the National ıgineering and Technology Research Center, Northeastern University, China.

d) **Future Challenges in Energy, Technology and Innovation** (Thursday)
Dr Ziggy Switkowski (FTSE, FAICD), Chancellor, RMIT University, Australia.

The IES Industry Forum will be held over two days - Tuesday afternoon and Wednesday afternoon and features approximately 17 industry speakers divided across four sessions: Power Systems and Batteries, Panels on Challenges for Cloud Managed Control Service Architectures, Electric Vehicles and Related Infrastructure.

A Technical Tour to the Australian Synchrotron has been organised for Tuesday with three visits scheduled for a limited number of 25 delegates per visit. Bookings for these tours need to be secured on Monday only - details are available at the registration desk.
CON 2011 delegates are invited to network at a variety of social events, including .e welcome reception (Monday evening), Gala Dinner (Wednesday evening), morning and afternoon teas and buffet lunches. In addition to the on-site programs, we encourage you to enjoy a variety of outstanding local attractions in and around Melbourne, Victoria.

A local touring organisation, AAT Kings has been secured to provide you with touring options at reduced prices to the Great Ocean Road, Penguins at Phillip Island, Puffing Billy Railway experience, Yarra Valley winery tour and of course the exciting Melbourne City tour. Please visit the AAT Kings booth for bookings and further information - available from Monday to Thursday.
Finally, we would like to thank all conference committee members and our reviewers who have graciously volunteered their time and efforts to make your conference

experience in Melbourne a memorable one. We sincerely appreciate our sponsors, including Intel, SEW Eurodrive, Advanced Manufacturing CRC, Opal RT Technologies, and the Melbourne Convention and Visitors Bureau for their financial support for IECON 2011. A very special thanks and appreciation to our technical sponsors, RMIT University, Curtin University of Technology, Monash University and Southeast University.

We hope you enjoy the IES conference experience in Melbourne and the wonderful Spring Carnival atmosphere that is currently on offer in Melbourne, Australia.

Yours sincerely, Organizing Committees - IECON 2011, ICELIE 2011, and 2011 IES Industry Forum

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