International Journal of Electronics Communication and Computer Engineering
Volume 2, Issue 2, ISSN (Online): 2249–071X, ISSN (Print): 2278–4209

Implementation of Low Frequency AC to High Frequency AC with Single Stage ZVS-PWM Inverter

S.Arumugam[1]
Research Scholar
Bharath University, Chennai, India.

S.Ramareddy[2]
Professor,
Jerusalem College of Engg, Chennai.

M.Sridhar [3]
Professor &Dean
Bharath University, Chennai,

Abstract- This paper presents a novel soft-switching pulse width modulation (PWM) utility frequency AC to high frequency (HF) AC power conversion circuit incorporating boost-active clamp single stage inverter topology. This power converter is more suitable and acceptable for cost effective HF consumer induction heating applications. Its operating principle is presented. The operating performances of this high frequency inverter using the latest insulated gate bipolar transistors are illustrated, which includes HFAC power regulation ranges and actual efficiency characteristics based on zero voltage soft switching operation ranges.. The simulation circuits are models are developed and they are simulated using ORCAD.

Keywords: Pulse Width Modulation, Boost active clamp bridge, utility frequency, AC to high frequency (HF) AC power conversion, zero voltage Switching.

I. INTRODUCTION

In recent years, new application fields of high-frequency induction heating (IH) power technology in consumer and industry have developed more and more in all electricity power utilization systems as energy saving. For example, these IH appliances are IH cooking heater, IH rice cooker, IH hot water producer, IH steamer, and IH super heated steamer for cleaning, disinfecting, drying and cooking. These new IH applications in addition to microwave oven for food processor have been expanding dramatically with tremendous development of the core technology of the state-of-the art high-frequency power electronics in IH technology. However, application-specific high frequency resonant inverters used for these appliances cause switching losses and conduction losses of power devices, getting larger cooling devices and heat release systems, decreased rated ability of power devices by switching surges. Furthermore, increased EMI/RFI noise levels due to high frequency leakage current in high frequency switching of conventional high frequency inverters operated under hard switching PWM. With tremendous advances of power semiconductor. Switching devices, the electromagnetic induction eddy. Current based direct heat energy processing products and applications using high frequency power conversion circuits, inverters, cyclo-inverters and cyclo - converters have attracted. Special interest for consumer food cooking and processing. Appliances [1]– [3], [8]–[10]. Recently, cost effective induction Heating (IH) appliances using high frequency inverters have been rapidly developed for utility frequency ac to high- frequency.ac power conversion system for consumer power and. energy applications. The equipments using high frequency. Inverter topologies have the practical advantages of safety. Cost effectiveness, energy saving, clean environment, high. Thermal conversion efficiency, rapid and direct focusing heating. Process, high power density, high reliability, environment. On-acoustic and low electromagnetic noise [4], [5]. These unique advantages are practically brought in accordance with Great progress of power semiconductor switching devices,. Digital and analogue control devices, circuit components and. high frequency soft switching inverters [6], [13], [14].Under the aforementioned technological situations, high frequency. Soft switching inverter topologies are indispensable for Consumer IH appliances.

These high frequency soft switching inverters must have the advantages of simple configuration. High efficiency, low cost and wide soft commutation operating. Ranges for high frequency operation [7], [12], [15]. The voltage source type soft-switching high frequency inverter using the latest insulated Gate bipolar transistors (IGBTs) and its modifications match the practical operating requirements mentioned previously. In this paper, a novel prototype of a boost-active clamp bridge single stage high frequency zero voltage soft-switching PWM inverter, which converts the utility frequency ac power into high frequency ac power with voltage boosting. This single stage high frequency inverter which is composed of single phase diode bridge rectifier, non-smoothing filter, boost-active clamp bridge type zero voltage soft switching PWM high frequency inverter, and induction heated load with planar type litz wire working coil assembly. Also we discussed in this paper in order to extend the soft switching operation ranges and to improve the power conversion efficiency. The aim is to control the output power for high temperature application including steel melting, brazing and hardening where the load parameters and frequency vary throughout the system operation. This paper is organized as follows.

The principle of operation is described in section II, Proposed system is described in section III. Simulation results are provided in section IV and Section V concludes this work

II. PREVIOUSLY DEVELOPED ZVS–PWM HIGH FREQUENCY INVERTER

Fig. 1 shows a basic circuit configuration of the previously developed active voltage-clamped edge-resonant ZVS–PWM inverter, which can operate under the principle of ZVS–PWM or VPCF control strategy in order to solve harmful acoustic noise in multi-integrated inverter type IH cooking heater for multi -burners, in addition to harmonic current reduction in the utility ac power grid side. This voltage-fed ZVS–PWM high frequency inverter using the Q_1, Qs, includes a VPCF function in the output load side and active power filtering function by connecting to a utility ac power grid interfaced single phase full-bridge diode rectifier with a non-smoothing dc filter. This high-frequency inverter is directly combined to the multi-integrated IH cooking heater with load pans and vessels, which are coupled to the ceramic spacer via two pancake-like heating working coils [11], [12].

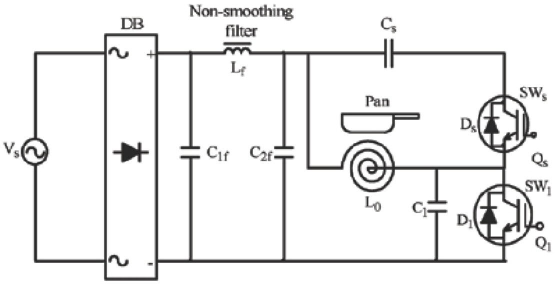

Fig.1. Previously developed HF inverter for IH cooker

The resonant capacitor C_S in series with the auxiliary active power switch Qs serves to clamp the resonant peak voltage across the main active power switch Q_1. The non-conduction period of Q_1 consists of two edge-resonant transition intervals during ZVS commutation operation and the auxiliary second resonant interval when voltage clamping with Qs and C_s.

The heating output power of this high-frequency inverter (see Fig. 1) can be continuously adjusted by varying the operating period under the principle of ZVS and the variable power control strategy can be achieved at a fixed frequency by interpolating during the second resonance mode. Since the current in the first resonant capacitor C_1 is generated only during switch transition, the current flowing through the voltage-clamping capacitor C_S is generated only during the clamping mode or conduction mode of Qs and capacitors with a low current rating can be used in this case.

III. NEWLY PROPOSED BOOST-ACTIVE CLAMP HIGH FREQUENCY INVERTER

A. Main Circuit Configuration

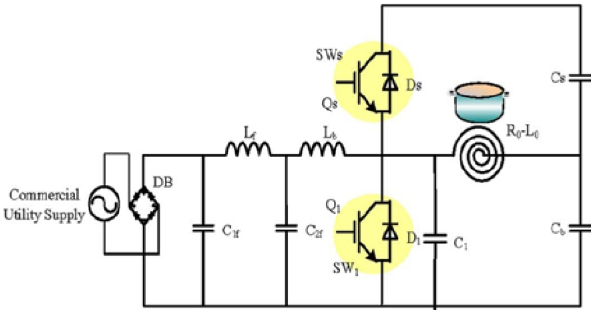

Fig. 2. Single stage soft-switching PWM HF inverter

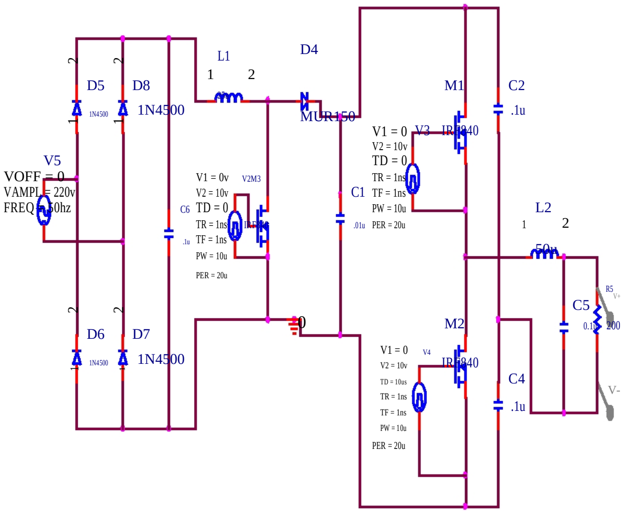

Fig.3.Proposed circuit model for IH Application

Fig. 2 represents the novel basic circuit configuration of the proposed single stage soft switching PWM power converter incorporating two switches only for boost chopper and active clamp bridge zero voltage soft switching (ZVS) high frequency PWM inverter .The boost-active clamp bridge single stage high frequency inverter circuit topology includes two active power switch blocks Q_1 (SW_1/D_1), Qs (SWs/Ds), divided series capacitors C_s and C_b and lossless snubbing capacitor C_1 in parallel to the IH working coil L_0 . In addition, the voltage boosted block composed of the boost inductor and active power switch Q_1(SW_1/D $_1$) from the circuit configuration of proposed topology, the switching block SW shares and performs the operation of both single-phase boost chopper converter and ZVS-PWM high frequency inverter. Moreover, the divided series capacitors C_s and C_b are used to block the lower frequency current dc components flowing through the IH working coil which is assembled from the planar type litz wire.

The IH load circuit of this inverter consists of the working coil composed of litz wire and IH metal-based object (pan or vessel) represented by the transformer equivalent circuit model (Load time constant $T=L_2/R_2$ [R_2: Equivalent effective resistance due to a frequency dependent skin effect of the heated material itself,L_2: the eddy current induced side self inductance]. Where L_1 is the self -inductance of the working coil, with loosely-coupled mutual inductance M.

B. High Frequency AC Power Control Scheme

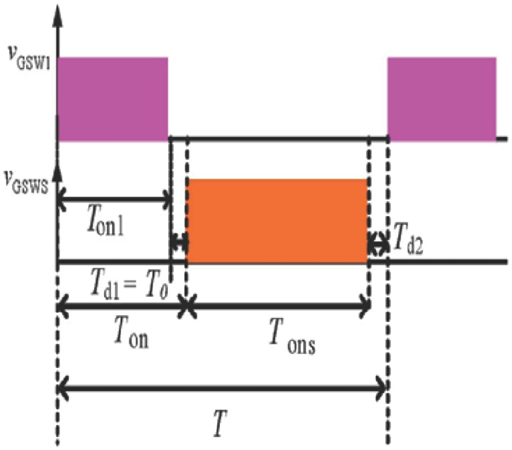

Fig. 4. Schematic PWM gate pulse timing sequences

The high frequency ac output power of the proposed inverter circuit, which is delivered to the IH load as IH cooking heater, can be continuously regulated by a constant frequency asymmetrical PWM control scheme under a condition ZVS. The gate voltage pulses timing signals sequences for Q_1, Q_s and are shown schematically in Fig. 4.Q_1 is first switched on during a period T_{on1} and before Q_1 is turned off by a time of T_0 . Then Q_s, is turned on after turning off Q_1 by a dead time of Td1. Q1 is again switched on after a dead time Td2as another period starts as depicted in Fig. 4. This high frequency inverter has equal dead time (td1=Td2)control scheme. The constant frequency asymmetrical PWM duty cycle is the ratio of conduction time Ton of Q_1 to total switching period T. As a control variable, the duty cycle is defined as

$$D = \frac{T_{on1} + T_0}{T} \qquad \text{----- (1)}$$

By varying the PWM duty cycle as a control variable, the High-frequency ac output power of this soft-switching inverter can be regulated continuously.

C. Operation Switching States and Equivalent Circuits

The operation states of the proposed single stage high frequency power converter during one switching cycle. The corresponding state equivalent circuits are represented in Fig. 5. The operation states are divided into six operating states during one switching period, which can be simply explained in the following.

State 1 (SW: ON, : OFF, SW : OFF and : OFF) This switching state equivalent circuit is shown in Fig. 5(a). In this operating state, two current loops in the equivalent circuit are formed. The magnetic energy is stored into the boost inductor through the loop of C_{2f}-L_b-Q_1-C_{2f} and the input power is delivered to the induction-heated load through C_b-L_0-Q_1-C_b.

State 2 (SW : OFF, : OFF, SW : OFF and : OFF) The equivalent circuit of state 2 is depicted in Fig. 5(b). In state 2, the resonant energy is stored into through the two composed loops of L_b-C_1-C_b-C_{2f} -L_b andL_0-C_1-L_0 .

State 3 (SW : OFF, : OFF, SW : OFF and : ON) The energy is stored into through the loop formed byL_b-Cs-C_b- C_{2f} -L_b and the energy is delivered to the IH load through the composed loop of Ds-Cs-C_{2f} -L_b. The equivalent circuit of state 3 is shown in Fig. 5(c).

State 4 (SW : OFF, : OFF, SW : ON and : OFF) The equivalent circuit of state 4 is depicted in Fig. 5(d) In this state, the energy is delivered to the IH load through the composed loop of Cs-Qs-L_0-Csand the energy is stored into capacitor through the composed loop of L_b-L_0-C_b-C_{2f}.

State 5 (SW : OFF, : OFF, SW : OFF and : OFF) This equivalent circuit of state 5 is delineated in Fig. 5(e). During this operating state, the energy is transferred to the IH load-working coil L_0 through the composed loop of L_0-C_1-$L_0$and the energy is stored into capacitor through the composed loop of L_b-L_0-C_b-C_{2f} as in state 4.

State 6 (SW : OFF, : ON, SW : OFF and : OFF) The switching equivalent circuit is depicted in Fig. 5(f). In state 6, the energy stored in the IH working coil is transferred into the capacitor through the composed loop of L_0-C_b-L_0 and the energy is stored into capacitor through the composed loop of L_b-L_0-C_b-C_{2f} .

IV.SIMULATION RESULTS

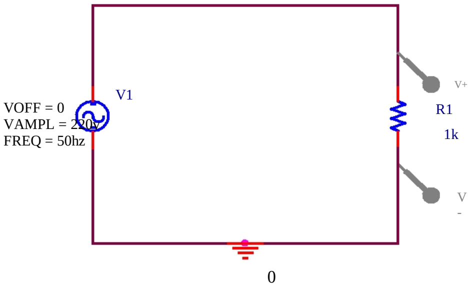

Fig.5.1.circuit to measure input voltage

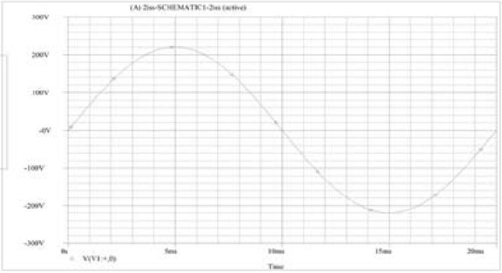

Fig5.2.Input voltage

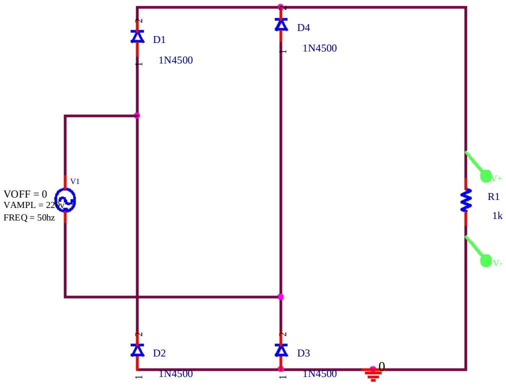

Fig5.3.Cirruit for rectifier

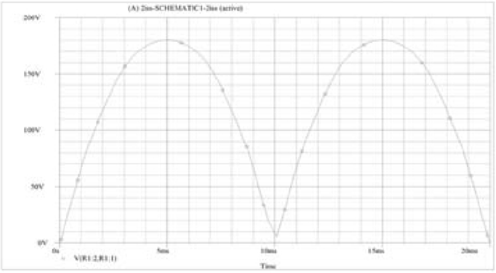

Fig5.4.Rectifier output voltage

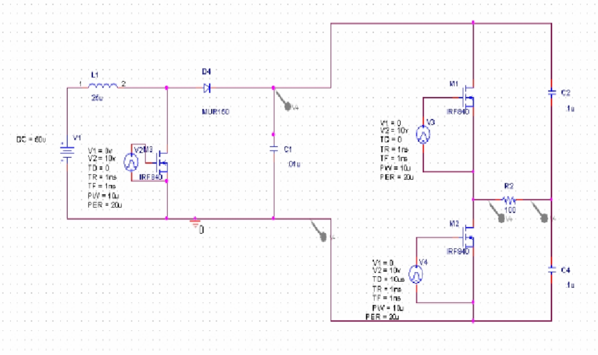

Fig.6.1. Boost circuit & half bridge inverter circuit

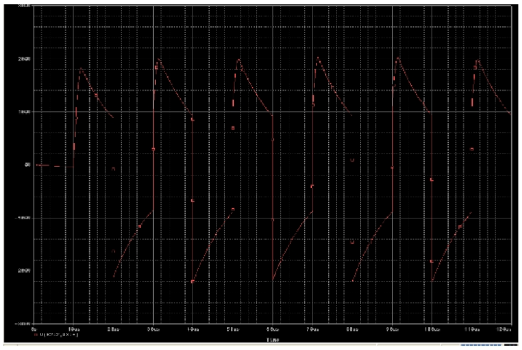

Fig.6.2.Boost circuit & half bridge invertervoltages

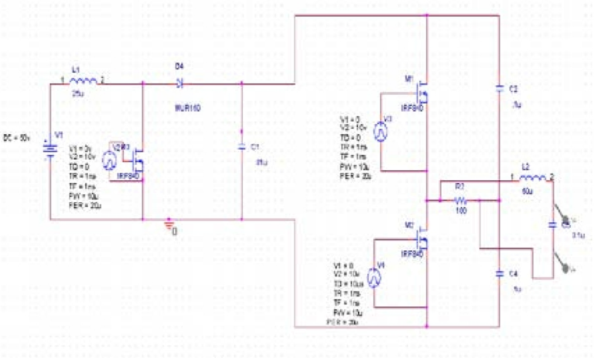

Fig.6.3. **circuit with addition of resonant circuit**

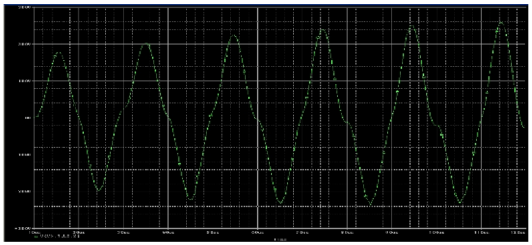

Fig.6.4.output voltage of Resonant circuit

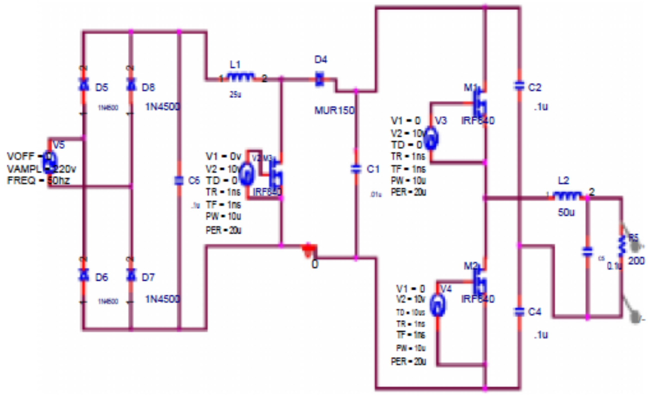

Fig.7.1. Proposed circuit model for Induction Heating

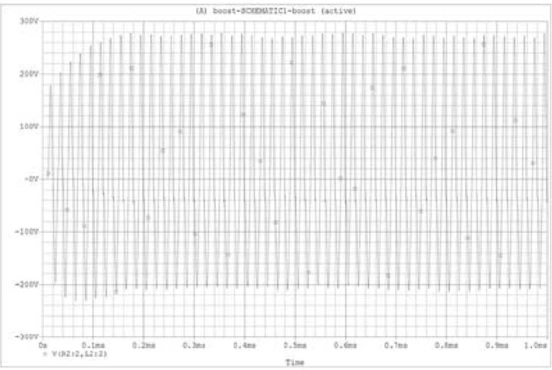

Fig.7.2.output voltages for Induction Heating

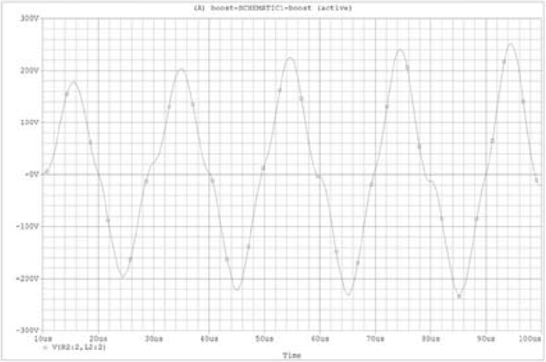

Fig7.3.Enlarged output voltages

Single stage zvs-pwm High frequency inverter system is simulated and the results are presented here. Fig.5.1. and Fig.5.3 shows to measure circuit input voltages and Rectifier output voltages. Scopes are connected to measure input and output voltages. It's corresponding input and output voltages are presented in Fig.5.2 and Fig.5.4.respectively. Boost circuit & half bridge inverter circuit is as shown in Fig.6.1. and it's output voltage is shown in Fig.6.2.Inverter circuit with addition of resonant circuit as shown in Fig.6.3.and its output is as shown in Fig.6.4. Proposed circuit model for Induction Heating is as shown in Fig 7.1. The required induction heating voltages are obtained and presented in Fig.7.2. Enlarged output PAN (IH) voltages are shown in Fig.7.3. In order to achieve unity power factor at the utility side and pure non-smoothing dc current at inverter side, we designed optimum value of filter parameters.

V. CONCLUSION

In this paper, a novel circuit topology of utility frequency ac to high frequency ac power converter employing boost active-clamped single stage ZVS–PWM high frequency inverter has been proposed for consumer induction heating appliances such as IH cooking heater, IH steamer, IH super heated steamer, IH fixing roller and IH far-infrared griddle. The new single stage high frequency IH inverter using boosted voltage function can eliminate the dc and low frequency components of the working coil current and reduce the power dissipation of the circuit components and switching devices. The operating principle of this high frequency inverter, the operation modes have been presented and discussed on the basis of simulation results. The simulation results are in line with the predictions. This work deals with simulation studies. Hardware implementation is not in the scope of this work.

For future work, the boost active-clamped bridge single stage high frequency power converter using the promising power switching devices ESBTs, SiC–SBDs, and SiC– MOSFETs will be evaluated and discussed in order to achieve much higher the overall power conversion efficiency and high power density

REFERENCES

[14] A. Okuno, H. Kawano, J. Sun, M. Kurokawa, A. Kojina, and M. Nakaoka, "Feasible development of soft-switched SIT inverter with load-adaptive frequency- tracking control scheme for induction heating," *IEEE Trans. Ind. Appl.*, vol. 34, no. 4, pp. 713–718, Jul./Aug. 1998.

[2] S. Hishikawa, M. Serguei, M. Nakaoka, I. Hirota, H. Omori, and H. Terai, "New circuit topology of soft switching single-ended high frequency inverter using IGBTs," *IEICE-J Energy Electron. Prof Meeting*, vol. 100, no. 628, pp. 19–24, Feb. 2000.

[3] M. Kaneda, H. Tanaka, and M. Nakaoka, "A novel prototype of single-ended push-pull soft-switching high- frequency inverter using a single auxiliary ZVS-PWM switch," *IEICE-J. Energy Electron. Prof.Meeting*, vol. 100, no. 628, pp. 31–37, Feb. 2000.

[4] H. Sadakata, H. Terai, H. Omori, H. Yamasita, and M. Nakaoka, "The development of ZCS-PWM-SEPP inverter with complexed control method," *IEEJ SPC-03-30*, Feb. 2003.

[5] H. Sugimura, N. A. Ahmed, T. Ahmed, H. W. Lee, and M. Nakaoka, “Utility ac frequency to high frequency ac power conversion circuit with soft switching PWM strategy,” *KIEE Int. Trans. Elect. Mach. Energ Conv. Syst.*, vol. 5-B, no. 2, pp. 181–188, 2005.

[6] B. Saha, S. K. Kwon, H. Omori, H. W. Lee, and M. Nakaoka, “A Novel utility frequency ac to high frequency ac power converter with boosted half-bridge single stage circuit arrangement,” in *Proc. Int. Conf. Elect. Mach. Syst. (ICEMS)*, Nagashaki, Japan, Nov. 2006, [CD ROM].

[7] H. Kifune, Y. Hatanaka, and M. Nakaoka, “Cost effective phase shifted pulse modulation soft switching high frequency inverter for induction heating applications,” *Proc. Inst. Elect. Eng.* , vol. 151, no. 1, pp. 19–25, Jan. 2004.

[8] K. Ogura, L. Gamage, T. Ahmed, M. Nakaoka, I. Hirota, H. Yamashita, and H. Omori, “Performance evaluation of edge-resonant ZVS-PWM high-frequency inverter using trench-gate IGBTs for consumer induction cooking heater,” *Proc. Inst. Elect. Eng.*, vol. 151, no. 5, pp. 563–568, Sep. 2004.

[9] H. Fujita, H. Akagi, K. Sano, K. Mita, and R. H. Leonard, “Pulse density modulation based power control of a 4 kW 400 kHz voltage-source inverter for induction heating applications,” in *Proc. IEEJ PCC*, Yokohama, Japan, 1993, pp. 111–116.

[10] J. Acero, R. Alonso, J. M. Burdío, and L. A. Barragán, “Modeling of planar spiral inductors between two multilayer media for induction heating applications,” *IEEE Trans. Magn.*, vol. 42, no. 11, pp. 3719–3729, Nov. 2006.

[11] W. F. Peschel, “Load power matching of high-frequency power supplies for induction heating,” *IEEE Trans. Ind. Appl.*, vol. IA-10, no. 3, pp. 351–359, May/Jun. 1974.

[12] J. Acero, R. Alonso, J. M. Burdío, L. A. Barragán, and D. Puyal, “Frequency- dependent resistance in litz-wire planar windings for domestic induction heating appliances,” *IEEE Trans. Power Electron.*, vol. 21 no. 4, pp. 856–866, Jul. 2006.

[13 J. M. Burdío, F. Monterde, J. R. García, L. A. Barragán, and A. Martínez, “A two- output series-resonant inverter for induction-heating cooking appliances,” *IEEE Trans. Power Electron.*, vol. 20, no. 4, pp. 815–822, Jul. 2005.

[14] N. J. Park, D. Y. Lee, and D. S. Hyun, “A power-control scheme with constant switching frequency in class-D inverter for induction-heating jar application,” *IEEE Trans. Ind. Electron.*, vol. 54, no. 3, pp. 1252–1260, Jun. 2007.

[15] B. Saha, K. Y. Suh, S. K. Kwon, T. Mishima, and M. Nakaoka, “Selective dual duty cycle controlled high frequency inverter using a resonant capacitor in parallel with an auxiliary reverse blocking switch,” *J. Power Electron.*, vol. 7, no. 2, pp. 118–123, Apr. 2007.

About Authors

S. Arumugam has obtained his B.E degree from Bangalore University, Bangalore in the year 1999. He obtained his M.E degree from Sathyabama University, Chennai in the year 2005.He is presently a research scholar at Bharath University, Chennai. He is working in the area of Resonant inverter fed Induction Heating. He has published more than 10 international journals. Presently he is working as a Assistant Professor in Electrical and Electronics Engg department at Ganadipathy Tulsis jain Engineering college, Vellore, Tamilnadu. He has published books on Basic Electrical Engg and Electrical machines.

S.Ramareddy is Professor of Electrical Department, Jerusalem Engineering College, Chennai. He obtained his D.E.E from S.M.V.M Polytechnic, Tanuku, A.P. A.M.I.E in Electrical Engg from institution of Engineers (India), M.E in Power System from Anna University.

He received Ph.D degree in the area of Resonant Converters from College of Engineering, Anna University, Chennai. He has published over 20 Technical papers in National and International Conference proceeding/Journals. He has secured A.M.I.E Institution Gold medal for obtaining higher marks. He has secured AIMO best project award. He has worked in Tata Consulting Engineers, Bangalore and Anna University, Chennai. His research interest is in the area of resonant converter, VLSI and Solid State drives. He is a life member of Institution of Engineers (India), Indian Society for India and Society of Power Engineers. He has published books on Power Electronics and Solid State circuits.

M. Sridhar
is a professor in Bharath University .He has published many Technical papers in National and International Conference /Journals. Presently he is the Dean A&P/IEQA of Bharath University Chennai.