New Generation Electromagnetic Induction Fluid Heating Appliance using Series Resonant PWM Inverter with Auto-Tuning PID Control-based Feedback Scheme

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Abstract

This paper describes a newly-developed of an electromagnetic induction fluid heating appliance using a heatedflow-through metallic package incorporated into the nonmetallic vessel in the pipeline, which is composed of series-loaded resonant phase-shift PWM high-frequency inverter using IGBT modules and their optirum driver modules in addition to an auto-tuning PID controller for temperature regulation.

This efficient inverter-fed type fluid heating appliance is more acceptable for high-quality heat energy transfer and delivery processing plants operated under a precise temperature control scheme as well as heat-energy storage and heat exchange processing plants because of clean, safty and high- efficient energy conversion, compactness in volumetric size, and ease to control.

In particular, the series capacitor-compensated resonant PWM inverter with a power factor correction and active sinewave line current-shaping functions is introduced for induction-heated pipeline fluid healing.

The original structure of electromagnetic induction-heated metallic package in the non-metallic vessel or tank for high-efficient fluid heating is demonstrated from a practical point of view, in which specially-designed fluid-through induction-heating metallic package assembly with a huge heating surface to induce the eddy current is incorporated into the nonmetallic cylindrical vessel with a working coil connected to a high-frequency AC power supply.

The inherent remarkable features of this power electronic appliance are schematically pointed out and confirmed. Its operating characteristics in the steady-state are illustrated and evaluated. The prospective applications of this new conceptional fluid heating appliance are mentioned herein.

Keywords : Series-Loaded Resonant Invertetr, High-Frequency Power Conversion, Insulated Gate Bipolar Power Transistors, Phase- Shifted PWM, Soft-Switching Operation, Power Factor Correction, Active Power Filter, Electromagnetic Induction- Fluid Heating, Auto-Tuning PID Controller, Distributed Pipeline Heating,

1. Introduction

Generally, an induction heating is an effective contactless method for generating the heat in conductive losses estimated by both inducing eddy currents and hysteresis

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losses in the work piece on the basis of high-frequency alternating magnetic fields, which can be produced by the high- frequency inverters using the latest MOS-gate controlled power switching devices and modules such as MOSFETs, IGBTs, MCTs and MOS-SITHs.

This is a convenient heating category because of its ready availablity, absence of combustion waste products, precision temperature control, flexibility, cleanness, speed of response, safty, compactness in physical size, and ease to control.

The high-frequency magnetic field is usually established by a spiral coil of conductors wrapped around the work piece or a sheet plate coil held parallel to the workpiece surface, to which the conductive work coil is respectively connected to the high -frequency inverters,; voltage-fed type and current-fed type. These types of inverters used for induction heating and melting can operate in a frequency range from 20kHz to 4MHz or so. The inverter operating frequency selected for a particular job is based on the load heating effectivenesses and power conversion system efficiency.

The high-frequency inverter circuits and systems become progressively more and more high-efficient, compactness in volumetric size, fast response control as well as ease of control in accordance with remarkable advances in MOS-gate new power semiconductor switching devices/modules as well as intelligent drive circuit modules and resonant and quasi-resonant circuit topologies and application-specific control circuit devices. The various practical applications of the inverter-fed induction heating power supplies involve the forging, forming, annealing, surface hardening, soldering, brazing, welding and semiconductor melting processings. Under these technical backgrounds, the authors have developed and proposed the state-of-the art electromagnetic induction fluid heating appliance using a voltage-fed high-frequency inverter with an auto-tuning PID control- based feedback scheme.

In recent years, the electromagnetic induction-based fluid heating appliance using the high-frequency inverter circuit and control technologies proposed by the authors have attracted special interest in the fields of industrial, medical, chemical, consumer and co-generation heat energy processing utilizations. The fluid heating based on electromagnetic induction is divided into two; pipeline wall heating and package-in -pipeline heating. The latter heating method is an extremely new and attractive concept proposed by the authors. The eddy currents are induced in flow- through metallic package incorporated into the nonmetallic vessel or tank by means of an external working coil connected to the voltage-fed high-frequency resonant inverter which is operated by the phase-shifted PWM scheme. This method is primarily used for pipeline heating as well as vessel or tank heating.

This paper presents an originally-developed next generation electromagnetic induction flow-through metallic package in nonmetallic pipeline type fluid (liquids or gases) heating apparatus, which is composed of a constant frequency phase-shifted PWM series-loaded resonant inverter using IGBT modules and their optimum intelligent driver modules. This appliance is designed so as to operate under the conditions of a unity power factor correction and active harmonic current compensation finctions in addition to an auto-tuning PID-operated controller for a stable and quick operntion. Its inherent steady-state characteristics including its application plant and performances are illustrated and evaluated from a practical point of view.

2. Electromagentic Induction-Based Fluid Heating Appliance

2-1 System Description

Figure 1 shows a schematic system configuration of the newly-developed electromgnetic induction fluid (liquids or gases) heating appliance using a series resonant PWM inverter with an active power filtering scheme. This fluid heating appliance used in the pipeline is mainly composed of a single phase full-bridge rectifier which dose not include smoothing filter in order to be capable of operating at a unity power factor correction and harmonic current compensation strategies, a voltage-fed full bridge type series-loaded resonant IGBT high-frequency inverter with a constant phase -shifted PWM power regulation scheme, a specially-designed electromagnetic induction fluid heating assembly composed of a fluid-through cylindrical and metallic package to achieve eddy current heating, which is tightly incorporated into the

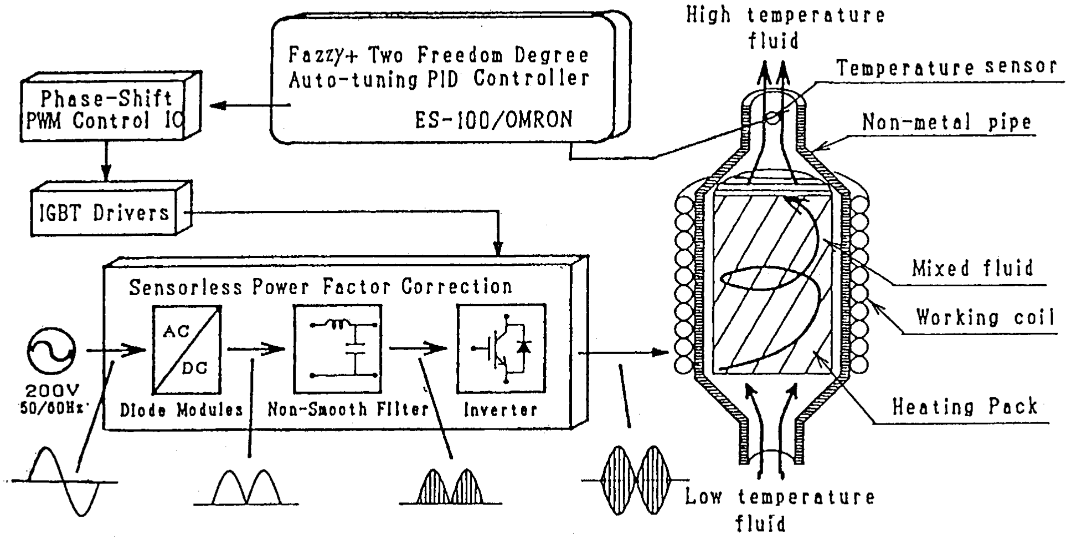


Fig. 1 The latest Schematic indution-heated electrical energy conversion & utilization system

nonmetallic vessel or tank in the pipeline system, the working coil for generating the high-frequency flux which is wrapped around the nonmetallic vessel or tank, and a precise temperature control implementation with an auto-tuning PID controller and a temperature sensor. This epock-making appliance is considered for fluid heat transfer and delivery processing plants as well as heat energy storage and heat exchange processing plants in the pipeline system and compact and efficient electromagnetic induction-heated boiler will be more cost-effectivc from a practical point of view.

2-2 High-Frequency Inverter-based Power Supply

Figure 2 shows the basic circuit of voltage-fed full-bridge type series loaded-reso-

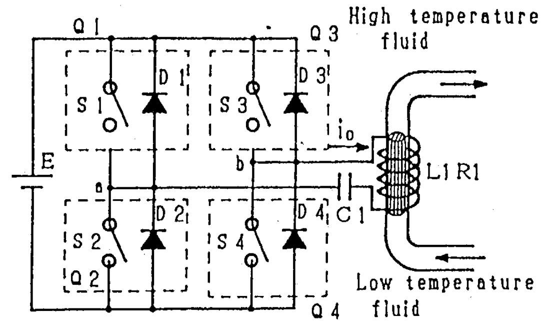


Fig. 2 A voltage-fed full-bridge type series-loaded resonant inverter

nant inverter using IGBT modules and their driver modules. The output voltage or current of this inverter can be regulated by means of phase-shifted PWM scheme under a oondition of a constant frequency. The operating voltage and current waveforms of the series-loaded resonant PWM inverter using IGBT modules are illustrated in a phase-shifted PWM mode. As can be observed in Figure 3, the turn-on switching currents isl/is2 of S1 and S2 in the bridge left leg is positive, but the S1 or S2 can turn-off under a condition of zero current and zero voltage soft-switching in spite of phase-shifted PWM conditions and load parareter variations. On the other hand, it is noted that S3 or S4 in the bridge right leg can turn-on under a condition of zero current and zero voltage soft switching in spite of a phase-shifted PWM scheme. However, these switches (S3,S4) must turn off at a hard switching condition. Figure 4 proposes a new

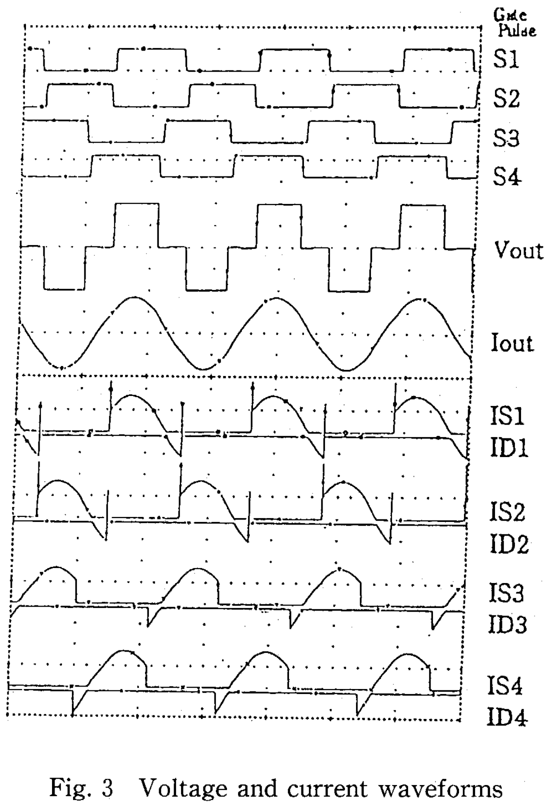


Fig. 3 Voltage and current waveforms

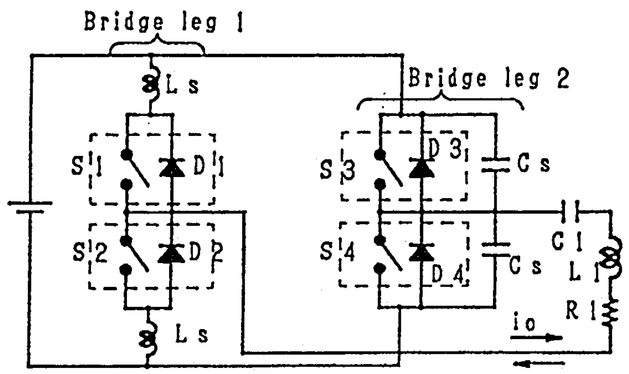


Fig. 4 A Phase-shifted soft-switching PWM high-frequency inverter using lossless inductors and lossless capacitors

topology soft-switched PWM series loaded resonant inverter using lossless inductor snubber bridge leg and lossless capacitor snubber bridge leg in order to achieve the complete soft switching operation for all the switches independently of a phase- shifted PWM regulation mode.

2-3 Induction-heated Flow-through Metallic Package

Figure 5 indicates a schematic fluid-through eddy current-heated metallic package developed newly, which is tightly incorporated into the nonmetallic vessel or tank in the pipeline. In Figure 6, the trially-produced stainless-steel layer package for induction-heated assembly is shown. Internal structure of this metallic package is drawn in

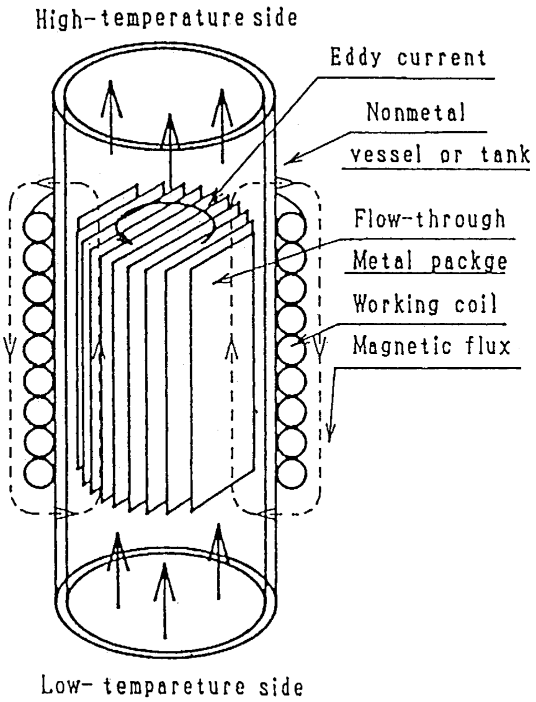


Fig. 5 Package inserted into the vessel and tank of the pipeline

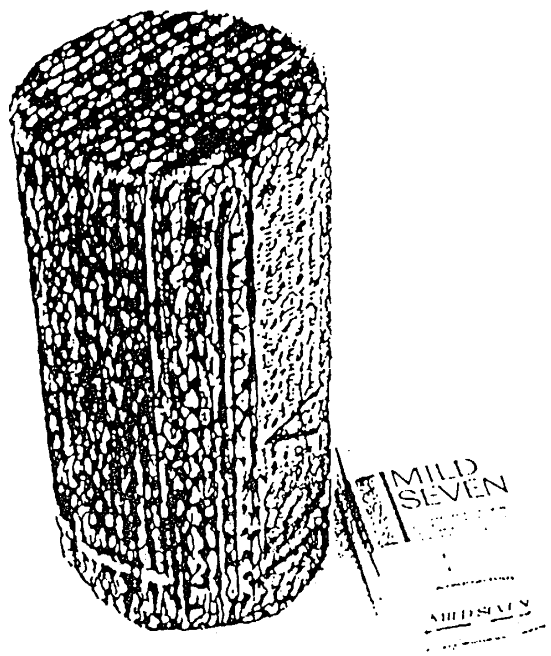


Fig. 6 Trially-produced induction-heated metallic package

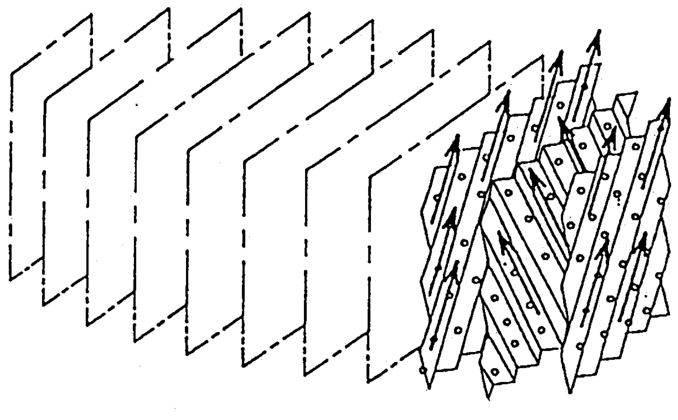


Fig. 7 Internal structure fluid-through specially-designed metal layer packing to generate tabulance fluid

Figure 7. When the fluid (liquids or gases) flows through the package in the vessel or tank connected to the pipeline, the tabulance fluid is to produce in the package. This moving tabulance fluid is to be instantaneously heated on the basis of induction heating due to eddy currents generated in ruge surface of mechanically-processed piling stainless-steel sheet package.

3. Remarkable Appliance Features

The salient features of new conceptional induction-heated boiler developeped newly are summarized as follows;

(1) Eddy currents in the metallic package incorporated into the vessel through a working coil connected to an inverter power supply are induced with a contactless high-frequency power transmission in the internal heating package, an electical wiring is not needed. Electrical insulation is completely sufficient. Because of maintenance free, no open chrcuit, the system reliability is high.

(2) Because 50 μ m stainless steel/titanium alloy type package as the heating body is used, the heat capacity of heating body becomes extremely small. Heating time constant in heating response is much shorter. Instantaneous electrical heating is realizable.

(3) Fluids (liquids/gases) heated by a contactless induction heating is to flow through this specially-designed package assembly. Heating surface to heat fluid becomes extremely large. In this example, heating surface of the cylindrical package is designed for 8.5m^2 under the conditions of 10cm in diameter and 19cm in height.

(4) Owing to tbe tabulance fluid generation based on the inherent flow-through package structure, the temperature distribution of the moving fluid obtained from the outlet of the vesel/tank, in which the flow-through package inserted tightly becomes constant. Tempeperature slope of heating package is constant. Easy to sense the temperature of the moving fluid in the pipeline.

(5) Ease to control under a stable condition by means of a phase-shifted PWM regulation and an auto-tuning PID-based controller. Intelligent control scheme can be easily introduced.

(6) Temperature regulation range of fluid heating in the pipeline extremely wide from a low temperature to a high temperature more than 800℃ with a precise temperature setting.

(7) Energy conversion efficiency is high. Because of energy saving, the running cost becomes relatively cheap.

(8) Compactness in volumetric size. Lighter weight is to be achieved.

(9) Owing to the active filtering function of this appliance, the unity power factor correction and sinewave current shaping in the utility-grid bus line is to be performed. Due to the soft-switching operation, voltage and current switching surges are to be largely reduced. As a result, EMI problem is to be alleviated.

(10) Clean heating and high quality heating are to be realized. This appliance is the most suitable for peripheral enviroment.

4. Experimental Set-up and Its performances

Table 1 indicates the design specifications of the electromagnetic induction fluid heating appliance using a series-loaded resonant high-frequency inverter with a self-tunig PID-based feedback control scheme. The external overview of the set-up produced for electromagnetic induction-heated boiler is shown in Figure 8.

Figure 9 illustrates the steady-state operating characteristics of this electromagnetic induction-heated boiler. Observing in this Figure 9, the output power can be continuosly regulated according to the phase-shifled angle ϕ as a control variable. Figure 10 shows the operating voltage and current waveforms in the series-loaded resonant high-frequency inverter with a phase-shifted PWM scheme as compared with those of a computer-aided simulating voltage and current waveforms. The input

Table 1 Design specifications of inverter-fed fluid heating Appliance

Items	Design Specifications
Input Voltage	Single-Phase 200VRms
Regulated Output Power	0~10Kw
Power Regulation Strategy	• Constant-Frequency • Phase-Shifted PWM
Operating Frequency	30KHz
Size of Heating Body	ϕ 100mm×h190mm
Temperature Control System	Fazzy+Two Freedom Auto-tuning PID

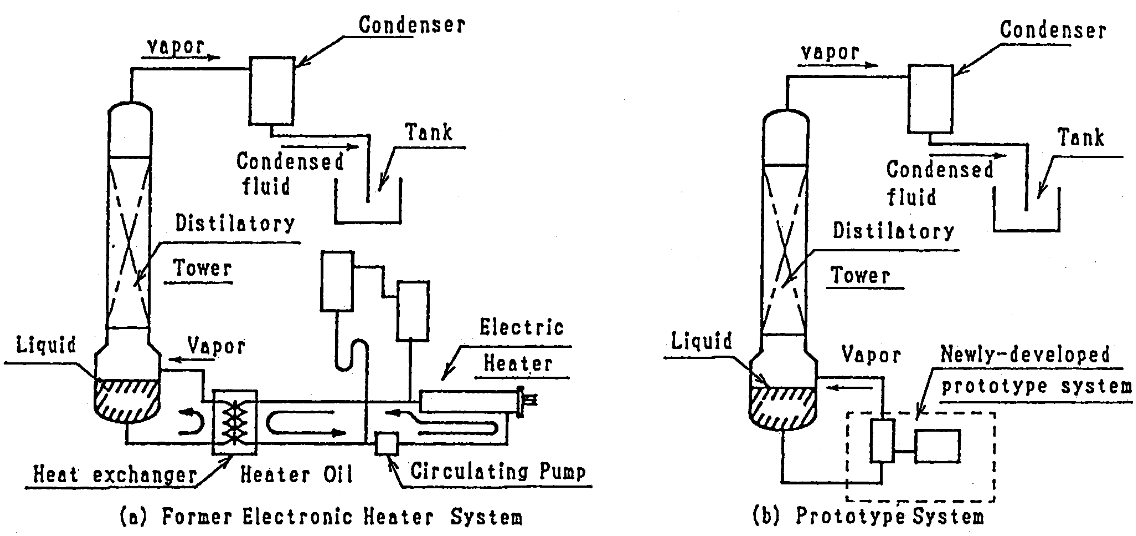


Fig. 8 Comparative feasible application between this induction-heated appliance and resistance-heated appliane

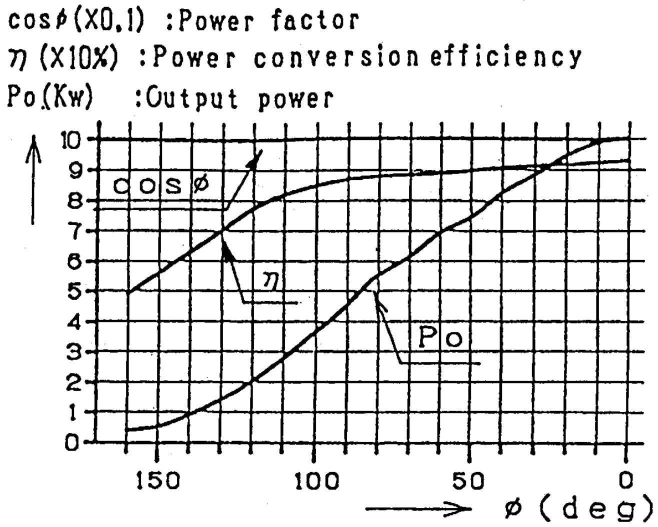
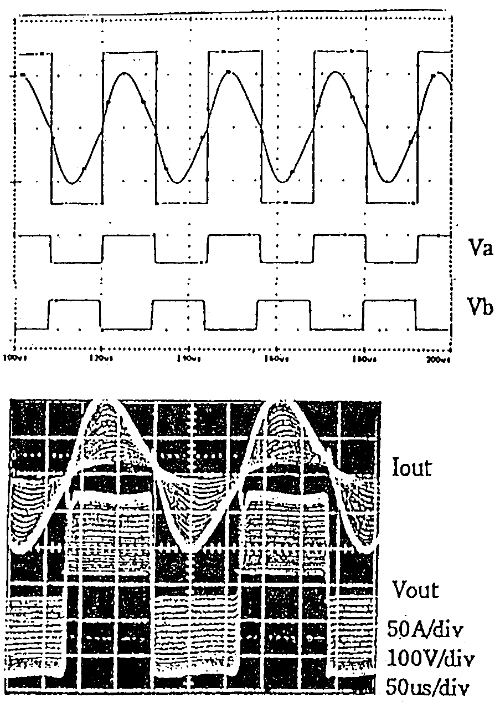
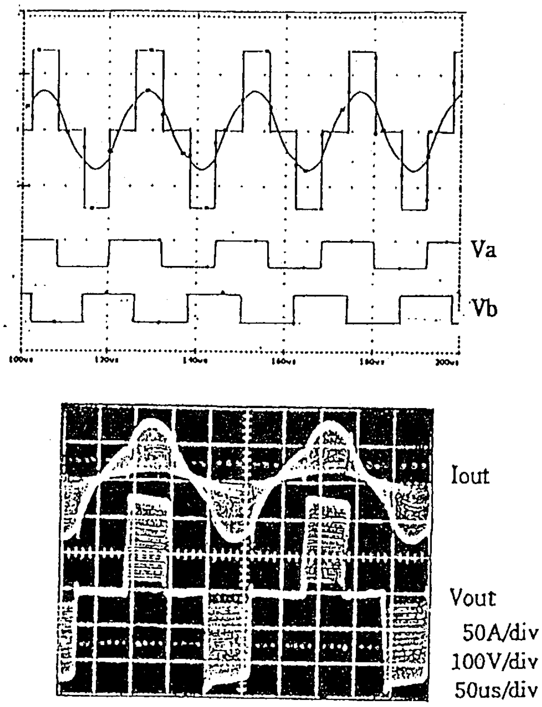


Fig. 9 Steady-state characteristics of this inverter system



(a) at full power load



(b) at half power load

Fig. 10 Observed output voltage and current waveforms and simulation waveforms

voltagc and current waveforms of this appliance are shown in Figure 11. The output current waveform corresponing to the input and current waveform is shown in Figure 12.

Observing the input voltage and current waveforms in Figure 11, the unity power

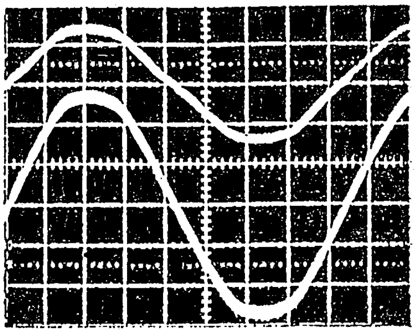


Fig. 11 Input voltage and current waveforms

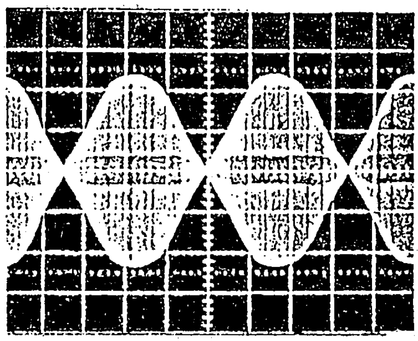


Fig. 12 Output current waveforms (utility frequency range)

factor correction and sinewave currrent shaping in utility AC grid line can be achieved without an active filtering converter control implementation.

5. Conclustions

In this paper, the state-of-the art attractive electromagnetic induction-based fluid heating appliance has been successfully proposed on the basis of a series-loaded resonant PWM high-frequency inverter using IGBT modules and its self--tuning PID control scheme.

It was emphasized that fluid heating principle of this appliance is based upon the electromagnetic-induced eddy current heating generated in a flow-through metallic package capable of delivering the partial tabulance fluid (liquids or gases), which is distributively incorporated into the nonmetallic vessel or tank in the pipeline system.

In this unique appliance, a voltage-fed series loaded resonant high-frequency inverter using IGBT modules has been introduced for an epock-making fluid heating based on the induction heating principle, which includes a fixed-frequency PWM-based power regulation scheme, precise and stable temperature control scheme with a self -tuning PID control strategy, the power factor correction and harmonic current compensation functions in the utility-grid AC line.

It has been practically proved that this appliance becomes more cost-effective and acceptable for electromagnetic induction-heated boiler, heat exchanger hot water producer, hot air blower & dryer, evaporator and pure water producer because of compactness in volumetric size, high-efficiency conversion, quick stable response, reliable and clean utilization and precise temperature control realization.

In the future, this new conceptional electromagnetic fluid heating appliance using the voltage-fed resonant high-frequency inverter using MOs gate bipolar power devices such as IGBTs, MCTs and MOS-SIThs should have to be used widely in the multi -diverse heat energy processing fields of industrial, chemical, medical, space, ocean, automotive, new energy, cogeneration and consumer applications.

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