Novel Electromagnetic Induction Eddy Current DPH based Continuous Pipeline Fluid Heating using Soft Switching PWM High Frequency Inverter

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***Abstract*—** This Paper presents an innovative prototype of a new conceptual electromagnetic induction eddy current based fluid heating appliance using voltage-fed quasi resonant zero voltage soft switching PWM high-frequency inverter using IGBTs, which can operate at a constant frequency variable power regulation scheme. The promising simple high efficient low noise inverter type electromagnetic induction eddy current based pipeline fluid heating appliance is proposed for saturated steam generator, superheated steam generator, hot water and hot air producer, metal catalyst heating for exhaust gas cleaning in engine. Under these technological backgrounds, a novel electromagnetic induction eddy current Dual Packs Heater (DPH) based pipeline fluid heating incorporates thin metal layer type package for continuous fluid heating appliances applying two types of voltage-fed quasi load resonant ZVS-PWM high frequency inverter. The unique features of a novel electromagnetic induction eddy current DPH based continuous pipeline fluid heating appliance is illustrated on the basis of simulation and discussed for the steady state operating characteristics and experimental results.

***Index Terms*—**Electromagnetic Induction Eddy Current, ZVS-PWM Inverter, Dual Packs Heater (DPH)

I. INTRODUCTION

With great advances in the latest power semiconductor switching devices such as MOSFETs, IGBTs, SITs, MCTs and SI-Thyristor, high performance voltage and current source type high frequency load resonant inverters for induction heating power supplies have been widely applied for the forging, brazing, sealing, welding, melting heat treatment processing in industrial power processing plants and induction fusion of the pipeline [1-2].

Nowadays, the electromagnetic induction eddy-current based heat energy processing in the pipeline fluid heating systems which incorporates the voltage-fed series resonant type, current-fed parallel resonant type, voltage and current hybrid-fed resonant type and quasi-resonant type high frequency inverters using the latest IGBT power modules have attracted special interest because of high efficiency, high reliability, high safety, cleanliness, compactness in volumetric size, light in weight, rapid temperature response as well as stable temperature tracking and precise temperature controllability. The new consumer products based on the eddy current induction heating which is ZVS-PFM high-frequency resonant inverter operating under the principle of soft switching are applied for cooking pan, rice cooker/warmer, and hot water producer. Under these technological backgrounds, an attractive electromagnetic induction eddy current dual packs heater based flow through metal layer type pipeline fluid heating appliance using voltage-fed load resonant and quasi load resonant ZVS-PWM high frequency inverter operating at a constant frequency variable power regulation scheme is proposed here [3-5].

This paper presents a new prototype of voltage-fed high frequency quasi resonant soft switching inverter with asymmetrical PWM control scheme or duty cycle control scheme which is developed for electromagnetic induction eddy current dual packs heater based continuous fluid heating in pipeline plants. Its operation principle and unique features of the newly developed electromagnetic induction eddy current dual packs heater based fluid heating appliance using high frequency soft switching inverter are described and discussed on the basis of simulation and experimental results.

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II. DPH BASED CONTINUOUS PIPELINE FLUID HEATING

A. Internal Fluid Heating Appliance

Fig. 1 has shown the outline of internal electromagnetic induction eddy-current based fluid heating tank using dual packs heater (DPH). This innovative induction heated fluid heating tank used for the industrial, chemical, and consumer pipeline systems is basically composed of cylindrical vessel made of non-magnetic ceramics vessel, litz wire as working coil and carbon ceramics as shown in Fig. 2.

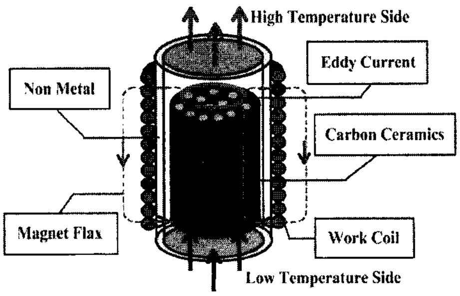


Fig. 1 System configuration of internal electromagnetic induction heated appliance

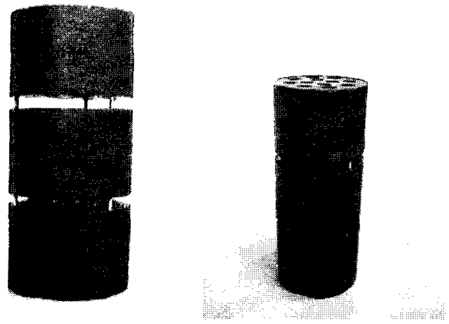


Fig. 2 Carbon ceramics as induction heater

B. External Fluid Heating Appliance

Fig. 3 shows a schematic total system configuration of the new conceptual external electromagnetic induction eddy current based continuous moving fluid heating appliance, which incorporates active voltage-clamped quasi resonant ZVS-PWM high frequency inverter using a single two in one IGBT power module.

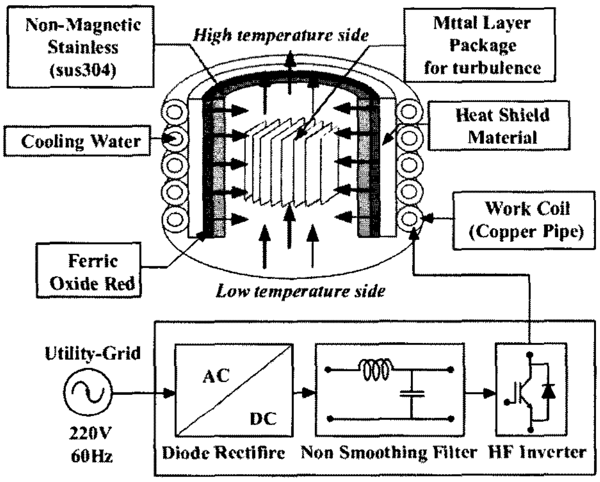


Fig. 3 System configuration of external electromagnetic induction heated appliance

This induction heated fluid heating appliances used for the industrial, chemical and consumer pipeline system are basically composed of a single phase diode rectifier with non-smoothing DC capacitor filter link, an active voltage clamped quasi resonant ZVS-PWM high frequency inverter with CFVP function, specially designed continuous moving fluid heater due to the induction heated vessel, which is made of electromagnetic induction heated type fluid through thin metallic layer laminated assembly with many spots and mechanically wavelike processed channel slits in mechanically wavelike processed channel slits in order to generate natural fluid turbulence in the pipeline systems.

This metal layer type package as shown in Fig. 4 consists of thin conductive and non magnetic metal sheet heating body with a large amount of eddy current based induction heating surface area, which is incorporated into the high temperature proof ceramic vessel with water cooled working coil connected to the high frequency inverter treated here. The turbulence fluid flowing through this appliance put tightly into the vessel serves to exchange efficient heat energy into the electromagnetic induction based fluid heating energy

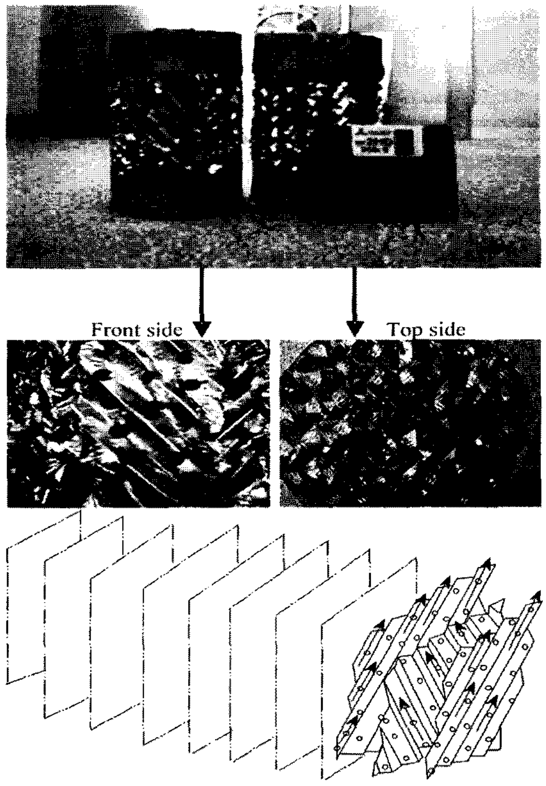


Fig.4. Specially-designed metallic laminated assembly to generate turbulence

III. QUASI-RESONANT ZVS PWM HIGH FREQUENCY SOFT SWITCHING INVERTER

A. Circuits Features and Operation

Fig.5 shows a high frequency load resonant inverter circuit topology for the electromagnetic induction eddy current DPH based fluid heating appliance, which operates under a condition of ZVS, constant frequency, asymmetrical PWM control strategy over wide load range and duty cycle control. This power electronic appliance using two cascaded high frequency inverters can solve a problem due to harmful acoustic noise generation in multi inverter-fed induction heating fluid heating because of operating width modulated power regulation. This high frequency quasi resonant inverter is composed of a voltage-source type quasi resonant ZVS-PWM inverter with a single active voltage clamping capacitor.

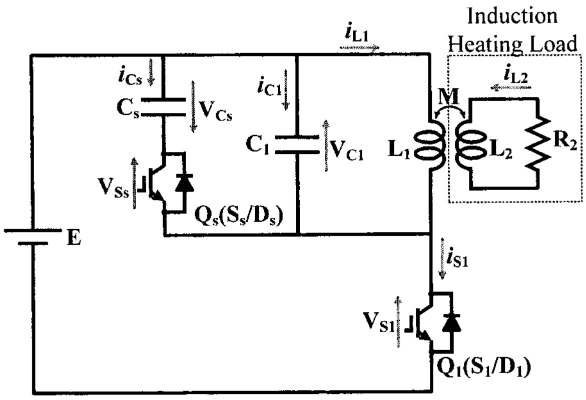


Fig. 5 Active voltage clamped edge resonant high-frequency inverter

Generally, this high frequency quasi resonant inverter with CFVP function is connected to a single phase utility AC grid, full-bridge diode rectifier, non smoothing filter for a power factor correction function and noise filter. It is noted that a newly developed quasi-resonant ZVS-PWM inverter with a CFVP function is directly combined to each induction heating load vessel or tank coupled to individual working heating coil. Its control processing circuit for a constant frequency power regulation and system protection schemes, and IGBT driver IC module circuits are incorporated into this high frequency inverter-fed fluid heating appliance, which operates under a principle of ZVS.

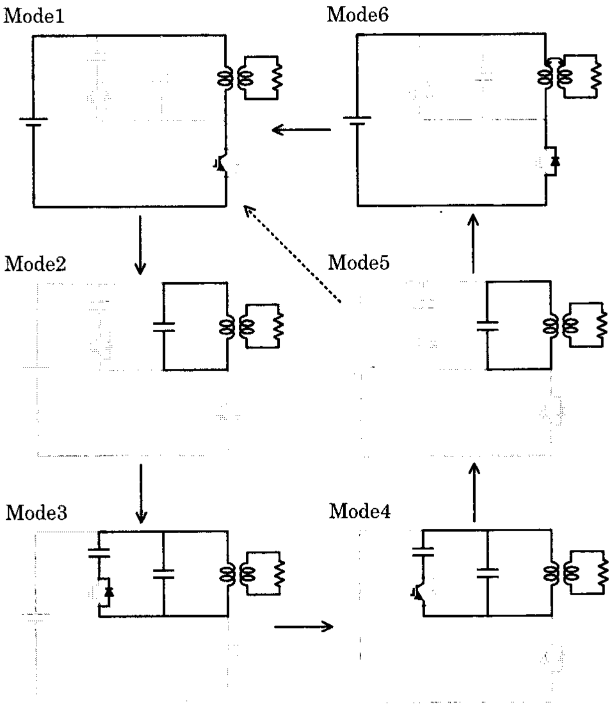


Fig. 6 Equivalent circuit for mode transition

The reverse conducting power semiconductor switching block devices, main switch; Q_1 (S_1 and D_1), and auxiliary active switch; Qs (Ss and Ds) incorporate a new generation high-frequency and lowered saturation voltage type IGBTs designed for soft switching control. Fig. 6 shows the equivalent circuit and steady-state equivalent circuit for each operation mode of this quasi resonant inverter.

IV. SIMULATION AND EXPERIMENTAL RESULT

When a duty factor D is below about 0.2, because of residual charges of the quasi resonant capacitor C_1 as lossless capacitor snubber, hard- switching mode (from Mode 5 to Mode 1) causes. In practice, this complete ZVS commutation range can be required in order to active a soft switching operating range.

Table 1 indicates the practical design specifications and circuit parameters of the feasible electromagnetic induction based fluid heating appliance using quasi resonant ZVS-PWM high frequency inverter using the IGBT modules.

Table 1 Design Specifications and Circuit Parameters

Item	Value
The DC power source voltage(E)	141.4[V]
The quasi resonance lossless capacitor (C_1)	0.16[μF]
The active voltage clamped capacitor (C_S)	3.30[μF]
The switching frequency(f_0)	25[kHz]
Electromagnetic coupling coefficient (k)	0.785
Work coil inductance(L_1)	65.0[μH]
The load time constant(τ)	15.50[μs]

Fig. 7 shows a schematic prototype of electromagnetic induction eddy-current DPH based fluid heating appliance inverter type induction heated boiler. The first stage fluid heater using No.1 inverter treated here is designed so as to produce saturated steam and the second stage moving fluid heater using No.2 inverter treated here can produce super heated steam over temperature ranging from 100℃ to 500℃; in some cases ranging from 100℃ to 1200℃ in case of using induction heated carbon ceramics type dual packs heater.

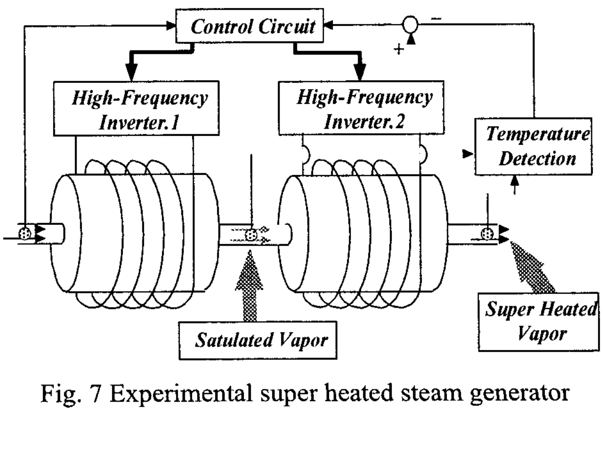


Fig. 7 Experimental super heated steam generator

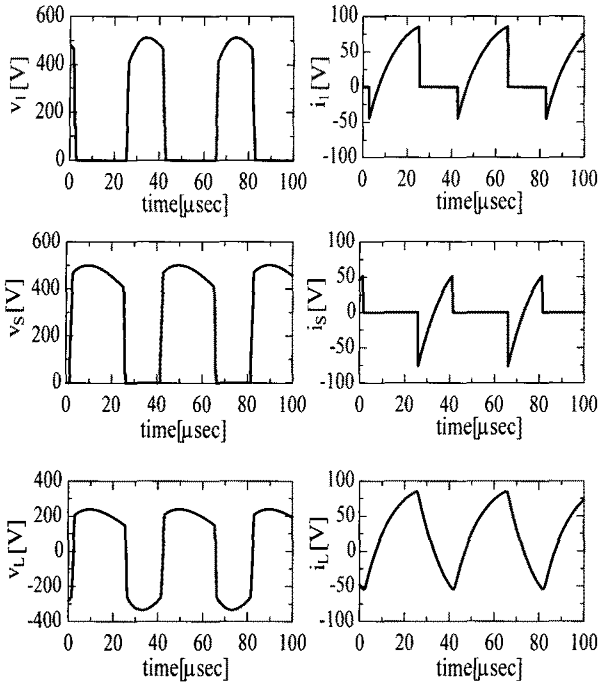


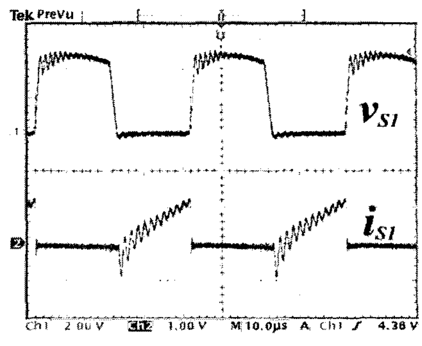
Fig. 8 Steady-state voltage and current operating waveforms under a condition of D=0.6

Fluid temperature is detected at three points in appliance displayed in Fig. 8 and is able to be regulated by a classical or modern PI controller. In feasible experiment, the first and second stage electromagnetic induction fluid heaters using dual packs heater are introduced by using two soft switching high frequency inverter treated here. Fig. 8 represent the steady-state voltage and current operating waveforms of the quasi resonant inverter operating under a constant frequency variable power (CFVP) control strategy, which are respectively illustrated by the computer simulation analysis in case of duty factor D=0.6 represented by Fig. 9.

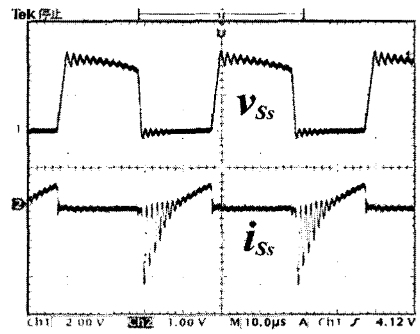
Fig. 9 depict the measured voltage and current waveforms of the main power semiconductor switching block; Q_1 (S_1 and D_1), voltage and current waveforms of the auxiliary power semiconductor switching block; Q_s (S_s and D_s) of this new inverter and electro- magnetic induction based fluid heating load under a condition of duty factor.

It is proven that this quasi resonant ZVS-PWM high frequency inverter with CFVP scheme can completely work under a soft switching operation for a wide duty factor control scheme. Besides, this high frequency inverter can clamp an excessive peak voltage applied to the main switching device; Q_1 (S_1 and D_1). Accordingly, the conduction losses and current stresses of switching power semiconductor devices can be reduced for this quasi resonant inverter circuit topology.

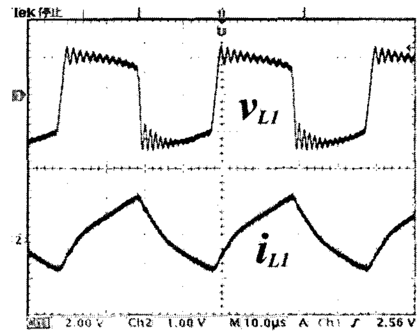
Fig. 10 represents duty factor vs input power characteristics under a fixed frequency PWM control strategy. As can be seen in this Fig. 10, it is clearly proven that duty factor D can be continuously adjusted in accordance with inverter output power adjustment under a principle of ZVS commutation.



(a) switch Q_1



(b) switch Q_s



(c) work coil L_1

Fig. 9 Experimental voltage and current waveforms (Duty Factor D = 0.6)

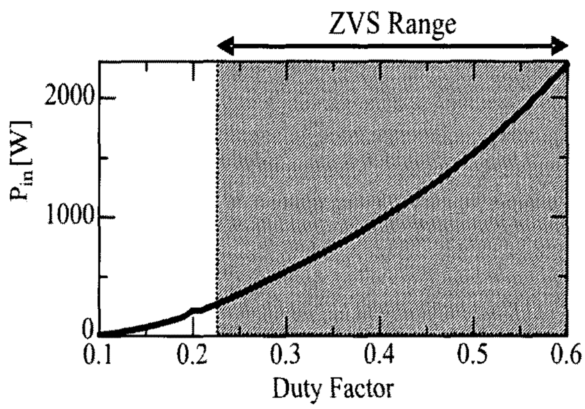


Fig. 10 Power regulation control characteristics

Fig. 11 illustrates temperature characteristics of the second stage moving fluid heater using inverter type induction heated dual packs heater for setup in experiment. These results show that this induction heated steam generator is able to produce a saturated steam within about 200 seconds and a super heated steam within 800 seconds. It is noted that this electromagnetic induction based fluid heating using inverter type induction heated dual packs heater can generate super heated steam faster than general gas combustion system or sheathed wired heating system.

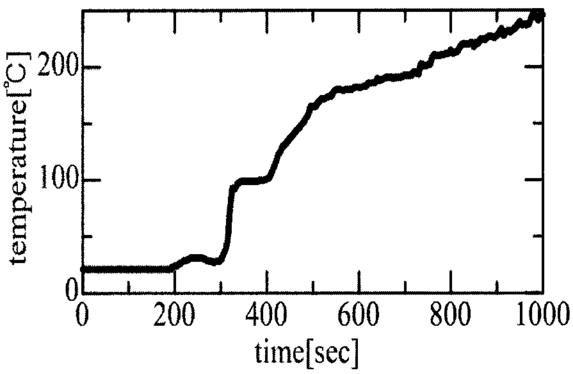


Fig. 11 Temperature characteristics of the induction heated second stage boiler

V. CONCLUSIONS

In this paper, an innovative prototype of the new electromagnetic induction eddy-current dual packs heater based fluid heating appliance has been proposed by using a voltage-fed type active voltage clamped quasi-load resonant ZVS-PWM high frequency inverter using power module IGBTs, which can efficiently operate at a soft commutation scheme on the basis of asymmetrical PWM scheme. It was also proven as a variety of industrial, consumer, medical, chemical and automotive heat energy processing plants that the new and efficient induction heated fluid heating appliances could be cost effective for the electromagnetic induction eddy current dual packs heater based steam generator and super heated steam generator than the conventional sheathed heated type steam generator, because of downsizing in volumetric physical size, cleanliness, high efficiency conversion, quick temperature response, stable and precise temperature control realization and on-site utilization.

In the future, the power loss analysis of this soft switching inverter should be reduced and the new generation power electronic appliances for electromagnetic induction eddy-current dual packs heater based fluid heating should be evaluated and discussed from a practical point of view. The computer aided design procedure of this power electronic appliance using a new inverter topology in the pipeline systems should be studied from a theoretical point of view.

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