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Choice of Semiconductor Switches for Energy Efficient Induction Heated Pipe-line using H. F. Mirror Inverter

Pradip Kumar Sadhu, Nitai Pal and Atanu Bandyopadhyay

Abstract—**An exhaustive method for the selection of different power semiconductor switches for high frequency mirror inverter fed induction heater is presented. Heating coil of the induction heater is made of litz wire which minimises the skin effect and proximity effect at high operating frequency. With the calculated optimum values of inductance and resistance of heating coil at a particular operating frequency, high frequency mirror inverter topology has been simulated using P-SIM software as well as constructing the experimental model of same rating. Obtained the voltage waveforms across heating coil and current waveforms through it, have been taken for further analysis. From this analysis selection of suitable power semiconductor switches like IGBT, GTO and MOSFET are made. Waveforms have been shown to justify the feasibility for real implementation of high frequency mirror inverter fed induction heater in industrial applications.**

Index Terms—**Induction heater, Eddy current heated metallic package, Mirror inverter, P-SIM, IGBT, GTO, MOSFET**

I. Introduction

Induction heater for industrial applications operates at a high frequency range from 1 kHz to 100 kHz as described by Sadhu et.al in [1], [2] & [6]. In the application of low frequency induction heating, the temperature distribution can be controlled by slowly varying magnetic fields below a frequency as low as 300 Hz. For medium frequency application, an auxiliary voltage-fed inverter is operated in parallel with the main current-fed inverter since the current-fed parallel inverters alone, when used for induction heating,fail to start [1], [3] & [4]. Mirror inverters for high frequency induction heating and melting applications are self-started. For self-commutation, a resonant circuit is essential. It is assumed that the circuit is under damped; a mandatory condition for the circuit. The capacitor required for under damping can be connected in series or in parallel with the load. In the modern times, IGBTs, GTOs, MOSFETs are preferred to SCRs mainly because they offer convenient turn OFF characteristics. Some auxiliary circuits and equipment are required to minimize switching losses occurring at high frequencies.

In this present paper, response of high frequency mirror inverter is tested & verified with different power switches and finally appropriateness of the switches is confirmed. With the same designed parameters of the said inverter circuit, various switches such as IGBT, GTO and MOSFET have been used. Complete inverter configuration then has been simulated using P-SIM.

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II. Analysis of High Frequency Mirror Inverter

The circuit operation has been discussed by Sadhu et.al in [2], [7] & [9]. The exact circuit diagram of the mirror inverter is shown in Fig. 1.

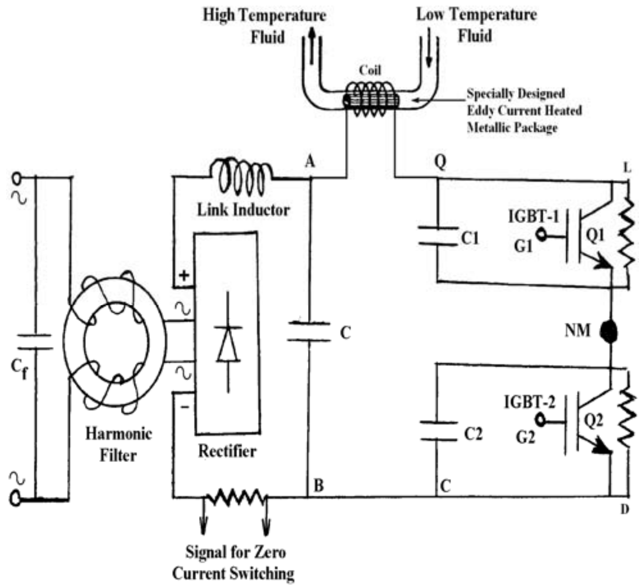

Fig. 1. Circuit diagram of Mirror Inverter using IGBT

Fig. 1 indicates a specially designed eddy current heated metallic package which is tightly incorporated into the non-metallic vessel or tank in the pipeline. The mechanically processed thin stainless-steel layer package with many spots and fluid channels for cylindrical induction-heated assembly is demonstrated in Fig. 2 [5], [8] & [9].

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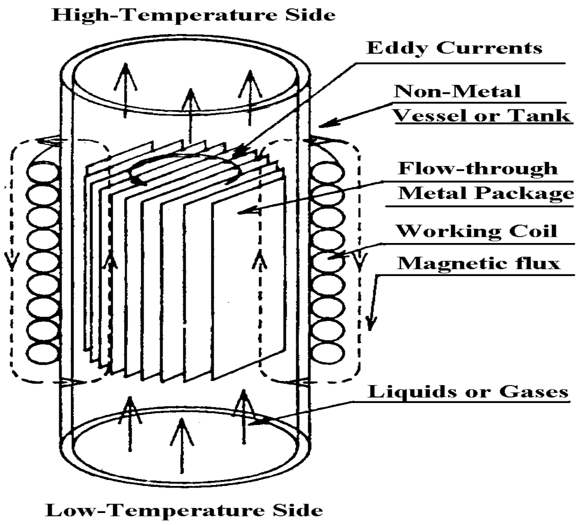

Fig. 2. Heating package in the vessel and tank in pipeline system

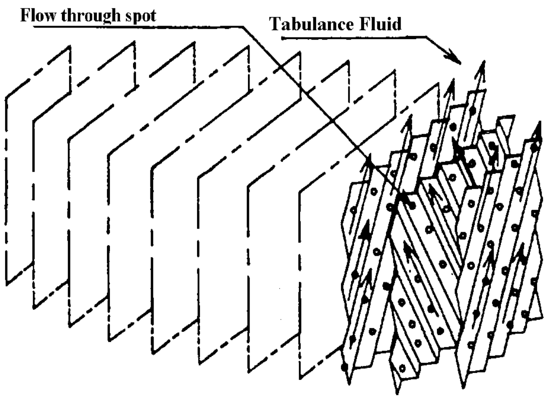

Fig. 3. Internal structure of fluid through specially designed metal layer packing to generate turbulence flow

When the fluid flows through the inherent package in the vessel or tank having a working coil connected to pipeline, the turbulent fluid is heated abruptly by eddy current losses generated inside the stainless-steel package. Internal structure of this metallic package to be heated by eddy current losses is indicated in Fig. 3. For operational analysis, equivalent circuit diagram as shown in Fig. 4. Single point 'NM, in Fig. 1 is shown as a stretched bar 'NM' in Fig.4. When there are no input signals to the IGBTs, both capacitors C1 & C2 are charged.

As soon as gate pulse is applied to IGBT-1, C1 gets discharged through 'QLMN' loop & C2 gets charged 'QLMNC' path. In the next cycle when input signal is given to IGBT-2 with gate pulse to IGBT-1 is removed, C2 gets discharged through 'NMDC' loop & C1 gets charged through 'QNMDC' path. Thus a frequency current flows through 'MN' bar in alternate direction & due to the low capacitive reactance of the capacitor 'C', this current also flows through the coil inductor. In this way, radio-frequency current generated in the short-circuited bar 'MN' is reflected into the induction coil. Now this current will generate alternating magnetic flux.

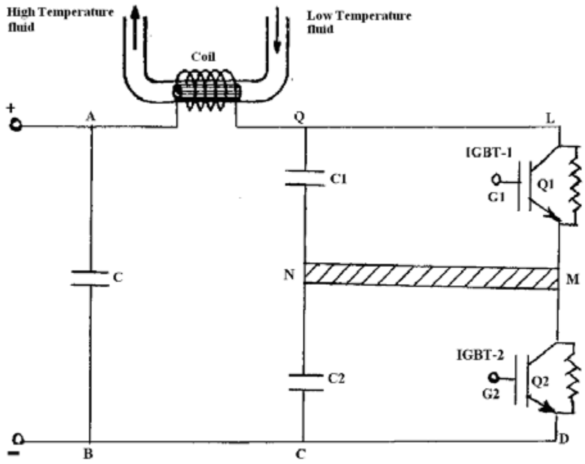

Fig. 4. Equivalent Circuit diagram of mirror inverter

Firstly, the inverter circuit is simulated with IGBT as power switch. There after IGBT has been replaced by GTO & MOSFET. In each case, coil current waveform & voltage across it have been recorded & investigated. A real time experiment has been carried out to validate the simulation result.

III. RESULTS AND DISCUSSIONS

With the selected circuit parameters & configuration, following waveforms have been obtained using P-SIM software and real time experimental model using different power semiconductor switches. Using IGBT in the mirror inverter circuit, it is observed in Figs. 5 & 6 that magnitude of current through the coil has almost equal in both positive and negative halves. Such a peak to peak symmetrical current produces more heat. Hence heating effect becomes very prominent for the same operating frequency range. Further, it is observed that the real voltage across heating coil and current through it, are almost identical to the P-SIM simulated result.

In Fig. 7 & 8, the real voltage across heating coil and current through it, are almost indistinguishable to the P-SIM simulated result. But, current through the coil using GTO in the mirror inverter circuit, doesn't have equal positive and negative peaks. Hence, rms value of the current will be less. So heating effect will also be less compared to IGBT. Furthermore, GTO-based topology requires the arrangement of sending a negative gate pulse through the gate terminal of GTO in order to turn it off which enhances the circuit complexity.

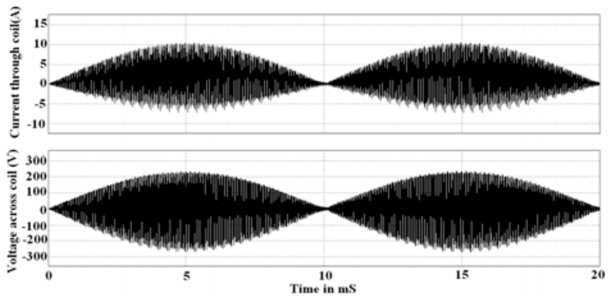

Fig. 5. Coil current & coil voltage using IGBT by P-SIM software

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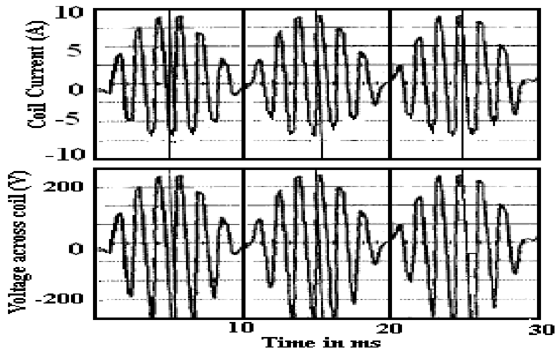

Fig. 6. Coil current & coil voltage using IGBT by real time experimental model

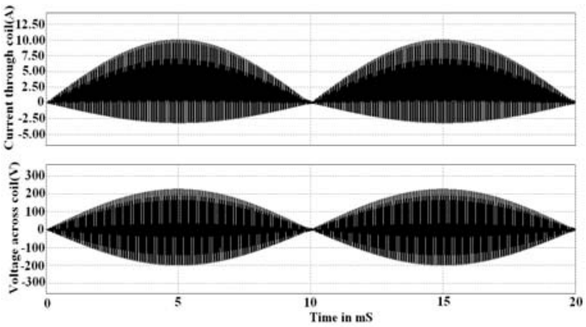

Fig. 7. Coil current & coil voltage using GTO by P-SIM software

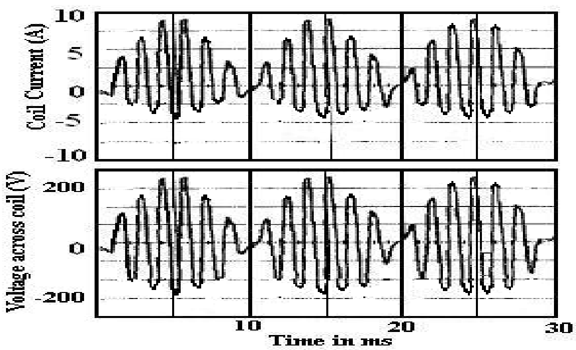

Fig.8. Coil current & coil voltage using GTO by real time experimental model

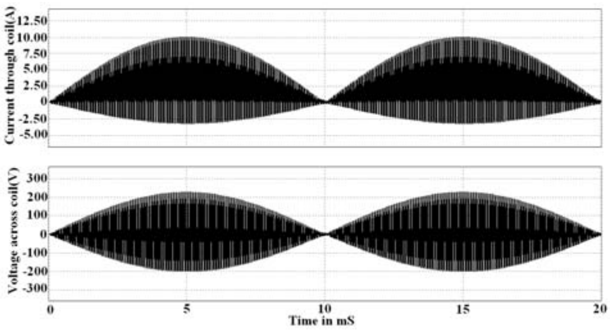

Fig.9. Coil current & coil voltage using MOSFET by P-SIM software

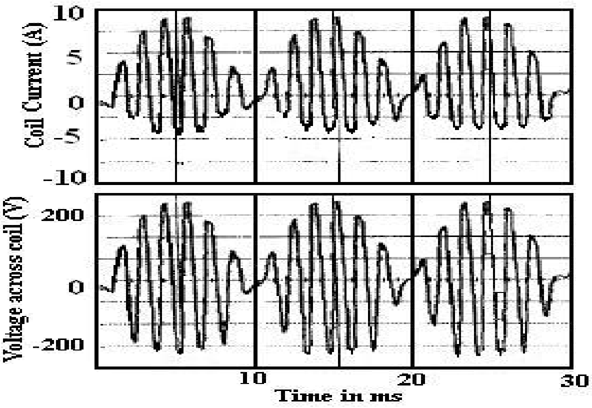

Fig. 10. Coil current & coil voltage using MOSFET by real time experimental model

Fig. 9 & 10 depict that using MOSFET in the mirror inverter circuit, the real voltage across heating coil and current through it, are almost same to the P-SIM simulated result. Here also, coil current doesn't have equal positive and negative peaks. Hence, rms value of the current will be less. So heating effect will also be less compared to IGBT.

IV. Conclusions

After having compared the wave-forms of P-SIM simulation and real time experiment, it is quite obvious that the selection of IGBT as a power semiconductor switch in high frequency mirror inverter is advantageous for induction heating purposes for frequency below 50 kHz and highly acceptable. IGBT offers highest rms value of coil current among all the probable configurations using different power semiconductor switches. For a frequency range of above 50 kHz, MOSFET will be a better option due its low switching & conduction losses.

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