Comparison of Class E & Class F3 amplifier Induction Heating systems

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Abstract - This document deals with the modelling, simulation and comparison of class E and class F3 amplifier systems. The power frequency AC is converted into DC using diode rectifier with c-filter. The voltage across the capacitor filter is applied to class E/ class F3 amplifier system. The circuit parameters of class E and class F3 are designed and simulation studies are performed. The results of the above mentioned systems are compared in terms of output power and THD. The simulation results indicate that the performance of class F3 amplifier system is superior to class E amplifier system and class F3 amplifier has advantages like single power switch and higher output power.

Key Words: Induction Heating, Dynamic Response, Zero Voltage Switching (ZVS), Power Amplifier.

1.INTRODUCTION

The non-optimum operation of the amplifier occurs when the zero-voltage switching (ZVS) condition is satisfied, but the zero-voltage-derivative switching (ZDS) is not equal to zero at the switch turns ON instant. The concept of nonoptimum operation of the Class-E amplifier was defined in the beginning of the Class-E history [3][5]. The first research on non-optimum operation has been done by Raab [7]. In this paper, the degree of freedom for the design amplifier was increased, and the ZDS condition was removed. The mixed-mode power amplifiers are the good choice for obtaining high-power and high conversion efficiency. The optimum conditions of the mixed-mode power amplifier families with a shunt capacitor have been presented in [9]–[10]. But the exact analysis on switch mode PAs are not presented. However, all of the Class-E/F amplifier analyses focus on how to achieve the optimum operation. Many power electronic devices only need to ZVS or zero-current switching (ZCS) condition [1]. In order to reach a Class E/F power amplifier with good performance, some methods have been suggested and implemented. The first method employs the push/pull topology to Class E/F in order to short odd harmonic like inverse Class F (demonstrated Class E/F PA). This configuration improved the amplifier performance such as maximum operating frequency and caused the reduction of maximum switching voltage to have maximum output power capability [11], which only in the ZVS is considered. But the non-optimum condition in the push/pull topology is considered with linear shunt capacitance. The second method is harmonic tuning in which a resonance network is inserted between the drain node and ground. In comparison with Class E/F amplifier, the performance of the power amplifier can be improved at the cost of the complicated circuit design [10]. Besides the aforementioned methods, some Class E/F amplifiers consist of resonance networks tuned at nonharmonic frequencies.

In this paper, the simulink results of the Class-E/F3 power amplifier with a shunt capacitor at the nonoptimum operation are presented. For the verification of our analytical expressions, design examples of the Class-E/F3 ZVS amplifier are presented. The design equations, switch, and output waveforms are obtained as a function of the phase shift and DC supply voltage. By changing the peak switch voltage and the peak switch current, the phase shift is changed, so these two parameters canbe considered as a design specification.

The analytical results are in good agreement with the measurement and simulation results. For nonoptimal operation, design instructions for one type of Class E/F3 amplifier are provided. The design specifications in this example are operating frequency, input DC supply voltage, load resistance, and peak switch voltage. Only three factors, such as operating frequency, input DC supply voltage, and load resistance, can be specified in the nominal circuit. The example procedures offered here, on the other hand, include four parameters. In the design process, other parameters such as peak switch voltage or peak switch current might be considered. The MOSFET is used to create this power amplifier. The MOSFET has been demonstrated to be a proper device from the standpoint of breakdown voltage.

2. IH System

The block diagram of the existing induction heating system is shown in the Fig1. DC is converted into high frequency AC using class-E amplifier.

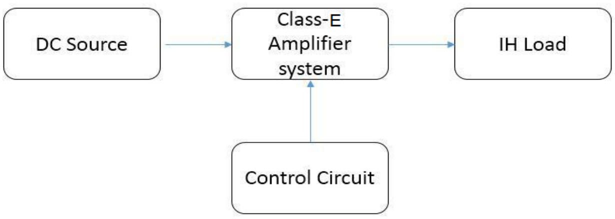


Fig -1: Block diagram of the Class E amplifier IH system

The block diagram of proposed system is shown Fig2. Low frequency AC is converted into DC using the uncontrolled rectifier. The output of the rectifier is converted into high frequency AC using the class F3 amplifier.

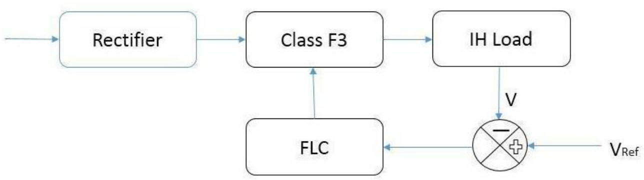


Fig -2: Block diagram of the Class F amplifier IH system

3. SIMULATION RESULTS

Class E and Class F3 amplifier systems are modelled using the elements of Simulink and the simulation results are presented in this section. The class E amplifier circuit is shown in Figure 3.1. This amplifier uses two power MOSFETs and two semiconductors. The internal capacitances of the devices are used to form resonance. The induction heater load is connected between the drains of two MOSFETs. The AC input voltage is shown in Figure 3.2. The voltage across the load is shown in the figure 3.3 and its peak value is 45 volts. The current through load is shown in Figure 3.4 and its peak value is 4.2A. The output power is shown in Figure 3.5 and its value is 248 Watts. The frequency spectrum for output voltage is shown in figure 3.6 and the THD is 3.49%.

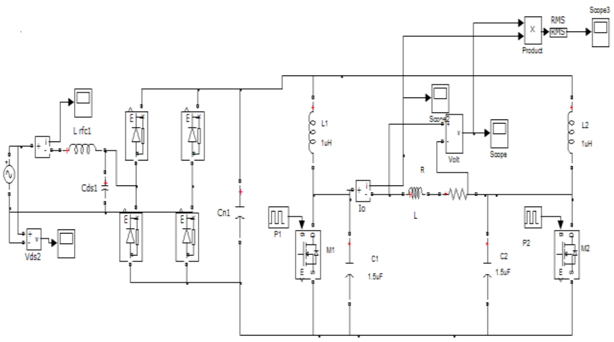


Fig 3.1: Class E amplifier system

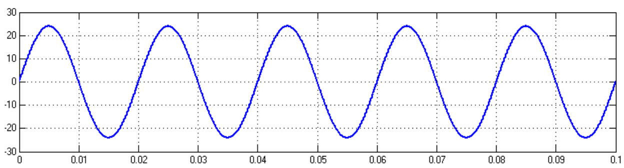


Fig 3.2: Input voltage to class E amplifier system

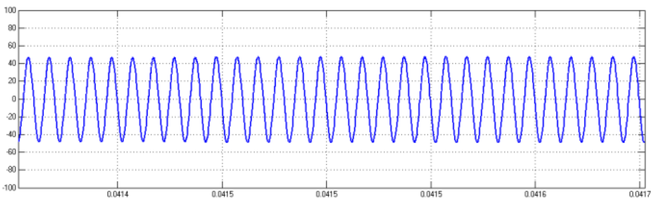


Fig 3.3: Output voltage of class E amplifier system

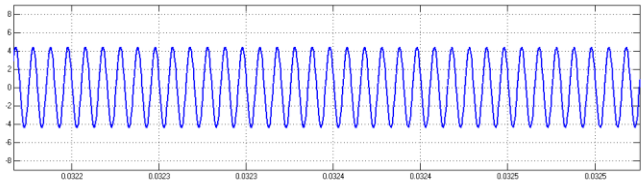


Fig 3.4: Output current of class E amplifier system

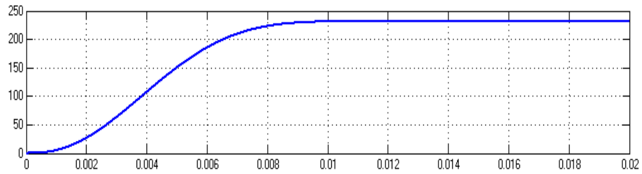


Fig 3.5: Output power of class E amplifier system

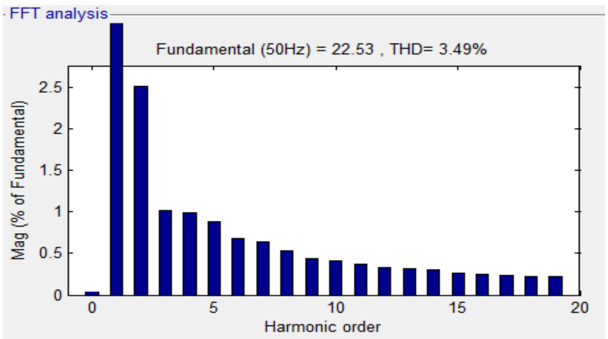
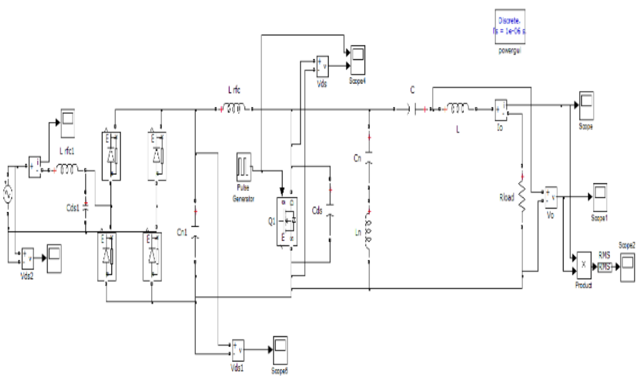


Fig 3.6: Frequency spectrum of class E amplifier system

The circuit of class F3 amplifier is shown in figure 4.1. The resonant capacitor is connected in series with the load. AC input voltage is shown in Figure 4.2 and the voltage across the load is shown in Figure 4.3 and its peak value is 450 volts. The current through the load is shown in Figure 4.4 and its peak value is 5A. The output power is shown in Figure 4.5 and its value is 700 Watts. The frequency spectrum for the output voltage is shown in Figure 4.6 and the THD is 1.1%. The comparison of performance of Class-E & Class-F3 systems is summarized in table1.



VRef

Fig 4.1: Class F3 amplifier system

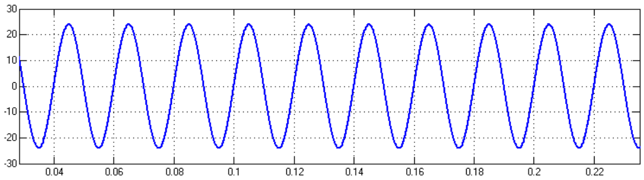


Fig 4.2: Input voltage of class F3 amplifier system

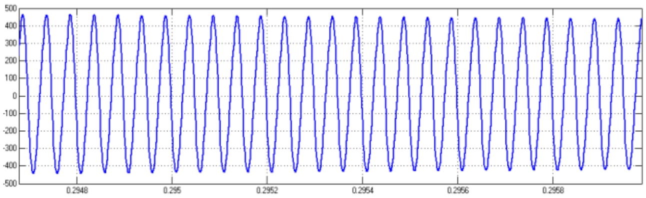


Fig 4.3: Output voltage of class F3 amplifier system

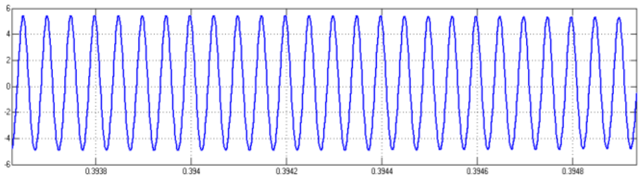


Fig 4.4: Output current of class F3 amplifier system

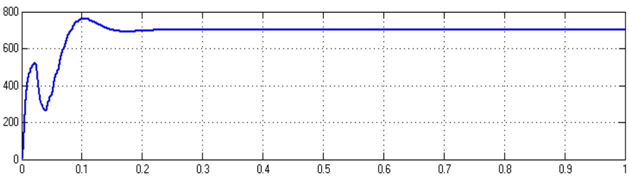


Fig 4.5: Output current of class F3 amplifier system

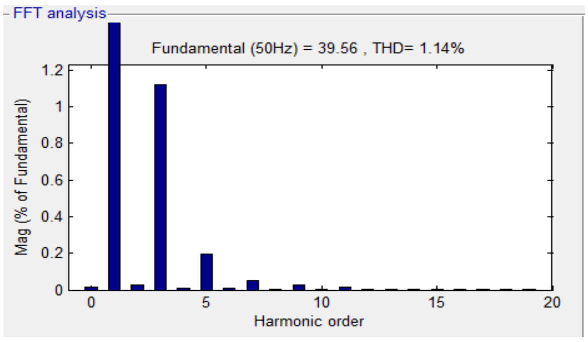


Fig 4.6: Frequency spectrum of class F3 amplifier system

Table1: Comparison of performance.

Converter	Vin	Io	Po	THD(I)
Class-E	24v	4.2A	248W	3.49%
Class-F3	24v	5.8A	700W	1.14%

CONCLUSION

Class E & Class F3 amplifier systems are successfully designed, modelled & simulated using MATLAB and the results are presented. The investigations indicate that the output power is increased by 452 Watts and THD is reduced by 2.35% in class F3 amplifier system. The advantages of the proposed system are simple power switch and simple driver circuit. The disadvantage of the class F3 is that it requires more number of reactive elements.

The scope of the present work is to compare class E and Class F3 amplifier systems. The comparison of Class D amplifier with class F3 amplifier will be done in future.

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