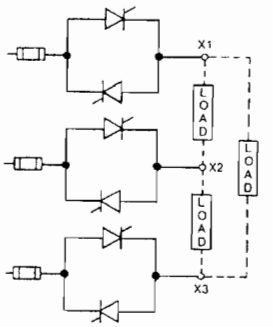
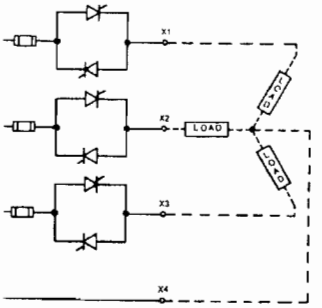
Harmonic Characteristics of Power Controlled Furnaces

INTRODUCTION

Power controlled electrical furnaces are commonly used in industrial applications. Temperature control of the furnace is typically obtained by adjusting the current supplied to the furnace heating elements by one of the following means: SCR control, saturable reactor control, or mercury contactor control. Heating elements in three phase controllers are normally connected in delta with no neutral, while single phase controllers are connected wye-grounded through an insulated neutral return wire so that each phase can operate independently. In Figure 1 the two circuits are illustrated for an SCR controller. Saturable reactors or contactors could be used in place of the pairs of SCR's. The considerations in choosing the appropriate control method include temperature control requirements, equipment reliability, equipment cost, effects on the power system, etc. This article focuses on the harmonic distortion characteristics of each type of control.



(a) Typical Three Phase Control



(b) Typical Single Phase Control

Figure 1

SCR CONTROLLED

The major types of SCR controlled furnaces include synchronous controlled, single phase (phase angle) controlled, and three phase (phase angle) controlled. Since each type of control displays a unique harmonic characteristic, they are discussed separately.

Table 1
Summary of Typical Maximum Harmonic Currents

	Harmonics (% of Full Load Current)			
	SCR Controlled		Sat. Reactor Controlled	
Harmonic	1 Phase	3 Phase	1 Phase	3 Phase
3	33.4%		24.8%	
5	14.5%	21.8%	8.5%	14.2%
7	11.2%	11.3%	4.7%	6.2%
9	8.0%		2.9%	
11	6.7%	8.7%	1.9%	3.4%
13	5.3%	6.4%	1.5%	2.2%
15	4.8%		1.1%	
17	4.2%	5.4%	0.8%	1.5%
19	3.9%	4.3%	0.6%	1.1%
21	3.3%		0.5%	
23	3.2%	3.9%	0.4%	0.7%
25	2.7%	2.9%	0.4%	0.6%

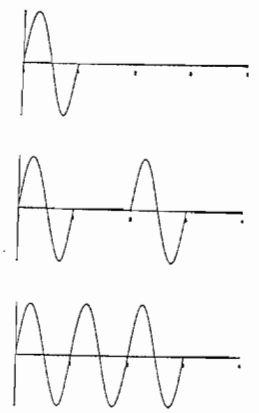


Figure 2
SCR Synchronous Control

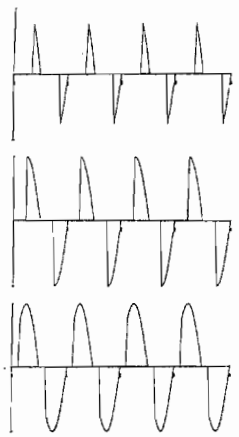
Example current waveforms of an SCR synchronous controlled heater are illustrated in Figure 2. The SCR is fired at a voltage zero crossing and conducts for an integer number of full cycles. The temperature is controlled by varying the percentage of time the SCR is in conduction. Since the SCR is fired at a voltage zero crossing and conducts for full cycles, no substantial harmonics are generated.

In Figure 3a current waveforms are given for three different firing angles for a single phase SCR controlled heater. Temperature control is achieved by firing the SCR at various phase angles which causes the SCR to conduct for only portions of a 360 degree cycle. This type of control generates appreciable amounts of harmonics as summarized in Figure 3b.

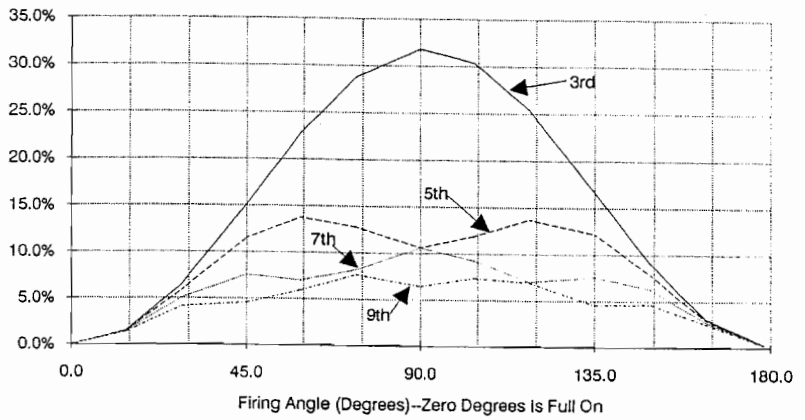
Figure 4a illustrates the current waveforms for a three phase SCR controlled heater for three different firing angles. Operation is similar to the single phase controlled type except that since the load is connected in delta, the triplen harmonics (3, 9, 15, etc.) do not occur as summarized in Figure 4b.

CONTACTOR CONTROLLED

The mercury contactor controlled furnace employs a bounce free contactor to switch the furnace heating elements on and off for specific periods of time. The operation of this furnace is similar to the SCR synchronous control illustrated in Figure 2, except that the on/off periods are generally longer (seconds as opposed to cycles). This type of furnace does not generate any substantial harmonics.

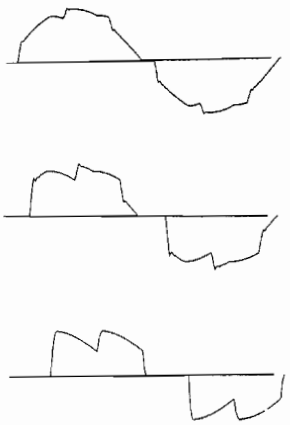


(a) Typical Waveforms

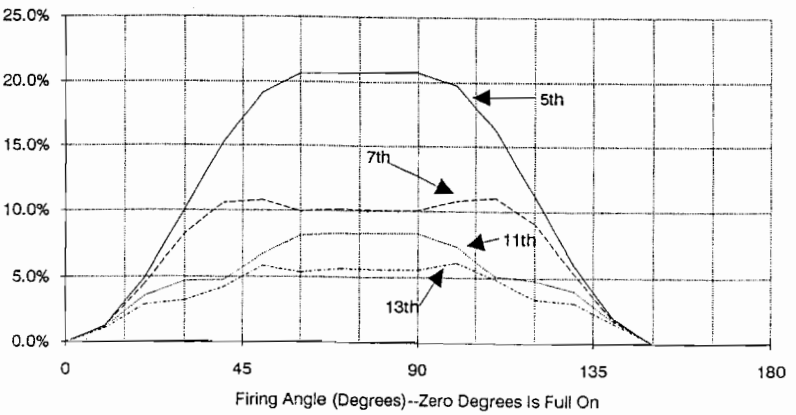


(b) Harmonic Characteristics (% of Full Load Current)

Figure 3
Single Phase SCR Controlled Currents



(a) Typical Waveforms



(b) Harmonic Characteristics (% of Full Load Current)

Figure 4
Three Phase SCR Controlled Currents

SATURABLE REACTOR CONTROLLED

Saturable reactor type furnaces are controlled by biasing a series saturable reactor to control current flow in the furnace elements. In Figure 5a current waveforms are illustrated for three operating modes of a single phase controlled saturable reactor furnace. The harmonic content is similar to that for the single phase controlled SCR type furnace. (Compare Figures 5b and 3b.)

Three phase controlled saturable reactor furnace currents are shown in Figure 6a for three different operating modes. The harmonic characteristics of this furnace are similar to that of the three phase SCR type furnace. (Compare Figures 6b and 4b.)

It should be noted that the saturable reactor furnaces generate substantially less higher order harmonics than do the SCR phase angle controlled furnaces.

CONCLUSIONS

1. Synchronous SCR controlled and mercury contactor controlled furnaces do not cause significant harmonic distortion.

2. Saturable reactor and SCR phase angle controlled furnaces generate significant harmonic distortion. (See the summary in Table 1.) These harmonics should be taken into account when applying other system equipment, especially shunt capacitors.

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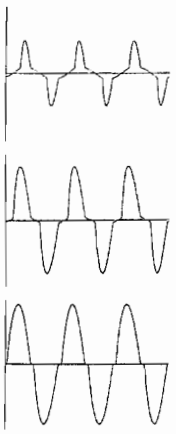
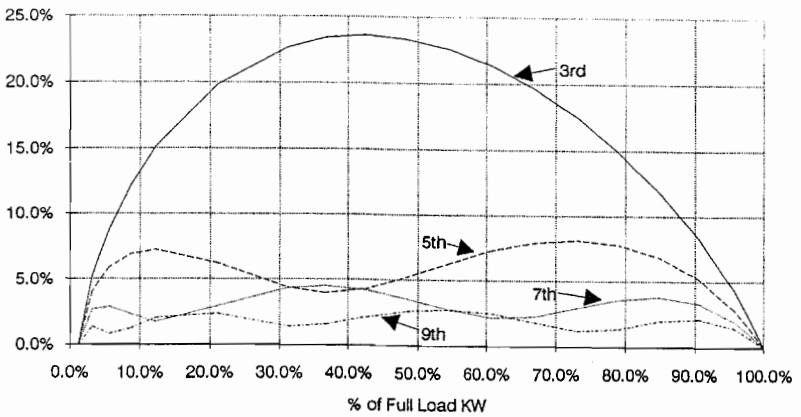
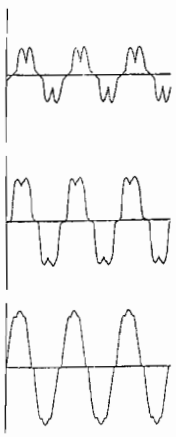


(a) Typical Waveforms

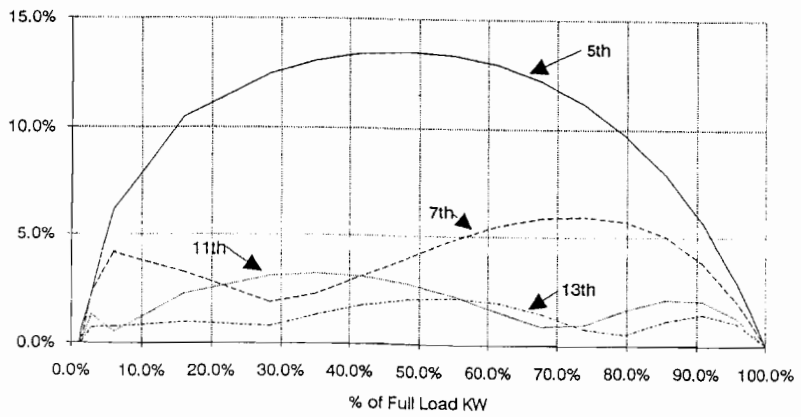


(b) Harmonic Characteristics (% of Full Load Current)

Figure 5
Single Phase Saturable Reactor Controlled Currents



(a) Typical Waveforms



(b) Harmonic Characteristics (% of Full Load Current)

Figure 6
Three Phase Saturable Reactor Controlled Currents