

# **Steady State, Transient and Harmonic Behavior Analysis of Home Appliances**

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## **Abstract**

Nowadays, a large percentage of power electronic based home appliances are connected in distribution system. It has become necessary to analyze the behavior of these loads. The steady state, transient and harmonic behavior of home appliances have been analyzed in this paper. In addition, current signature technique has been used to measure the current transient response of home appliances. The current signature technique is already found applications in identification of motor faults. The information achieved from current signatures is beneficial to power utilities, consumers and appliance manufacturers. The power factor of various home appliances was also measured and results are presented in this paper.

## **Keywords**

Home appliance; current signatures; transient state; steady state; harmonics.

## **1. Introduction**

The distribution system carries electrical power from transmission system and delivers it to various types of consumers. Various linear and non-linear based appliances are installed throughout the low-voltage distribution network. The non-linear appliances are basically power electronic converter based loads. Non-linear loads such as switch mode supplies, Uninterruptible power supply (UPS) units, compact fluorescent lamps (CFLs), fluorescent lamps, adjustable speed motor drives, CRT and LCD television sets, DVD players, desktop computers, laptops, fax machines and battery chargers etc are connected with distribution system. During last couple of years, the use of nonlinear loads have increased tremendously. Various studies have been conducted to investigate the different aspects of home appliances. Approaches like harmonic analysis (Asres et al. 2019), (Bakar 2008), (Djordjevic et al. 2018), (Ghorbani et al. 2011), (Huang et al. 2011), (Mahar et al. 2011), (Nikum et al. 2016), (Patidar and Singh 2009), (Panda et al. 2019), (Sun et al. 2011) current signatures during steady state (Bakar 2008), (Lee et al. 2004), (Hart 1992), (Sultanem 1991) Active/Reactive power signatures (Laughman et al. 2003), (Wilsun and Dong 2012) etc were used to analyze the characteristics of home appliances. In some studies, waveforms of full wave rectifiers were used to analyze the startup characteristics of domestic loads (Ting et al. 2005). The term “signature” of an appliance means the changes of voltage and current on the electrical circuit when the appliance is turned on, off or changes its states (Lia et al. 2012).

In this paper, current signatures during transient state of several home appliances are presented. The harmonic spectrum and power factor of these loads are also included in this paper. The research paper organized as follows: Section 2 describes the methodology and experimental setup. Section 3 presents the experimental results of several home appliances. Section 4 describes the comparisons of results and final section 5 includes conclusion.

## 2. Methodology and Experimental Setup

The arrangement of experimental setup is shown in Fig. 1. It consists the 43B fluke power quality analyzer, workstation with fluke view software and various home appliances. The appliances under test are energized from 220V ac source. The current signatures during startup, current waveforms during normal state and harmonics of every load were captured and analyzed by using fluke view software.

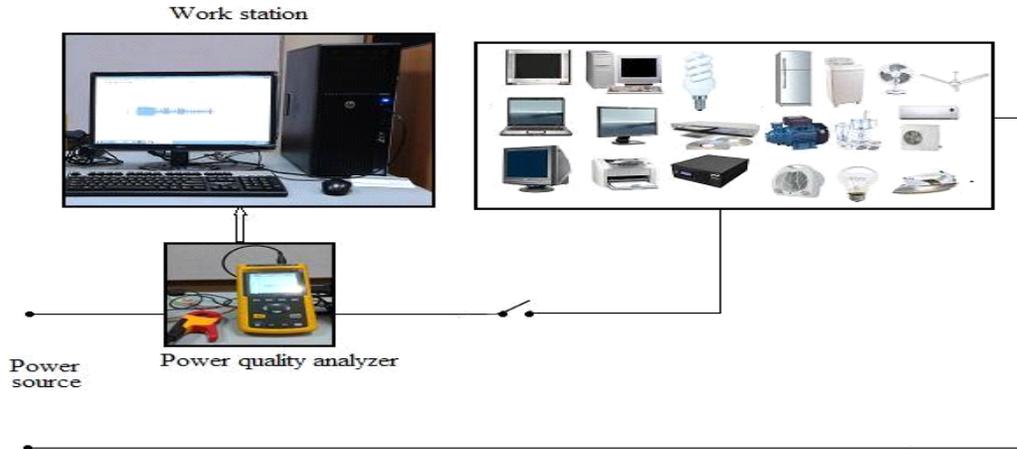


Figure 1. Experimental setup

## 3. Experimental Measurement

The current signatures and harmonic spectrum of several home appliances are presented in this section. The information from current signatures is important for smart meters which communicate the very information to power utilities. Besides, this information is much prudent for the selection of protective home devices. These devices can be fuses, circuit breakers, earth leakage circuit breakers, magnetic contactors, relays etc.

### 3.1 Current Signatures and Harmonic Measurement of Lap top

The lap top computer is one of the nonlinear load used by various consumers. The measurement results are shown in Fig. 2. The current waveform of this load is non-sinusoidal which contains harmonics.

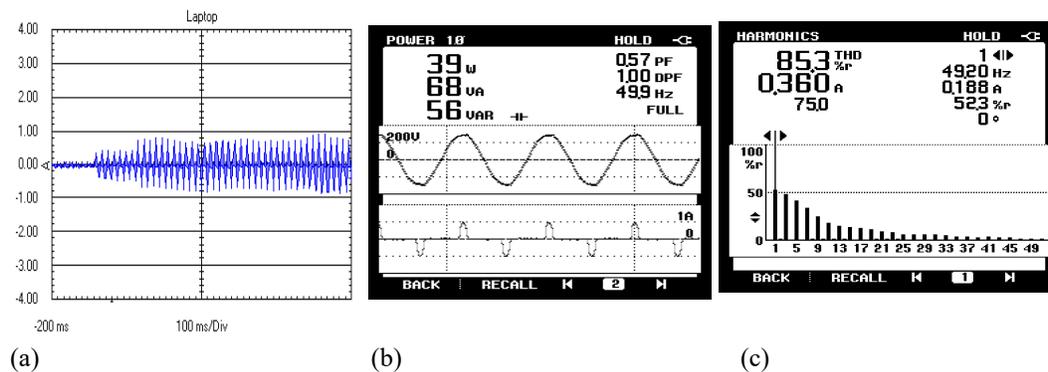


Figure 2. Results of Lap top (a) current signature (b) voltage and Current waveform (c) Harmonic spectrum

### 3.2 Current Signatures and Harmonic Measurement of Energy saver

The energy savers are generally used by various type of consumers in homes, shops, marriage halls, offices and industries. From the energy consumption point of view they are economical and consume low kWh. The current signature, voltage-current waveforms and harmonic spectrum is shown in Fig.3.

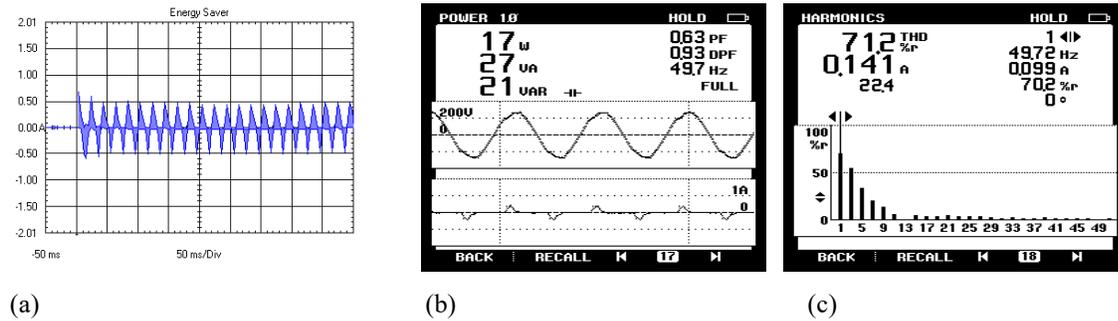


Figure 3. Results of Energy saver (a) current signature (b) voltage and Current waveform (c) Harmonic spectrum

### 3.3 Current Signatures and Harmonic Measurement of UPS

During the last two decades, Pakistan is facing daunting energy crises resulting in the frequent outages and load shedding. As a result, the use of UPS, a non-linear load, has increased tremendously. The results of this load with 12 V lead acid battery as shown in Fig.4 was captured during charging.

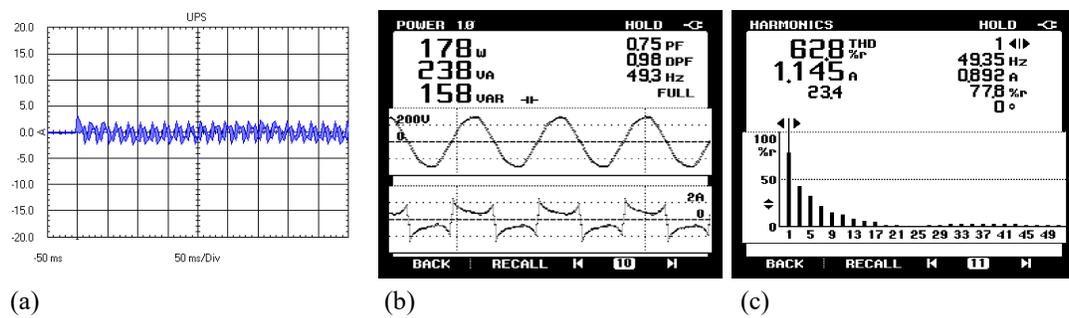


Figure 4. Results of UPS (a) current signature (b) voltage and Current waveform (c) Harmonic spectrum

### 3.4 Current Signatures and Harmonic Measurement of Desktop PC

The results of this load is shown in Fig.5. It is clear from results, the current waveform is non-sinusoidal which contain harmonics. The total harmonic distortion (THD) of this load is 68.8%.

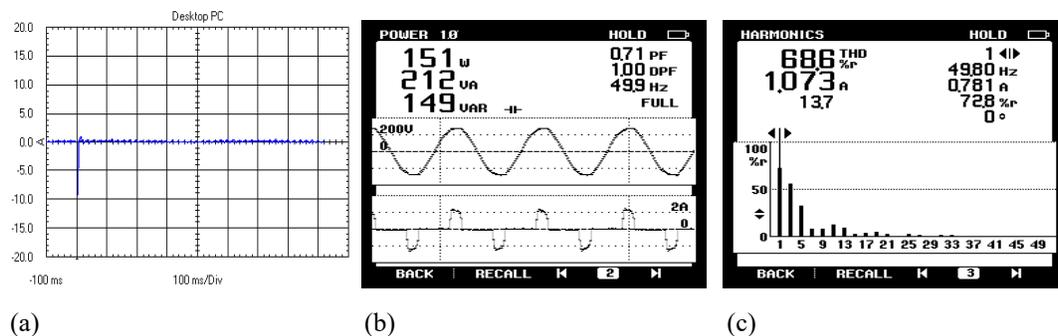


Figure 5. Results of Desktop PC (a) current signature (b) voltage and Current waveform (c) Harmonic spectrum

### 3.5 Current Signatures and Harmonic Measurement of CRT TV Set

Cathode rays tube (CRT) televisions are widely used by domestic consumers in Pakistan. This nonlinear load has high starting current and significant amount of THD. These results are shown in Fig.6.

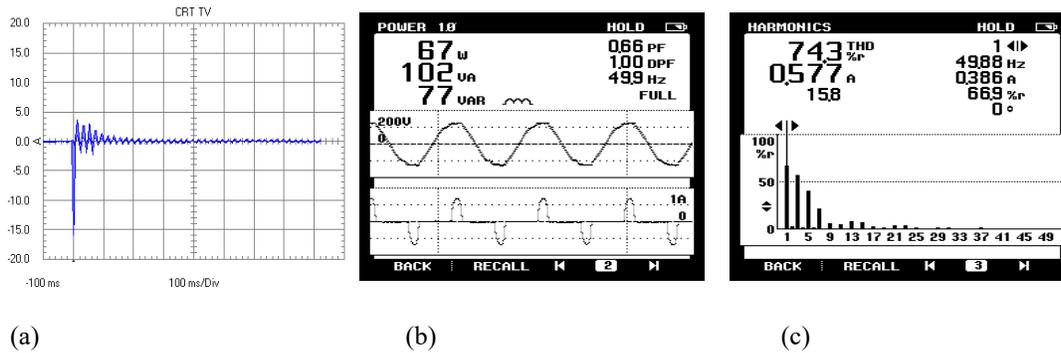


Figure 6. Results of CRT TV Set (a) current signature (b) voltage and Current waveform (c) Harmonic spectrum

### 3.6 Current Signatures and Harmonic Measurement of Split ac

In order to test single phase ac motor driven home appliances, the current signatures of these loads were captured. These appliances are considered as resistive-inductive loads. The split air-conditioner was also tested and results are shown in Fig.7. It can be seen from captured signatures that a large peak transient current appears during turn on of appliances that gradually decreases to steady state because of the increase in back EMF of the motor loads.

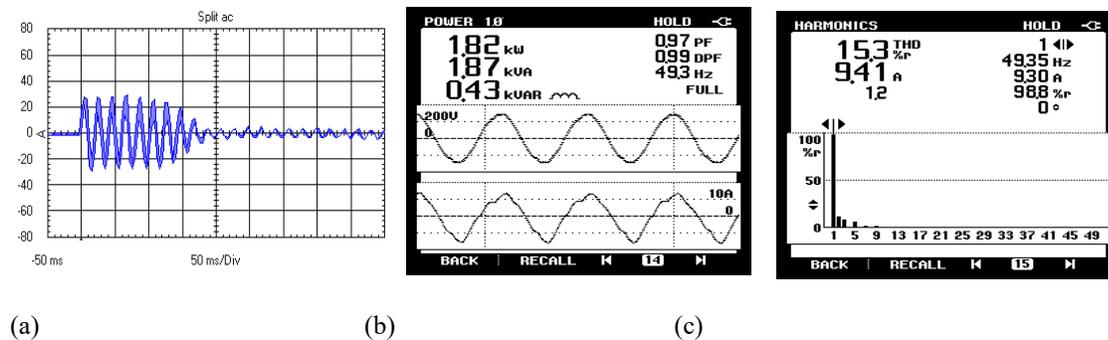


Figure 7. Results of Split ac (a) current signature (b) voltage and Current waveform (c) Harmonic spectrum

### 3.7 Current Signatures and Harmonic Measurement of Refrigerator

The use of refrigerators is very common among the domestic consumers. During the testing, it was observed that this type of load has only 8.6% of harmonics. The current signature, current & voltage waveforms and harmonic spectrum is shown in Fig.8.

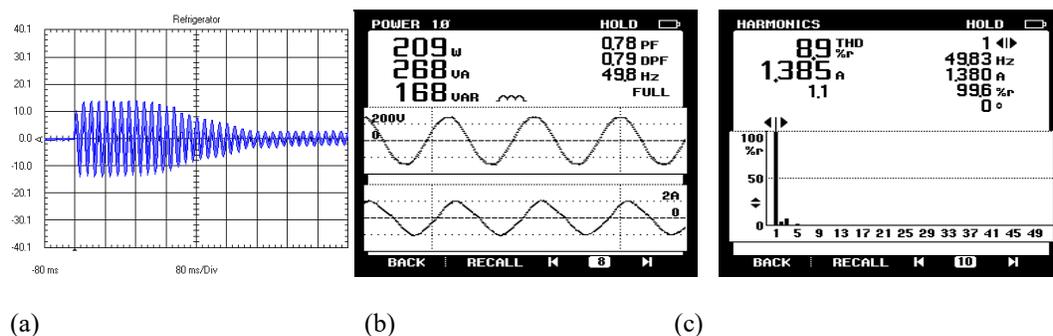


Figure 8. Results of refrigerator (a) current signature (b) voltage and Current waveform (c) Harmonic spectrum

#### 4. Result Analysis and Comparison

The comparison of inrush current, power factor, total harmonic distortion and harmonic components of various domestic appliances are recorded in Table 1. Nonlinear home appliances were also tested in this research work. The power electronic converters are widely used in home appliances because of their smart features [1]. These converters are variable structure systems and produced nonsinusoidal current when energized from sinusoidal voltage. The nonsinusoidal current of appliances generates harmonics during the operation. The harmonics and problems associated with it are of great concern to power industry and customers [1]. The comparison of harmonic components of various appliances are shown in Fig. 9. It is clear from the results that the loads such as CRT TV set, desktop computer and energy saver have highest value of 3<sup>rd</sup> harmonics. Fig.10 indicates that the lap top has highest value of THD.

Table 1. Comparison results of home appliances

Sr No	Home appliances	Inrush Current (A)	PF	THDi (%)	Harmonics (%)			
					3 <sup>rd</sup>	5 <sup>th</sup>	7 <sup>th</sup>	9 <sup>th</sup>
01	LAP TOP	No transient	0.43	85.3	48	41.8	33.6	24.6
02	Energy saver	0.68	0.63	71.2	55.4	34.2	20.7	13.9
03	UPS	No transient	0.75	62.8	42.3	32.3	22.0	15.5
04	Desk Top PC	9.3	0.71	68.6	56.1	32.9	8.8	8.0
05	CRT TV Set	15.9	0.66	74.3	56.8	40.0	21.2	5.6
06	Split AC	28	0.97	15.3	8.2	5.8	1.2	1.2
07	Refrigerator	14	0.78	8.9	7.6	1.6	1.0	0.1

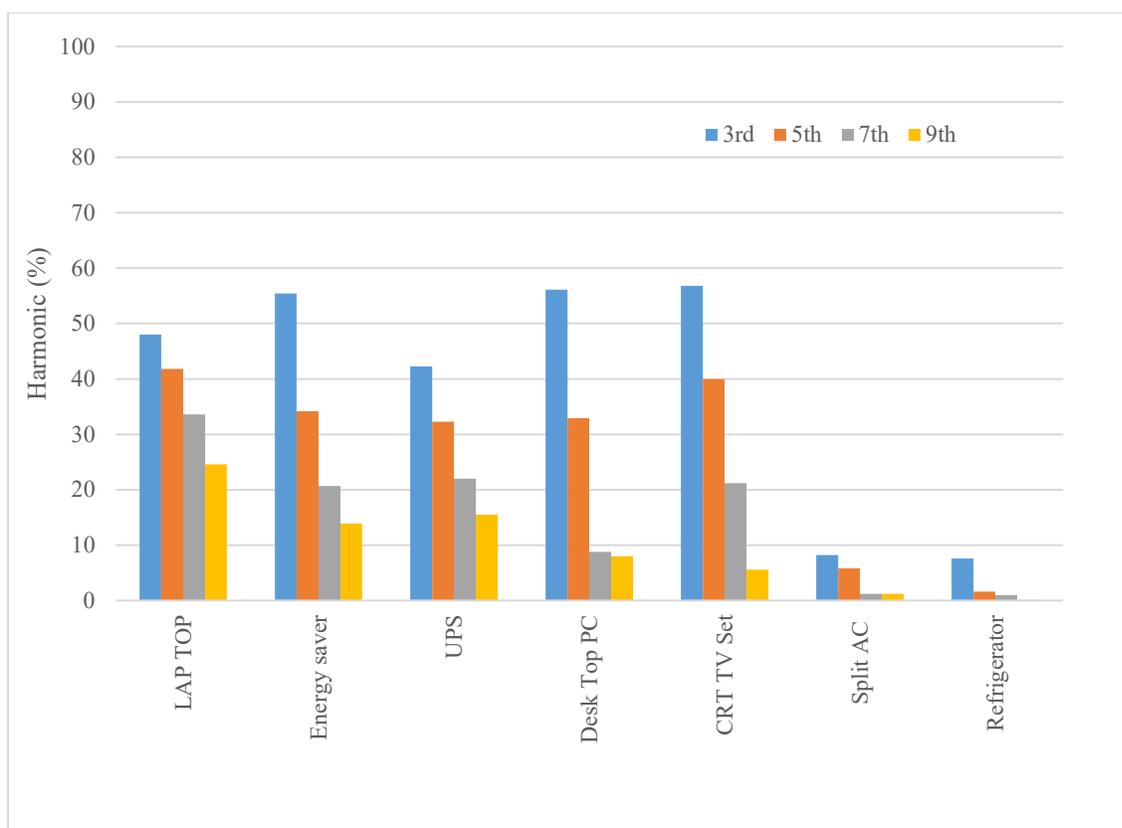


Figure 9. Comparison of harmonic components of home appliances

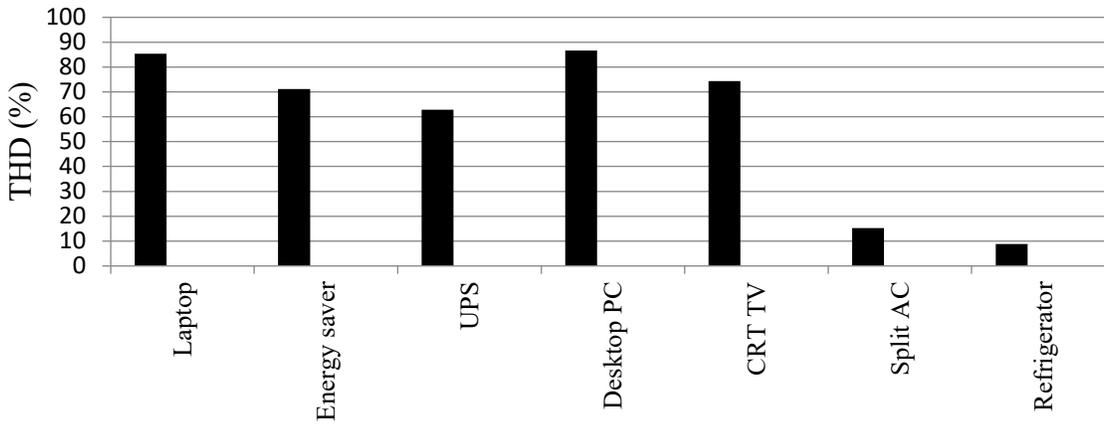


Figure 10. Comparison of Total harmonic distortion of home appliances

The inrush or transient current and steady state currents of different kinds of home appliances are shown in Fig.11. It is clear evident from the figure that UPS and laptop have no inrush current. The energy saver has slightly higher current from its normal value during start up. The desktop pc and CRT TV set has maximum transient current. The power factor of home appliances is also measured with power quality analyser. Power factor comparison of these appliances are shown in Fig.12. It can be seen from figure the laptop has lowest value of power factor among all other appliances.

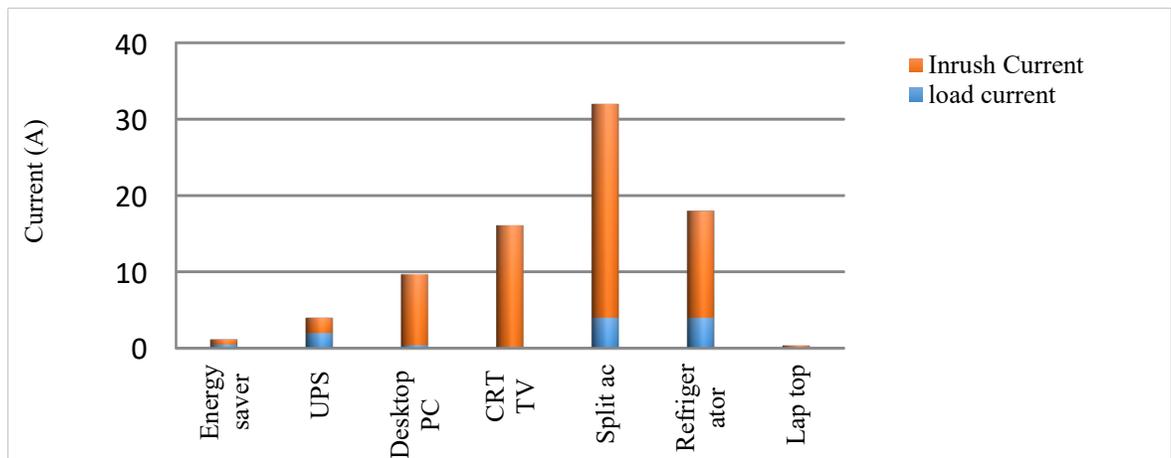


Figure 11. Comparison of transient current and steady state currents of home appliances

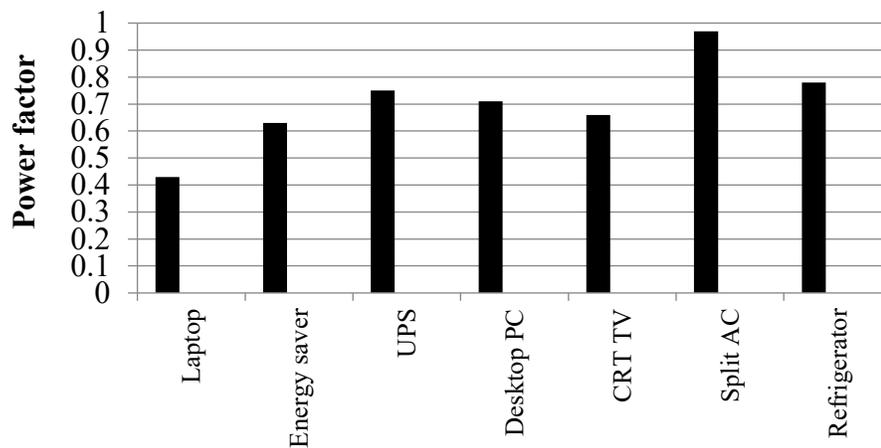


Figure 12. Power factor comparison of home appliances

## 5. Conclusion

In this work, current signatures, current & voltage waveforms, power factor and harmonic spectrum of several home appliances are presented. It is concluded from the transient results that the current signatures are distinctive for different appliances. It is also clear from the results that motor driven home based appliances loads draw a large maximum current during turn on but it gradually comes to normal within few cycles. The non-linear loads like desktop PC and CRT TV set also draw high inrush current during startup. The information achieved from current signatures of home appliances is much prudent to the power companies, supply consumers and appliance manufacturers. Moreover, this information is quite beneficial for the selection of home protective devices. These devices can be fuses, circuit breakers, earth leakage circuit breakers, magnetic contactors, relays etc. In this research work, the harmonics spectrum of various nonlinear loads were analyzed. The harmonic order and power factor of various loads are also compared. It is clear from the experimental results that the loads like laptop have low power factors and highest THD magnitude as compared to other loads. The loads such as CRT TV, desktop computer and energy saver have highest value of 3<sup>rd</sup> harmonics.

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