# Identification & Monitoring of Domestic Loads by analyzing the Different Signatures

Shoaib Ahmed Shaikh, Ghulam Akbar, Waqar Khokar, Muhammad Fawad Shaikh and Shoaib-ul-Rehman

***Abstract* – A preliminary term from practical technologies is the electric load signatures information which incorporates the recognition of types of electric load and the monitoring of its operational condition. The revolution of distribution system from a traditional grid to a smart grid has immense characteristics which have become advantageous for consumers, power utility companies, appliance manufacturers and stakeholders and have grown the vast research ways. This research work, a method in the Non-Intrusive Appliance Load Monitoring (NIALM) context focuses on the various types of domestic appliances and its nature includes current signatures (both steady state and inrush current),Power signature and harmonic signature for detection, monitoring and controlling.**

**This paper comprises of the methodology and the annotations of load signatures in different modes as operation mode or switching on mode. The current, power, power factor is measured and characteristics of wave form signatures of household appliances (motor driven or inductive loads, non-linear loads and resistive loads) are also analyzed with the help of a Fluke 43B power quality analyzer. By examining the collected results of experiments, it is decided that researchers who are involved in smart grid and manufacturers to introduce "smart meter" and the different signatures of household appliances will become advantageous for all, utilizing companies, appliance manufacturers and responsive load management.**

***Index Terms* – Domestic load analysis, IALM, NIALM, Inrush current, Harmonics, Power and Power factor.**

## I. INTRODUCTION

Power system consists of four categories as power generation, power transmission, power distribution and power utilization. The main category is power distribution which plays a dynamic role in the overall power system network, linked with various 1-phase and 3-phase types of loads (Resistive, Inductive, Capacitive etc.) depending on the requirement of consumers.

Different forms of energy exist in this world, electricity is the flexible and resourceful energy form that has made our life convenient with daily needs and it also enhances the quality of services and supplies. As the consumption is limited, and the demand is growing day by day, which has forced the power utility companies to control and monitor the domestic consumers Electricity consumption prototype. Substantial energy saving can be endowed with by household energy consumption management [1].

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At the moment, appliances are responsible and dependable of a major part of the electricity consumption bill in domestic and commercial buildings. For instance, there is 30% representation of lighting and appliance energy consumption in U.S. [2]. Appliance Load Monitoring (ALM) has become a key usage for utilization considerate and energy savings categorized as; Intrusive and non-intrusive appliance load monitoring (IALM & NIALM).

In IALM, a plug meter or an enthusiastic sensor is connected to each consumer side, which not only senses load silhouette but also detects the consumption of the power with connected load. This system is consistent and advantageous due to precision, though it's very expensive to connect one sensing device (plug meter) with every consumer and it also needs appropriate installation for electrical wiring. The other technique, NIALM follows the attainment of current signature (transient and steady state), removal and categorization of events and structures. This technique is cost-effective, and it works with an accessible electric cabling system which is used for home, but it requires multifaceted signal processing systems or algorithms [3]. In 1980, George Hart and Fed Schweppes at MIT had developed one of the earliest approaches to NIALM, which had its foundation to monitor the domestic load in housing buildings [4, 18-19].

In the past, analog energy meters were in usage and familiar for the energy consumption, a few years later digital meters were invented and became famous. Although many other pre-programmed options occur from taking out the essential data of each consumer's total energy consumption (kWh) of current and previous month, reactive power, time, however the volume of data for each consumer has increased by digital meters. In this circumstance, different methodologies of detecting the accurate load and monitoring of the energy utilization of each piece of equipment are anticipated, that are assumptions based.

New and advanced technologies are capable of a better consideration of the utilization of electric power and have assured to fortify the connection between electric utility companies and their customers [5]. The "smart meters" which can analyze and evaluate electrical load signatures for keeping an eye on the use of load and transferring of this information to the electric utility company. Electric load signature has become the backbone of practical and advanced technologies for load diagnosis, load measurement, load monitoring, power quality control, power consumption effects and power circuit design. Such knowledge of the electric load signature is beneficial for all, including utilities, consumers, regulators, equipment manufacturers and others. The utility can perk up planning, forecasting and developing new products and services such as developmental building energy audits and surveys, optimized and reliable operation and other energy services.

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Consumers get advantage of beneficial cost and improved power quality and reliability. Regulatory authorities can improve and recover the accuracy and significant policies, rules and regulations. Appliances and equipment manufacturers can advance the improved quality and compliance while foreseeing the demands of the market and supplying the most effective, well-organized and efficient products.

In this paper the current signatures of different residential appliances are represented during transient state which can be beneficial for consumers, power utilities and appliance manufacturers by taking the information regarding power quality, current scenario, harmonics, power, power factor etc. The power quality analyzer was the main tool used for capturing the steady and transient current signatures throughout the starting up of the load and the waveforms captured from power quality analyzer were examined.

## II. OVERVIEW OF RESIDENTIAL APPLIANCES

An important part of distribution side the domestic load, which has engaged the utility companies for proper designing and installation of equipment, cables, etc. The appliances have many pros and cons during starting up operation and normal conditions. The appliances, by monitoring and controlling their utility are categorized as; permanent consuming appliances which remain ON at every moment (refrigerator, AC and safety appliances, etc.), On-off consuming appliance (CFL, IL, halogen lamp, induction cooker, Fan etc.) and FSM or Finite state machine [6] in which appliance must pass through numerous specific running conditions (Mixture-grinder and washing machine). The various types of domestic loads are elaborated as:

### 2.1 Linear Loads:

Linear loads are basically conventional appliances which do not create any harmonics in current but somehow least number of harmonics is generated in the current signal offered that applied voltage waveform is pure sinusoidal. Two-dimensional signature spaces are a main source of identification of these types of loads. The examples are fans, heaters, motors, etc. [7].

### 2.2 Non-linear Loads:

The relatively new type of loads exists called Non-linear loads which are mostly power electronic based devices. High quantity of harmonics is created in these types of loads due to non-linear current which changes the shape of applied pure sinusoidal waveform. Its identification is quite complicated and difficult as compared to linear loads with two-dimensional signature spaces [7].

### 2.3 Resistive Appliances:

The commonly domestic loads are resistive (current and voltage are in phase) encompassing heating, electrical devices such as incandescent lamps, heaters, ovens, dishwater, kettle, heating elements of washing machine, etc. The resistive appliances have following characteristics: unity power factor, no any transient occurs during starting of load but in rare cases shortest transient (<50Hz period), negligible reactive power, not having any inrush current with significant amount. Hence Real power is the prime measurement for their recognition.

### 2.4 Motor Driven Appliances

These types of appliances are mostly inductive (current lags the voltage) take a large amount of current (inrush current) on switching of the load but return to normal load current after a few seconds or cycles. This category keeps vital role in household appliances includes chopper machine, fan, washing machine, water pump motor, and refrigerator, deep-freeze, dish water etc. The characteristics of these appliances are: odd harmonic numbers, circulating current produces significant reactive power in motor winding, which is wattles power return to the source, characteristics and long transient when energized.

### 2.5 Electronically fed Appliances:

This category involves non-linear loads mostly are low consumption electronically fed appliances. Applications of such type of appliances are PCs, Television, Video-recorders, LCD, UPS, CFL and Laptop etc. The characteristics in this category include harmonic components have high current spectrum, short but high amplitude of transients on switching of load.

## III. ANALYSIS BY MEANS OF TYPES OF SIGNATURES WITH APPLIANCES

Signatures keeps vital role due to their characteristics of monitoring the various appliances on load. Various researches were involved to work on the signatures for scrutinizing and examining the loads. Three types of signatures exist, i.e. power signature, harmonic signature and current signature, which is explained specially for load or electrical appliances [8]. The above three signatures are also useable in smart grid or two-way communication. Advantages occur in power system Electrocardiogram (ECG), human signature, fingerprints and voice are inimitable for all individuals similarly each residential load has an incomparable utilization prototype which may be described by its working uniqueness [9]. The technique Current Signature Analysis is familiar for identifying and diagnosing the induction motor faults represented as motor current signature analysis. This method has already been discussed by various researchers which helps the concerned workers to detect and diagnose the malfunction etc. [10-12]. The domestic load consumption behavior, with current signatures is assessed by either their signatures as steady state and inrush or transient signatures.

### 3.1 Analysis by means of Power signature:

The Power signatures are familiar due to monitoring and for identification of loads or appliances. Several residential electrical devices exist, the energy utilization pattern is changed, and consumption of power is inimitable in $\Delta P$-$\Delta Q$ horizontal [13]. Initially, this method was applied to monitor the prototype of energy consumption.


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The steady-state analysis is also used for identifying the load type and measuring the active and reactive power. The equations are given as [14]:

$$P(kw) = \sum_{k=0}^{n} P_k - \sum_{k=0}^{n} V_k * I_k \cos \emptyset_k \quad (1)$$

$$Q(var) = \sum_{k=0}^{n} Q_k - \sum_{k=0}^{n} V_k * I_k \cos \emptyset_k \quad (2)$$

Where P and Q denote the real and reactive Power, whereas V and I denote magnitudes of voltage and current correspondingly having Ø the phase difference in between them and k denotes the order of harmonic [14]. Hart brought in a way by means of their active (P) and reactive power (Q) consumption measurement obtained from the main feeding panel to desegregate each load from housing building [15].

3.2 Appliance recognition by means of their current signature:

This category illustrates the state of current by connecting single load and different types of loads connected all together. The electric appliance draws current in its normal state (steady state), the prototype to depict current for each electrical device is exclusive that works for as "finger prints" which have been using to make out process of fastidious load type, although several loads are working all at once [16]. These prototypes for current are called as "current signature", have been familiar to recognize the electrical load. Current signatures being used for recognition of loads and monitoring of loads are categorized as transient current signature and steady state current signature [17]. The appliance disaggregation technique was obtained for classifying the household electrical appliances with several characteristics like current waveform (CW), active and reactive power (PQ), Switching transient waveform (STW), Current signature's harmonic content, Eigen values (EIG) and instantaneous power waveform (IPW) [18].

3.3 Analysis by means of Harmonic signature:

Latest technological and scientific world with high speed of time has replaced all the old appliances with new efficient and cost-effective appliances as IL and CFL with LED, CRT television with flat-panel televisions i.e. LCD and LED screen. In fact, there are so many advantages by utilizing these new appliances, but there are some drawbacks of non-linearity. Each non-linear load creates harmonics and keeps bad impact on the electrical distribution system due to harmonic pollution. Harmonic spectrum of each electrical appliance or load (total harmonic distortion) is idiosyncratic which is used for monitoring purposes [19-20].

## IV. METHODOLOGY

Various domestic appliances are being used for experimental work to analyze and observe the inrush current signatures, which are commonly found in every home. The information from experimental results will be beneficial for consumers, power utilities and appliance manufacturer. The whole experiment setup consists of a PC or Laptop, Power quality analyzer and types loads. The power quality analyzer is here connected in between the load and socket shown in figure.01 with the experimental set up.

The device consists of two leads for checking the voltage (V) and quality. Current transformer (CT) is placed across the appliance with a lead having wire's diameter greater than the voltage leads. The power quality analyzer with the help of CT capture the transient (inrush) current signatures (wave form and power factor), during the switch on of the loads. These captured waveforms were analyzed on computer screen by connecting PQ analyzer with it.

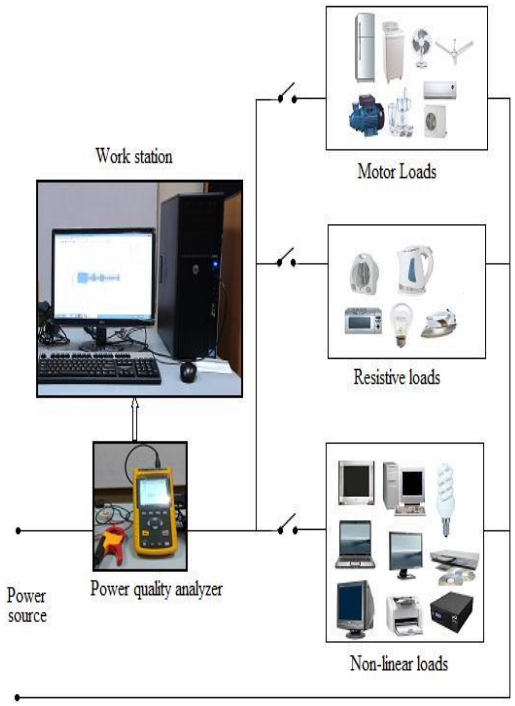


Fig. 1 Experimental setup with different loads

The formulas used for the calculation of voltage, current, power and power factor for single phase and three phase loads are given with the below relation:

$$P = VI\cos\Phi \quad (3)$$

$$P = \sqrt{3}VI\cos\Phi \quad (4)$$

Where,

P= Power (watt)
V= r.m.s Voltage (volt)
I= r.m.s Current (ampere)
CosΦ = Power factor

In addition to above experimental set up, the whole research work is also represented in the form of flow chart shown in figure: 4.2, which clearly shows the all characteristics of the domestic load monitoring.


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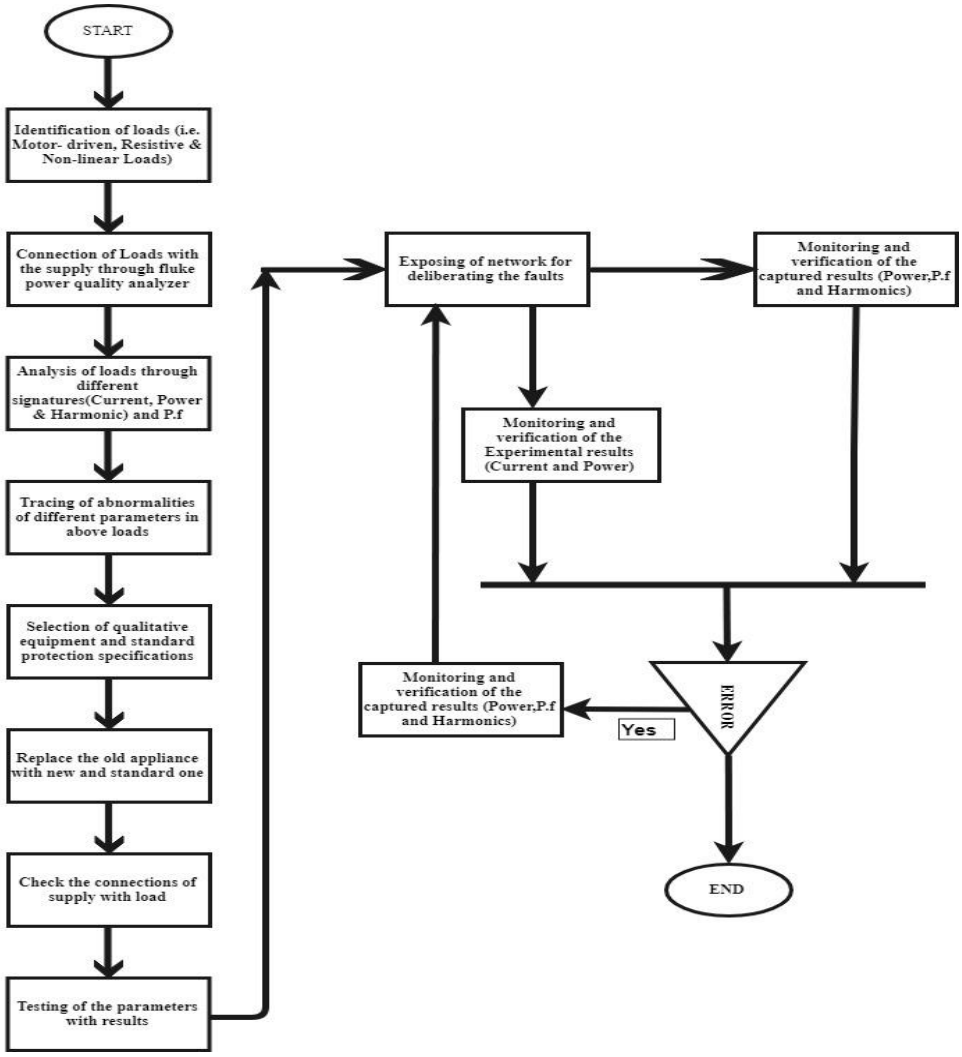


Fig. 2 Flowchart of the whole work

## V. EXPERIMENTAL RESULTS

This session elaborates the profile of different types of loads used in house. The profile shows various features of appliances as current, power, power factor, harmonic spectrum, etc. A bar Chart shows the current signatures of all types of loads in the last of this session.

### 5.1 Motor Driven Appliances

This category, having familiarities due to its lot of applications in the household appliances, plays major role in the distribution system. The motor load converts electrical

Energy into mechanical energy, having an occurrence of phase difference because the current lags the voltage. Circulating current in the motor winding produces reactive power (VAR) or wattles power that gets better to the source. Many motors driven appliances such as refrigerator, chopper machine, fan, and water-pump motors has facilitated our needs and are common in our daily life. The captured pictures and table of different inductive loads are attached here, which shows the performance of current and other parameters.

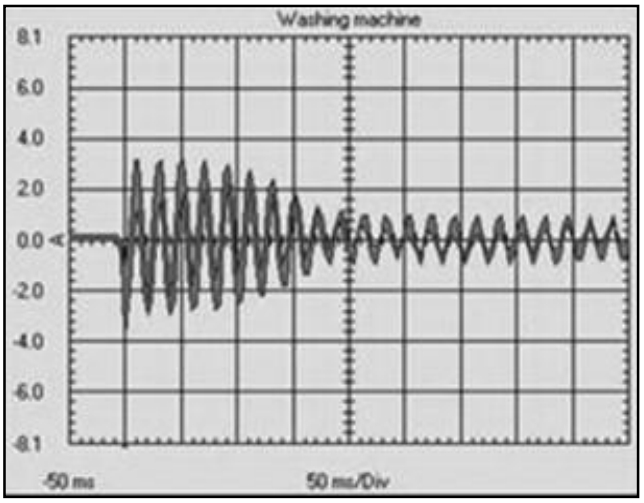


Fig. 3 Washing Machine


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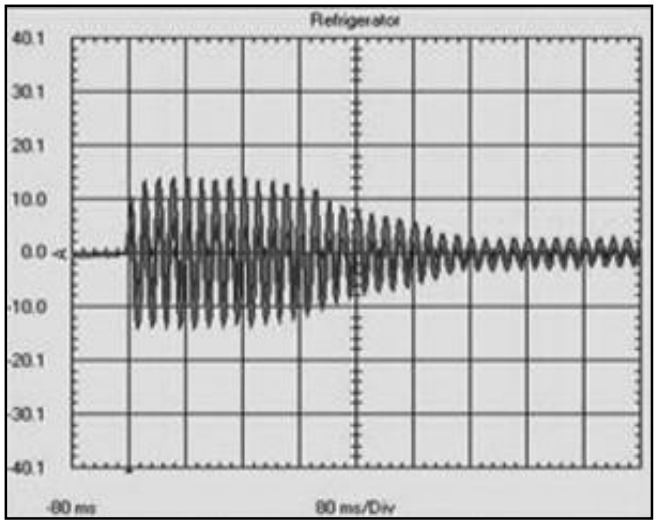


Fig. 4 Refrigerator

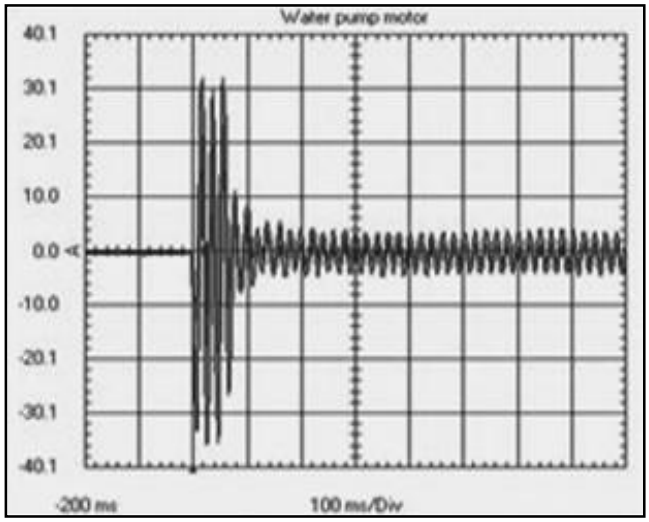


Fig. 5. Electric motor

After obtaining the all results shown in above figures and table-I it is précised here that when we initially energize the motor driven appliances (inductive load), they take a large amount of starting current (an inrush current) which decreases to full load running current after a few cycles or milliseconds. All the above-mentioned motor-driven loads, i.e., washing machine, refrigerator, electric motor, ceiling fan and split AC have almost same signature of current due to inductive nature.

TABLE I. MOTOR DRIVEN APPLIANCES:

| S. No | Types of Loads | Inrush current (A) | Inrush Current (m-second) | Steady State Current |
|---|---|---|---|---|
| 1 | Washing Machine | 3.2 | 150 | 1.0 |
| 2 | Refrigerator | 14 | 400 | 2.8 |
| *3* | Electric Motor | 32.1 | 100 | 4.0 |

5.2 Resistive Load

Resistive loads having voltage in phase with the current consume active power and maintains power factor which is advantageous and beneficial for the power system network. However, dissipation of power is in resistive loads. Power factor plays major role in electrical power system which not only affects the cost but other essential factors also.

The current profile or signature of resistive loads is taken during the process of monitoring. The apprehended signature specifies that the peak inrush current is identical to its normal steady state limit in almost all resistive loads as electric kettle and electric iron except microwave oven due to its resistive nature. A microwave oven that heats the food by waves having resistive and heating nature showed slightly higher inrush current value from its normal or steady state current value during its energizing or starting up of an appliance.

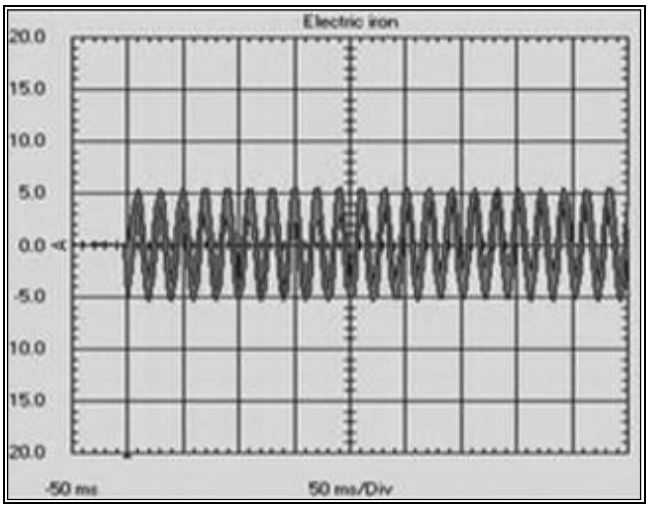


Fig. 6 Electric iron


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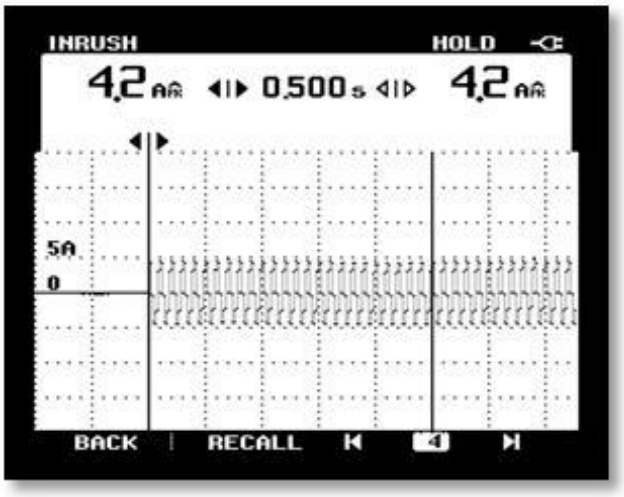


Fig. 7 Microwave oven

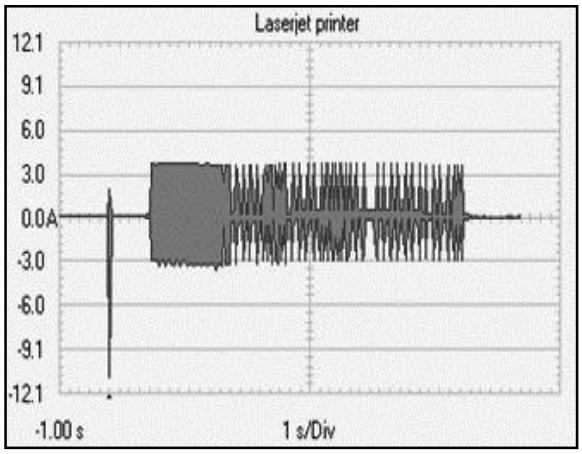


Fig. 8 Laser Print

After capturing the resistive loads' practical results, it was summarized that when we switch on the resistive loads, current rises quickly to its normal steady state value and remains same till the switching offload without first increasing to a sophisticated value likewise in inductive loads which then remains same up to the switching of the load. Another thing is also observed during the experiments that the power factor remains unity or close to unity due to its resistive nature which clarify here that the current is in phase with the voltage or sinusoidal. Though, these types of load can also be recognized by further electrical features and techniques as P and Q consumption difference.

5.3. Non-Linear Loads

Commonly known and harmonic pollutant loads have led other types of loads in our daily life due to its compact size, cost, shape and other features. These types of loads are familiar in worldwide due to its major advantages, but it generates harmonics which are harmful for power system network and kept bad impact.

CFL being efficient lamp among other lighting loads, LCD, Printers have the major drawback due to non-linear in nature. These types of load have a low power factor as shown in figure and obviously current is out of phase with the voltage. The current signature of the CFL, LCD, Printer, is also captured which shows the current is high on switching on during the first few cycles as shown in figure and table-II. The printer has lowest power factor value as compared to other non-linear loads, which causes the conductor to draw more current and eventually conductors being heated affects the power quality and is harmful to the power system.

The LCD and Laptop having non-linear characteristics show the odd harmonics; even harmonics are cancelled out in the harmonic spectrum. The total THD of LCD screen is 78.8% and Laptop is 83.5%, which is harmful to the power system network. UPS is familiar due to continuity of emergency power supply when utility power fails. When UPS is starting to bypass the main supply, it is observed here the current signature and the harmonic signature, which indicates the current as slightly higher from its steady state during the first few cycles.

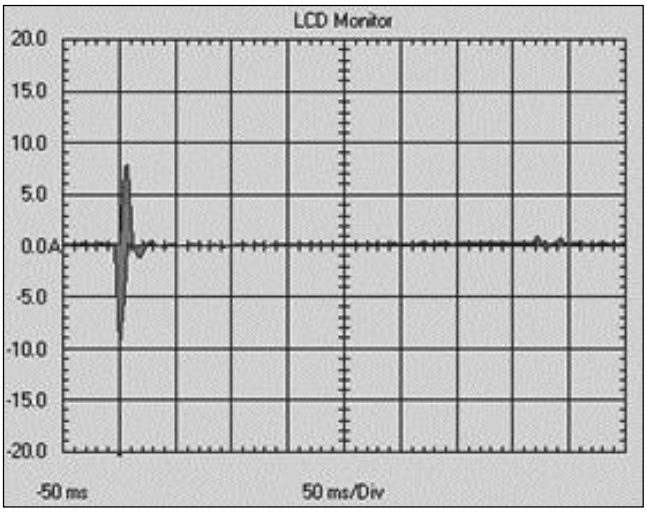


Fig. 9 LCD Monitor

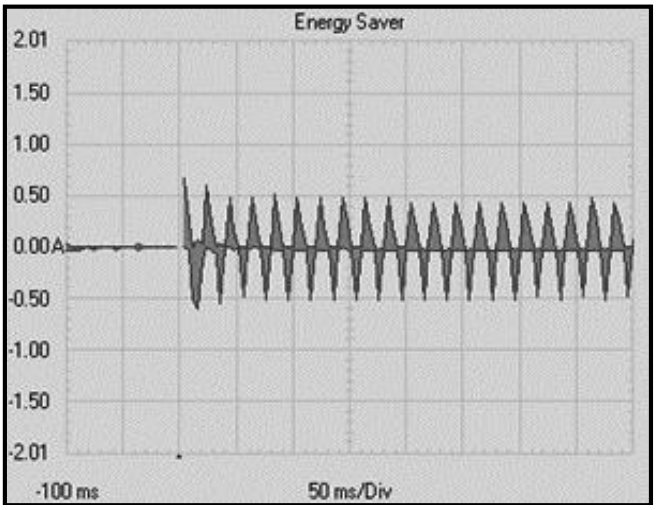


Fig. 10 Compact Fluorescent Lamp


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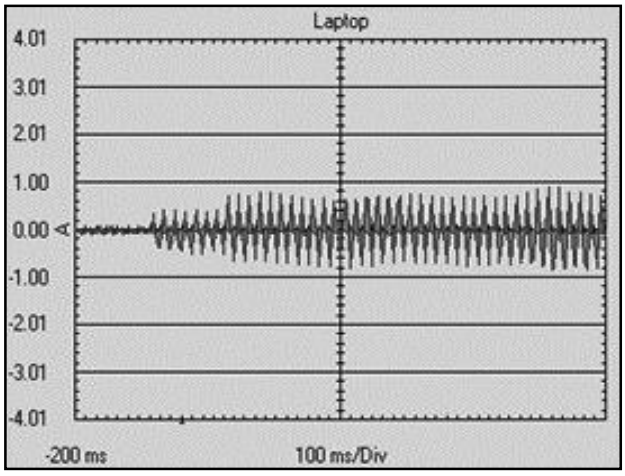


Fig. 11 Laptop

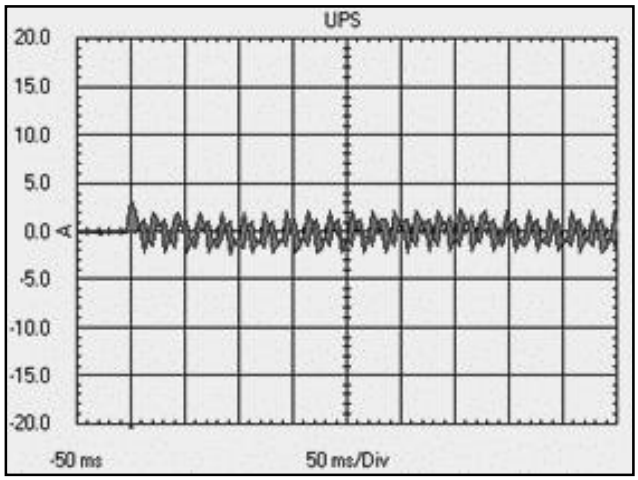


Fig. 12 Uninterrupted power supply (UPS)

TABLE II. NON-LINEAR LOADS

| S.NO | Types of Loads | Inrush current (A) | Inrush Current (m-second) | Steady State Current |
|---|---|---|---|---|
| 1 | LCD Monitor | 10.1 | 20 | 0.2 |
| 2 | Laptop | 0.76 | 60 | 0.44 |
| 3 | Laser Jet Printer | 11.1 | 0.1 | 3.8 |
| 4 | UPS | 3.4 | 10 | 2.0 |
| 5 | CFL | 0.68 | 0.1 | 0.48 |

It is perceived and concluded from the obtained practical outcomes of non-linear domestic appliances or harmonic pollutant loads, that each nonlinear load has inimitable current signatures on starting up or when switched on first. The UPS and Laptop haven't any transient current during the initial switch on. But, energy saver has somewhat greater value from its normal range. The other non-linear loads such as CRT televisions, LCD monitors, Laser printers and CRT monitors have a large value of inrush currents throughout starting up (first few cycles) for short intervals.

After the elaboration of all categories of load, the bar chart has been depicted below which spectacles household appliances' inrush currents in %age form. In the bar chart, Steady stat current is represented by Blur color while inrush current is represented by Red color. It is clearly seen in the following figure.5.3.6. that the household appliances have different percentage value of steady state along with inrush current due to different nature of load.

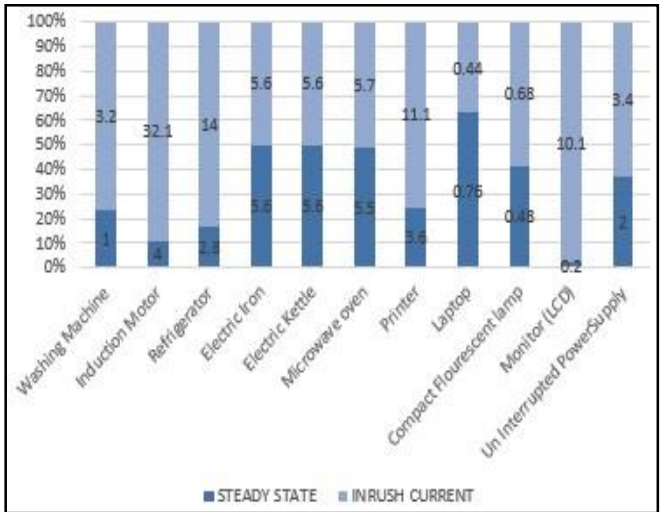


Fig. 13 A bar chart of domestic appliances

5.4. Power factor of domestic appliances:

Power factor which is equal to cosine of angle between voltage and current or active power (P) to apparent power (S) ratio, depends upon the load type (Resistive "R", inductive "L" and capacitive "C"). Each type of load has different characteristics and features. In a purely resistive load, V is in phase with I and real power is consumed. Whereas, in load then in second phase go back to the power source. In reactive loads (Inductors and capacitors) energy is stored in the load which then shows effect in a time difference or in their Voltage V and Current I in the wave form. The bar chart in figure.5.4.1 depicts the power factor of household appliances as split AC, Motor, Refrigerator, Machine, laptop, printer, ceiling fan, etc. From the results shown in the bar chart, it is observed that motor having the inductive nature has decreased the value of power factor (P.F) value i.e. 0.32. Among the domestic loads being taken during the experiment. The value of resistive loads is unity due to resistive nature as Electric kettle or electric iron and printer for non-inductive loads have the smallest value of power factor among the category of non-linear loads.


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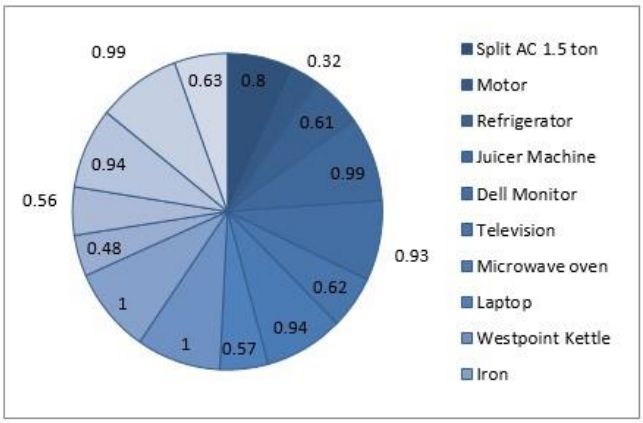


Fig. 14 Power factor of domestic appliances

## VI. CONCLUSION

Several appliances were being taken under consideration and testing. Their results as transient or inrush current, harmonic and power signatures are existed. These types of signatures are essential to manage the load for users and power utility companies.

It is observed from verified practical outcomes that inrush currents of resistive loads are almost identical as steady state or normal current. In some cases, the inrush current is somewhat higher than steady state current and reaches to normal range after few cycles i.e. IL and microwave oven. It is found from the results of inductive loads or motor driven appliances that large peak inrush current is existing and in greater range on switching on of loads, but it slowly reduces to normal or steady state in short time. After the observation of consumption prototype and signatures of several domestic loads, it is précised that current signatures of non-linear domestic loads are idiosyncratic for different types of load. The applications like CRT televisions, CRT monitors, Liquid crystal display monitors and laser printer contain large inrush current for a small interval throughout switching on or starting up state. The statistics regarding the transient or inrush current signatures is significant for appliance manufacturers, consumers and utility companies while designing the protection scheme for home appliances as CBs, fuses, relays, contactors, meters etc.

From the power signature it is also observed here that value of power factor is very low in motor-driven loads, unity and nearly equal to unity in resistive loads and slightly less than unity in non-linear loads.

It is observed from harmonic pollutant or non-linear loads that LCD and Laptop show the odd harmonics; even harmonics are cancelled out. The total harmonic distortion of the LCD screen and laptop is 78.8% and 83.5%, which is worst for power system network and power quality.

We will extend our work in future which will be on the comparison of the power quality parameters results through PQ analyzer and CRIO.

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