Modified Nonintrusive Appliance Load Monitoring For Nonlinear Devices

Mahmood Akbar, Dr Zubair Ahmad Khan
Electrical Engineering Department
University Of Engineering & Technology Lahore , Pakistan
Zubair.khan@kics.edu.pk,mahmood94@gmail.com

*Abstract*__**NIALM is a modern technique to know load profiles of individual appliances by monitoring the whole load at a single point by one recording device[5]. Each appliance has its own characteristics which results in a unique magnitude and sign in active and reactive Power as well as have unique frequency spectrum when it is switched on. Existing technologies use two dimensional signature space of real and reactive Power (ΔP-ΔQ Plane) for house hold appliances , while a three dimensional space with axes denoting real power ,reactive power and third harmonic is used in buildings for load monitoring[1]. During last decade , low cost power electronics devices and their efficiency have resulted into their increased use in household appliances, examples of house hold appliance using these devices are CFL , electronic chokes , AC inverter fed motors in washing machine, vacuum cleaner and appliances using variable speed motors etc. These devices are highly nonlinear which results in increased harmonics. These harmonics are used for load identification This research is focused on monitoring and analyzing current harmonics.. Then based upon analysis, frequency domain spectrum is used in combination with real and reactive power to identify nonlinear loads. So this research is focused on the development of appliance signature in frequency domain and time domain both In this way nonlinear devices are also identified. For this purpose current of CFL ,Dimmable fan , dimmable light are observed and their FFT is analyzed. After developing signatures, algorithm is also proposed for identification so that we could use it in real time applications.**

I. BACKGROUND AND EARLY APPROACHES

One of the earliest approaches to nonintrusive monitoring, developed in the 1980's at MIT by Professor Fred Schweppe and Dr. George Hart, had its origins in load monitoring for residential buildings. Under Dr. Hart's ingenious scheme, the operating schedules of individual loads or groups of loads are determined by identifying times at which electrical power measurements change from one nearly constant (steady-state) value to another. These steadystate changes, known as events, nominally correspond to the load either turning on or turning off, and are characterized by their magnitude and sign in real and reactive power. Recorded events with equal magnitudes and opposite signs are paired to establish the operating cycles and energy consumption of individual appliances[3].

The 1999 CAP article [2] describes a five-step process for load disaggregation through the detection of changes in aggregate power consumption. First, an edge detector is used to identify changes in steady-state levels. Second, a cluster analysis algorithm is used to locate these changes in a two-dimensional .signature space. of real and reactive power (ΔP-ΔQ Plane). The signature space reduces the potentially complicated load transient data to a two-dimensional space of changes in power consumption with a pleasing and useful graphical interpretation. Third, positive and negative clusters of similar magnitude are paired or matched (especially for .two-state. loads that turn on, consume a relatively fixed power, and turn off). In a fourth step known as anomaly resolution, unmatched clusters and events are paired or associated with existing or new clusters according to a best likelihood algorithm[1]. In the fifth and final step, pairs of clusters are associated with known load power consumption levels to determine the operating schedule of individual loads. This step uses information gathered during a training or survey phase in the building. This five-step approach to nonintrusive load monitoring has the advantage of making intuitive sense, and has been demonstrably successful in certain classes of buildings, such as residences. There are a number of limitations of the technique of examining steady-state changes in a signature space.

The two-dimensional signature-space technique relies on assumption that limit its effectiveness. The assumption is, that different loads of interest exhibit unique signatures in the ΔP-ΔQ Plane . which may not be true Because First of all Loads are increasing with the passage of time which result in congestion in ΔP-ΔQ Plane. Secondly Voltage variations results in overlapping of Loads in ΔP-ΔQ Plane. Third problem is, that nowadays electronically fed appliances are getting popularity, These devices use power electronic inverters or dc/dc converters which produce rich harmonics in current waveform and in order to regulate their output power they use variable width pulses , width of these pulses vary due to two reason first reason is when input supply voltage varies then in order to regulate their output voltage these converters increase input current pulsewidth and vice versa . Second reason is when their output power requirement increases while the supply voltage is fixed then in order to regulate their output voltage these converters increase input current pulsewidth and vice versa. The problem in these devices is that their position in ΔP-ΔQ is not fixed rather their real and reactive

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power varies with the appliance voltage variation and their output power requirement variations. So two dimensional signature space would not be sufficient in order to identify nonlinear loads . In order to identify all loads with a reasonable accuracy there is a need to develop a modified technique for load identification.

II. PROPOSED TECHNIQUE FOR MONITORING

Home appliances can be divided into two categories

A. *Linear Loads*

These are conventional appliances like heaters , fans , motors etc These appliances does not produce harmonics in current or very low amount of harmonics are produced in current signal provided that the applied voltage is a pure sinusoid .These devices can be easily identified using two dimensional signature space[2] .

B. *Nonlinear Loads*

This category of appliances is relatively new. These are the appliances which use power electronic devices. These appliances are called nonlinear appliances because when we apply a pure sinusoidal voltage waveform across these devices they produce very nonlinear current which is rich in harmonic current[2] . Identification of these devices is relatively difficult in two dimensional signature space .

Nonlinear devices rich harmonic current is used in this research to identify these devices. As it is difficult to save harmonic current waveform for each appliance because it would result in usage of a lot of memory so proposed scheme is to store frequency spectrum for signature development. In this research FFT of different appliances is analyzed. In real time application when a device will switch on it would produce an incremental change in current waveform this incremental change would also produce increment in real and reactive power. After getting this incremental change in current its frequency transformation would result in a unique signature. Now first of all based upon real and reactive power we can identify the area in two dimensional signature space which corresponds to this device then in order to identify device, Actual frequency spectrum of device would be compared with frequency spectrum of the devices in that particular area of graph. And using maximum likelihood algorithm we would be able to identify actual device.

Linear devices would have little harmonic in their current waveform so with this additional parameter of frequency spectrum their identification accuracy would also increase.

III. MAIN TYPES OF HOUSEHOLD APPLIANCES

A. *Resistive Appliances*

They form the largest category, encompassing:- heating appliances such as panel heaters, cookers, ovens, etc , heating elements of the washing machine, dishwasher or other complex appliances, incandescent lighting. These appliances are characterized by: zero reactive power, no transient when switching on, or a very short transient (lower than the ***50* Hz** period), absence of harmonic components of the current. Active power is therefore the principal measured value used for their identification.

B. *Pump Operated Appliances*

These are electric motors driving a pump. Several electrical household appliances enter this category, in particular: refrigerator, deep-freeze, dishwasher and washing-machine drain pumps etc. These appliances are generally characterized by: substantial reactive power, long and characteristic transient when switched on, odd-numbered harmonic current.

C. *Motor Driven Appliances*

This category encompasses the other appliances bearing an electric motor such as a washing-machine, fans or various types of mixers. These appliances differ from pump-operated appliances by their generally less substantial switching on transients.

D. *Electronically fed Appliances*

This category comprises low consumption appliances such as televisions, video-recorders, personal computers or High Fidelity equipment. They are characterized by: short but very high amplitude switching on transient, a current spectrum rich in harmonic components.

E. *Electronic Power Control Appliances*

This category includes various appliances which are increasingly encountered everyday, such as halogen lights, some convectors, some vacuum cleaners or some cookers. Their characteristics generally vary with the power level at which they operate.

F. *Fluorescent Lighting*

This type of lighting is characterized by: a long two-step switching on transient, very high generation of the third harmonic of the current, substantial current-voltage phase shift.

IV. MEASUREMENTS AND OBSERVATIONS OF DIFFERENT NONLINEAR LOADS

One of nonlinear load in household appliances is CFL. Current waveform of CFL is shown in figure below and also its FFT is shown.it is observed that frequency transformed waveform of CFL made by different manufacturers is almost same. Magnitude of the harmonics increase with CFL wattage almost linearly. current waveforms of different nonlinear loads observed and are shown below.

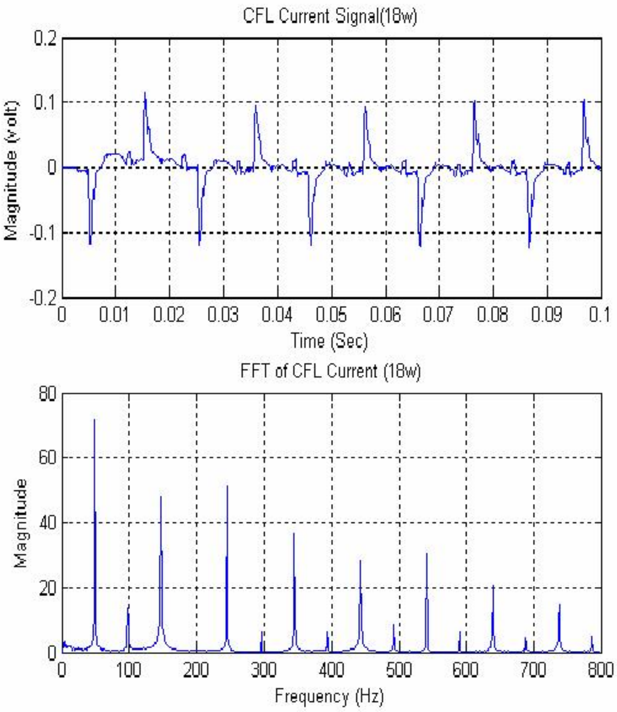

Fig. 1. Compact Fluorescent Lamp Current Signal Plot in Time and Frequency Domain

From above figure it can be seen that CFL is a highly nonlinear device and it has a unique frequency spectrum. It is observed during measurement that mostly CFL behave in the same way and exhibit almost the same waveform in time domain and frequency domain both with a very little variation. Nowadays CFL is the mostly used lighting load in household.

Another load which is observed is Light dimmer which operates on the principle of change in firing angle of triac to adjust its light. Current waveforms are shown below for Light dimmer both in time domain and frequency domain as below.

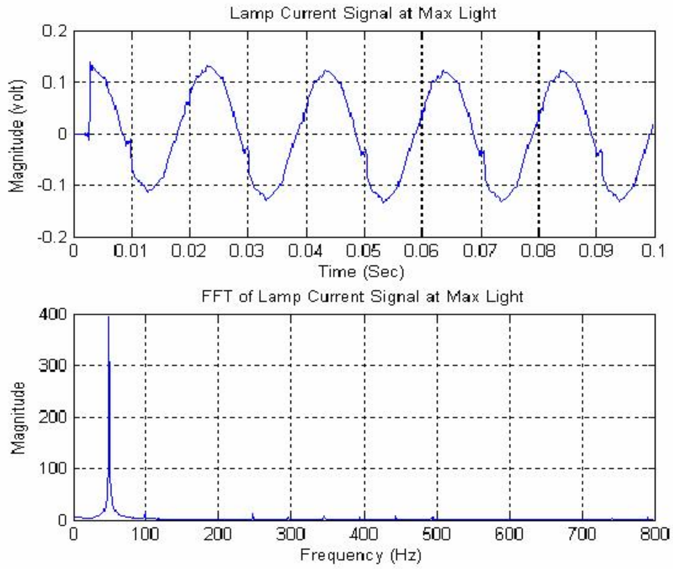

Fig. 2. Lamp Dimmer Current Signal Plot in Time and Frequency Domain when Light is at Full Glow

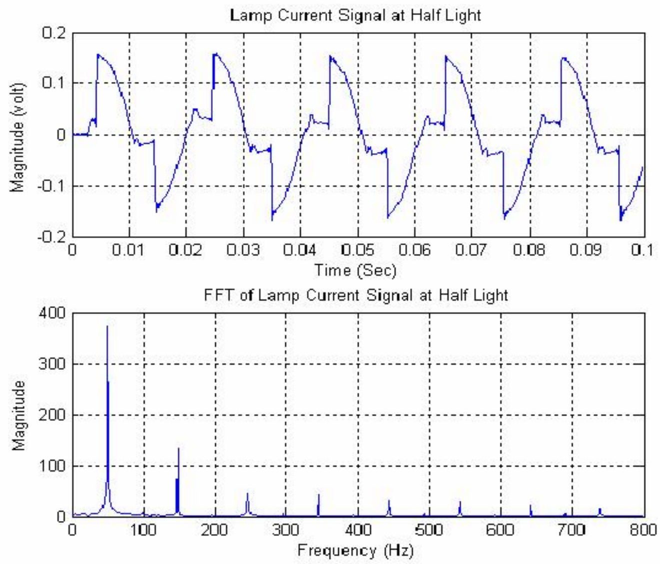

Fig. 3. Lamp Dimmer Current Signal Plot in Time and Frequency Domain when Light is at Half Glow

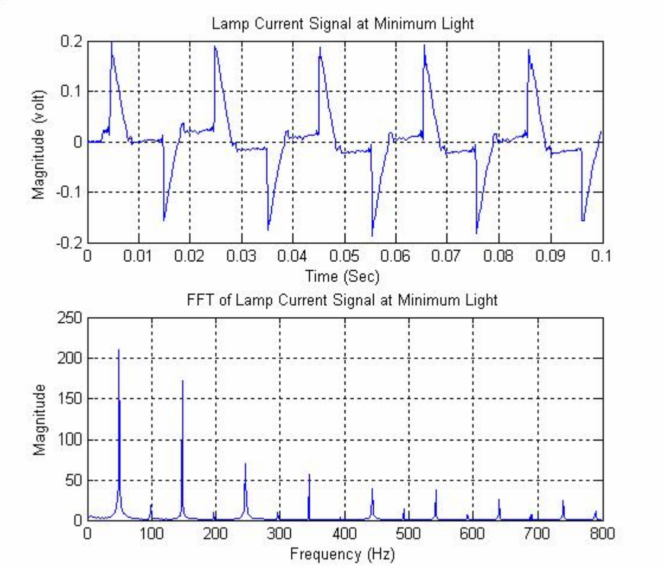

Fig. 4. Lamp Dimmer Current Signal Plot in Time and Frequency Domain when Light is at Minimum Glow

From above figures it is clear that FFT plot of CFL and Light dimmer is different . But for further identification accuracy we would in first step go for real and reactive power in order to find region in two dimensional plane for the appliance and then in second step we would go for FFT comparison to identify device accurately.Same dimmer is used in fans for speed control Now we will observe waveforms of fan current and its FFT .which are given below.

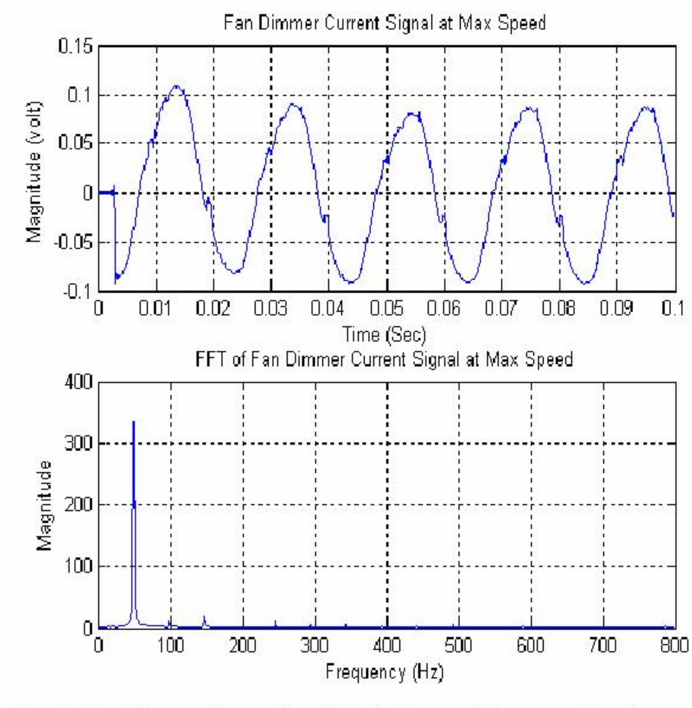

Fig. 5. Fan Dimmer Current Signal Plot in Time and Frequency Domain when Fan is at Full Speed

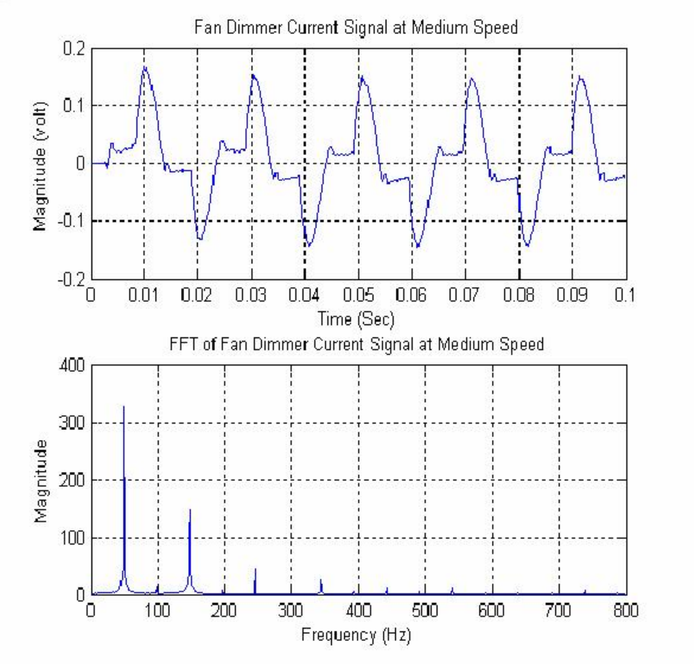

Fig. 6. Fan Dimmer Current Signal Plot in Time and Frequency Domain when Fan is at Medium Speed

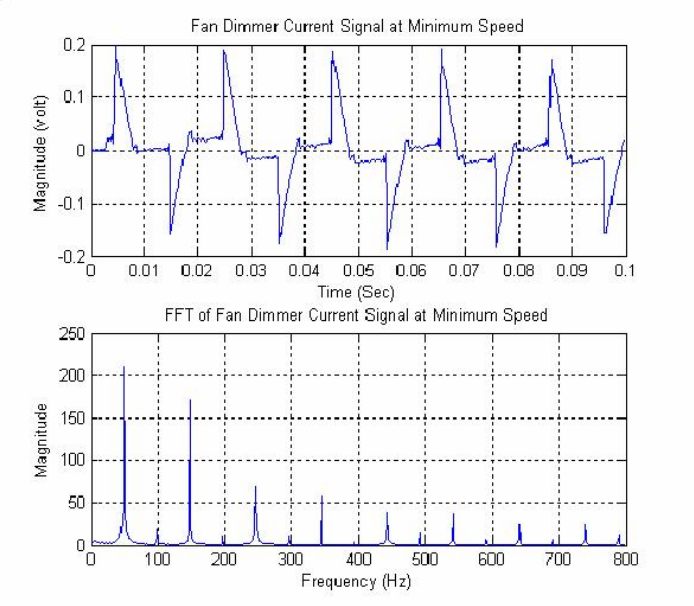

Fig. 7. Fan Dimmer Current Signal Plot in Time and Frequency Domain when Fan is at Minimum Speed

From above figures of fan current with the same dimmer it is clear that in light dimming application harmonics produces are greater as compared to fan. Secondly when fan runs it consumes some reactive power which as compared to light dimmer is larger. Even though at some positions of light dimmer FFT of current for fan and light dimming appliance seems to be same but these can easily be separated when we go for observing real and reactive power of both loads .Fan is an inductive load so it always consumes reactive power while in case of light bulb reactive power is very less.

V. IDENTIFICATION ALGORITHM

Identification procedure starts from observing and storing real and reactive powers of each home appliance and its FFT in a appliance signature space. Now in real time applications whenever system real and reactive power will change then we go for finding region in two dimensional signature space of real and reactive power for that appliance once we reach that particular region in real and reactive power graph .Then we take FFT of incremental current signal and compare it with the FFT signatures already stored for that particular region of graph.

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