

A review of high frequency emission in 2-150 kHz range

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Article Info

Article history:

Received Jun 27, 2019

Revised Feb 11, 2019

Accepted Mar 25, 2020

Keywords:

Harmonics supraharmomics

Measurement

Photovoltaic inverter

PLC

Power quality

ABSTRACT

This paper reviews state-of part of discussion that concern about high frequency emission. Sometimes there may be emission in the range of high frequencies because of the fast improvement of energy saving equipments in our homes. Investigators and standardized organization given a very much importance to the disturbances of power quality that occur in the range middle of 2-150 kHz. Disturbances of these high frequencies are becoming an increasing concern in the industry, particularly due to the growth of distributed and embedded generation. Now days, a large number of researches are proceeding at a large number of places, yet information regarding supraharmomics remains confined.

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1. INTRODUCTION

Today the popularization of smart grid is increasing, which encourages the power line communication (PLC) and also the integration of DG units into the smart grid. There are so many power quality issues such as voltage dip, swells, slow voltage variations, long voltage variations etc [1]. Harmonics is considered as one of the major issues. Harmonics are mathematically defined as the component having a frequency which is an integer multiple of the fundamental frequency. In power quality, the 50 or 60 Hz power frequency is considered as the fundamental frequency and the integer multiples of these frequency are called harmonics. Now days a serious attention has been achieved for the emission of high frequency in the range 2-150 kHz. [2, 3]. The PLC plays an important role in supraharmomic emission. Several high frequency switching circuits devices that are capable of generating significant supraharmomics are growing continuously with increasing energy efficiency. During normal operation, some of modern appliances can emit high frequency including the compact fluorescent lamp, light emitting diodes, PV inverters, battery chargers, etc.

The diodes, thyristors are considered to be the dominating valves of power electronics in the past days. With these semiconductors, due to the process for commutating the flow of current, harmonics of very low order are generated. The generation of harmonics a multiple of the fundamental frequency in line commutated rectifiers and converters is little imperious. The propagation of the emission has been transferred to higher frequencies due to establishment of the transistors which is considered to be a self-commutated valve. Sometimes there may be emission in the range of high frequencies because of the fast improvement of energy saving equipments in our homes. Disturbances of supraharmomics are becoming an increasing concern in the industry, especially with the growth of distributed and embedded generation. The large number of

distributed renewable energy sources with their fluctuating power can increase negative influence on the electricity-supply

System. High-frequency emissions in future grids and the impact on connected consumers are described in [4]. There will be no limits for the emission for frequency of 2 to 150 kHz, except for induction hubs and for lamp above 9 kHz frequency. Emission for another equipment is circumscribed only for harmonics that is up to 2 kHz and also above 150 kHz. Due to this high supraharmmonic distortion will occur and effects such as malfunction of household devices have been increasing day to day. A severe concern from international standard Community can be observed in information of voltage bias, current bias in high frequency range, it is known as "Supraharmonics". Now days, a large number of researches are proceeding at a large number of places, yet information related to supraharmonics remains confined.

This paper reviews the harmonic emission in 2-150 kHz range. Part II reviews about the sources of supraharmonics, disturbances in supraharmonic range, power line communications. The effect of supraharmonics in various equipments such as photovoltaic inverter [PV inverter], Light emitting diode, Compact fluorescent lamp, and Power electronic converter are discussed in part III. The details about the primary emission and secondary emission are explained in part III. Measurement techniques, challenges and mitigation measures are explained in part IV.

2. SUPRAHARMONICS AND IT'S SOURCES

The term "supraharmonics" (SH) is used to specify a bias that occurs in the current and the voltage waveform in the frequency range of 2 to 150 kHz. "High Frequency" term is already used by the International Telecommunication Union (ITU) to define the frequency range 3 to 30 MHz at the IEEE PES 2013 general meeting; the name supraharmonics was first introduced. Increasing capacitive currents that damage the power supply increase the neutral current and thus it increases the safety risk such as:

- Causes dimmers in lamps and failures in touch control operators
- Overheating of transformer and also capacitor banks
- Failures in protection devices and communication problems
- Decrease in the service life of LED lights and fluorescent lamps

2.1. Supraharmonics sources

When referred to supraharmonics, the SH disturbances are not caused by the distortion of the fundamental frequency waveform. It is mainly due to switching of inverter output circuit. The inverter circuits in distribution networks can also increase the level of supraharmonics.

The transfer from the power electronic converter that is tied to the grid to self commutated linked to the propagation of supraharmonics. There is a continuous expansion of number of other devices having switching circuits with high frequency. The objective is to improve the energy efficiency.

PLC transmitters and the power-electronic converters, either with active or with passive switching are considered to be the two main causes of supraharmonics. The emission has shifted from harmonic to the supraharmonics frequencies after the introduction of self-commutated valves. Instead of having an increased emission at higher frequencies, designers need to design the product that satisfies emission limits at the harmonic frequencies. Some examples of device that have high frequency emission are:

- Oscillations over commutation notches [up to 10 kHz]
- Industrial size converters [9 -150 kHz]
- Electric vehicles chargers [15 kHz 100 kHz]
- Photovoltaic inverters [4 kHz - 20 kHz]
- Power line communication [9 - 95 kHz]
- Household devices [2 - 150 kHz]
- Street lights [up to 20 kHz]

2.2. Disturbances in supraharmonic range

There are some equipment with distortion of voltage when exposed to high frequency range. Several measurements have been performed for these and it leads to subdivision of disturbances [5].

- Broadband signals
- Narrowband signals
- Recurrent oscillations

The narrow band signals are emitted by the equipments occasionally for eg. The HF ballasts of fluorescent lamps that emits remnants of switching-frequency components. "Broadband signals" can be seen in some power line communicating techniques (detailed explanation is given in upcoming section). "Recurrent oscillations" mainly occurs from other sources and it remains back from commutation at the controlled

rectifiers for e.g. the variable speed drives. There are certain types of loads that can generate narrowband signals, but they are normally emitted by PLC equipments. The power line communication uses this signal at 43 kHz and induction cooker at 40 kHz. Examples of narrowband and the broadband signals are shown in Figure 1 and Figure 2.

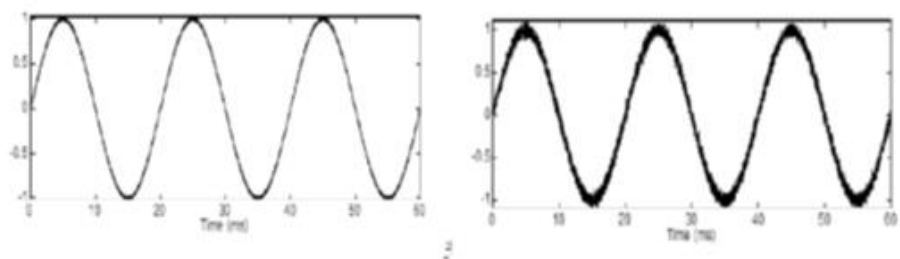


Figure 1. Narrow band signal [time and frequency domain]

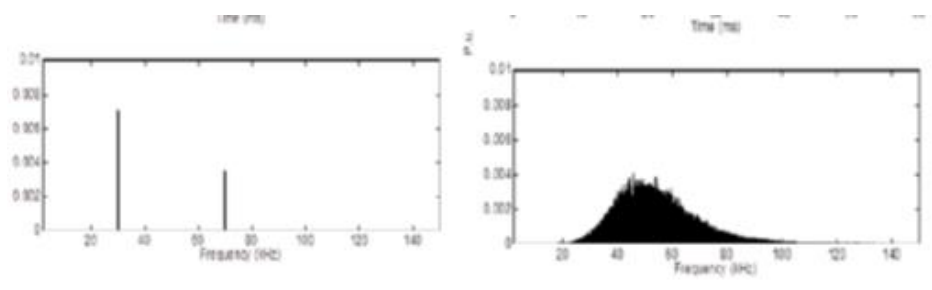


Figure 2. Broad band signal [Time and frequency domain]

As signal that contains damped oscillations, a recurring oscillation is characterized in [6]. Some equipment can emit this kind components but the origin of these signals can be found in active PFC circuits. Due to dc motor drives or May due to certain types of UPS, there is a similarity between the characteristics in recurrent oscillations and commutation notches. Frequency domain for a synthesized signal showing recurrent oscillations is shown in Figure 3.

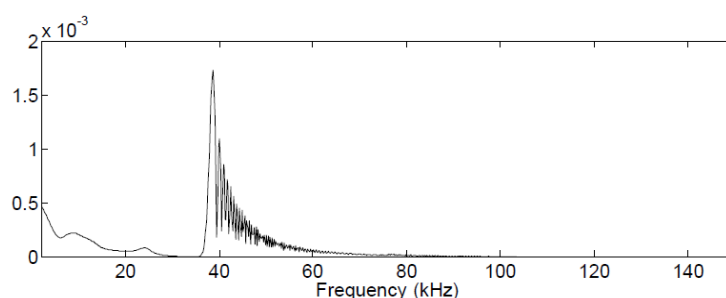


Figure 3. A synthesized signal showing recurrent oscillations in Frequency domain

2.3. Power line communications

Due to formularization of electrical grid which includes a variety of operational and energy measures that promotes the usage of the Power Line Communication technology [PLC], the supraharmonics distortion become more relevant today [7]. The use of this high frequency in PLC network is one of the good logic for turning the consideration to this range. It usually between the ranges of 9 - 148.5 kHz frequency. PLC is an emerging home network technology that connecting home devices each other and sometimes to the internet by allowing the consumers to use their existing wiring system.

The frequency that used by the network operators for the PLC is between the ranges of 9–95 kHz according to European standards [8]. The power line communication technology is broadly used in applications such as Home networking and Internet Access, Automatic meter reading, Home Automation Transmitting radio programs etc. It is used for electrical installation within the buildings [inside] and homes and so called as in-home PLC. Attenuation which are frequency-dependent, changing the impedance, fading and unfavourable noise conditions are some of the negative properties of the PLC transmission channel. PLC need to be operated in a spectrum of frequency of up to 30 MHz in order to provide higher data rates. The design of the power line is insufficient for the transmission of high frequency signal, there is some adverse effect on high signal in PLC network and it was mainly design for transmission of energy. Power lines are majorly designed to transfer electric power from a few generators to an enormous number of consumers between the ranges of 50-60 Hz frequency.

3. EFFECT OF SUPRAHARMONICS IN EQUIPMENTS

3.1. Emissions from pv inverters

The current that is injected to the power grid by using the PV inverter is some extend distorted. The high value of grid impedance will lead to a high level of distortion of voltage. From the terminals of PV inverter, the consolidation of primary and secondary emission can be calculated [9].

Main contribution of this emission is primary emission that occurs due to part that is left after a greater part has been used removed of the switching frequency of converter. Emissions of harmonics from PV-plants is somewhat it may be constant with regards to the production and is acceptably low [9]. Residue from the switching of the inverter is typically at a few kHz. The grid commutated single phase PV inverters that are accessible in our current market are of self commutated. They employ Pulse Width Modulation switching for producing the sinusoidal voltage waveform at the output. It releases HF emission into the grid because the switching occurs at high frequency. There are different topologies that are used in small, the grid-tied PV inverters such as:

- PV inverters having low frequency transformers
- PV inverters having high frequency transformers
- PV inverters that is Transformer-less

In order to study the HF emissions from Photo voltaic inverters of these topologies, so many experiments were carried out. The measurements that carried out at the University of Wollongong, Australia, and at the Technische Universitaet Dresden, Germany were described in [10]. Here at the output of the inverters, a sinusoidal reference voltage which is of 230V/50Hz having low distortion levels was maintained. In accordance with the line to-neutral loop impedance for low voltage installations rated [less than 75A], the impedance between the programmable generator and the PV inverter is $(0.4 + j0.25) \Omega$ at 50Hz. There will be an unrealistic high value at higher frequencies due to the reactive part would change for different switching frequencies. The HF emissions from PV inverters takes place in frequency bands and each of them contain additional side bands. The first emission band was considered because it provides 90% more than that of the total HF emission for a single-phase inverter [11].

The final inverter stage will largely control the HF emissions from a PV inverter. The HF emissions which arise due to this stage depend heavily on the input DC voltage. In order to find the amount of High frequency emissions that given into the grid, we have to consider the damping provided by any components of the PV system or by the output filters. HF emissions from the three phase and single-phase inverters are different. The HF emissions will be lower in inverters of lower frequency, medium for inverters of high frequency and will be higher for transformer-less inverters [10].

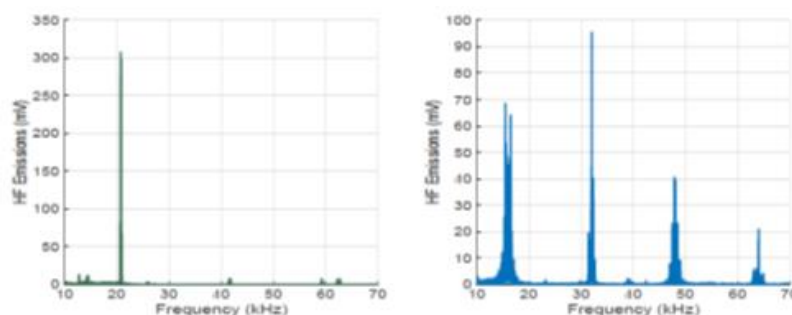


Figure 4. HF Emission [single phase and three phase inverters]

3.2. Emission from compact fluorescent lamp

Over last decades there has been a change in the types of devices connected at the low voltage network. Strive to reduce the use of electrical power has led to more energy efficient appliances. The obvious example is the change from incandescent lamps to compact fluorescent lamps (CFLs). For CFL lamp, the supraharmonic impedance that varies on timescale shorter than 20 Ms. Also most fluorescent lamps above 25-Watt of power are equipped with so-called “active power factor correction” which strongly limits their emission of low-order odd harmonics.

The combination of secondary and primary emission is measured on the terminal of an appliance in supraharmonic emission. For studying the interactions between different devices that connected inside the same installation, a number of experiments have been conducted. A comparison has been made between emissions that propagating inside the installation and emission from the installation as a whole. The spectra of current calculated at three CFLs are shown in Figure (b, c, d) together with measurement of the combined current by all three lamps shown in Figure (a) [12]. The switching frequency of the lamp is assumed to be lied in the range of 40 and 50 kHz frequency. At the point of delivery, the amplitude in ampere of the supraharmonics between 40 and 50 kHz drops and the amplitude of the supraharmonic current calculated at each individual lamp increases by the addition of a greater number of lamps. When compared to propagation of harmonic currents, the propagation of supraharmonic current is found to be significantly different.

During an experiment involving 48 fluorescent lamps that is equipped with high frequency ballast [13], the result was found to be same as shown in Figure 5. It shows that by the addition of more lamps at the point of common coupling, there is a decrease in amplitude of the residues from the switching circuit between 50 kHz and 90 kHz. Around the zero crossing of the voltage, oscillation of few kHz also produced by current drawn by lamps. There is an increase in amplitude of frequency component as more lamps were added.

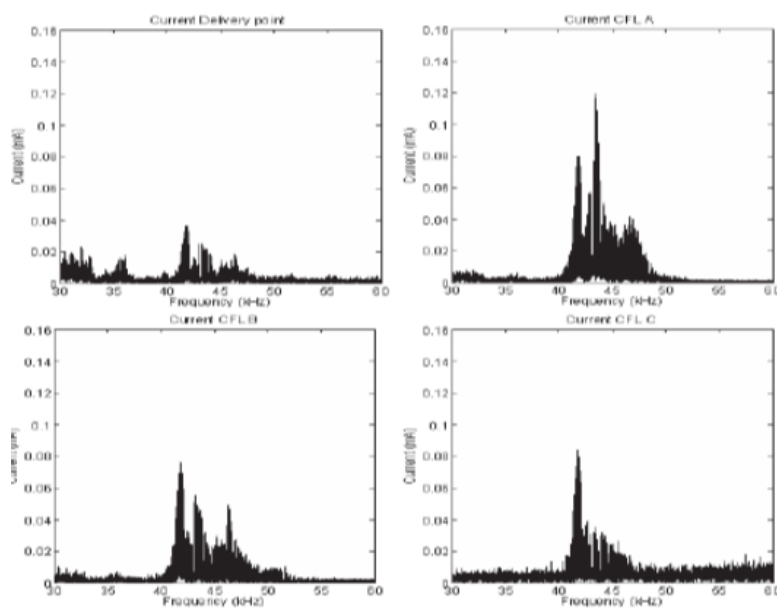


Figure 5. Current observed at three CFLs (b, c, d) and the combined current observed by all three CFLs (a)

3.3. Emission from led

LED lamps show a large diversity of topology such as:

- Type I lamps: higher level of emission [frequency up to 2 kHz]
- Type II lamps: Mainly a fundamental capacitive current [at 50 Hz frequency]
- Type III lamps: medium level of emission [up to 2 kHz frequency]
- Type IV lamps: higher level of emission [above 2 kHz frequency]

Type II to IV as defined in [14] will have the biggest impact in the supraharmonic range. The residue from the switching in LED lamp type I will also appear in the supraharmonic spectra but with amplitude below that is associated with types III and IV. Supraharmonic spectra for type II to IV are shown

in Figure 6, Figure 7, and Figure 8. The different types are not only sources of primary emission; depending on the type they also differently affect the impedance level at supraharmmonic frequencies. For type II lamps, due to the capacitor combination to the grid, secondary emission can dominate the spectrum. There will be an impact on grid such as reduction in the peak current, reduction in the losses and also a smaller increase in the harmonic distortion due to the reinstatement of incandescent lamp by LED's and CFL's.

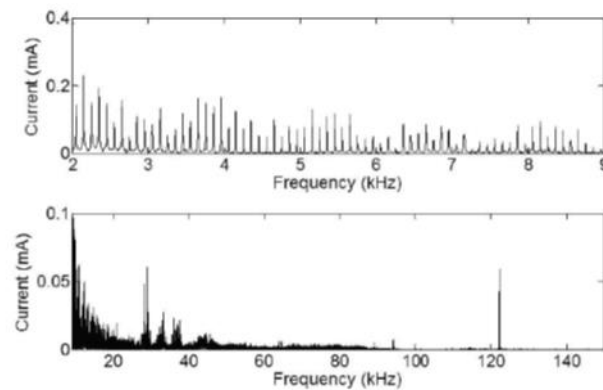


Figure 6. Supraharmonic spectra for type II LED lamp

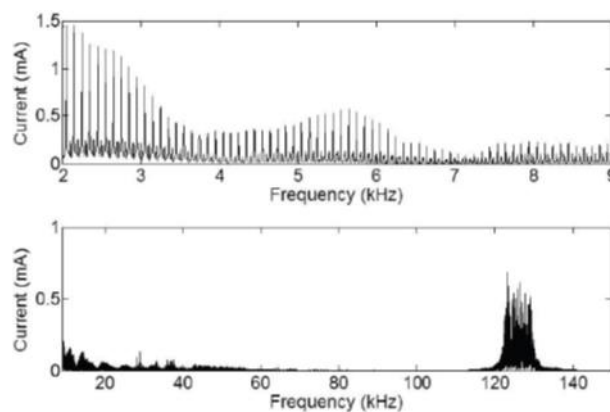


Figure 7. Supraharmonic spectra for type III LED lamp

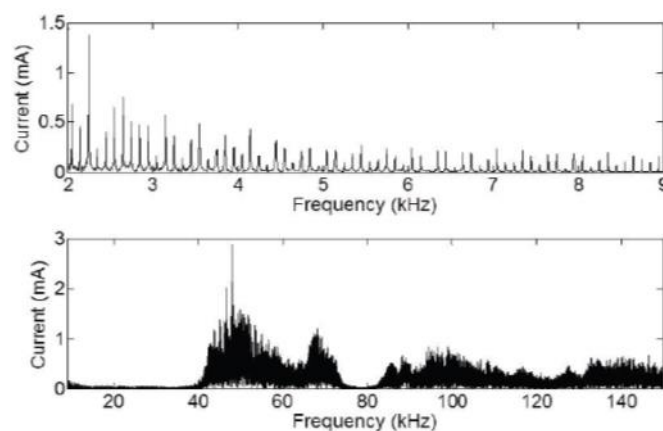


Figure 8. Supraharmonic spectra for type IV LED lamp

The levels of supraharmmonic components of type II are lower than those measured for type III and IV. Due to the capacitive character of the lamp the measured levels of emission are believed to consist mainly of secondary type of emission. The component just over 120 kHz originates from the measuring system. The strongest supraharmmonic emission component is visible slightly above 120 kHz. In the spectrogram, the component visible as a narrowband component with variable frequency supraharmmonics 49 and slightly above 120 kHz displayed as a broadband component in frequency domain representation of type III lamps. For type IV the supraharmmonic emission covers basically the entire frequency above 40 kHz.

3.4. Emission from power electronic converter

Power electronics is a highly developed technical knowledge that plays a key important role in most of the areas. It is an important cause of waveform distortion and also it can act as a key factor to mitigate distortion [15]. The origin of high frequency emission is a part or quantity that is left after a greater part has been used removed from switching frequency of converters. For high power equipment, these frequencies can be lower as 1 kHz but majority of devices has 2 to 150 kHz switching frequency. There will be common 40 and 50 kHz switching frequencies and it is because of the lower frequencies interfering with infrared remote controls and high frequencies causes harmonic that ending up above 150 kHz.

In order to increase the capability of handling the voltage and current, to increase the speed of switching of power devices, power electronics were used. There is a necessity that the connection of low voltage switching devices must be series to synthesize output of medium voltage and the inclusion of this lower voltage cell can reduce cost, reduce volume and high scalability. This leads to the development of multilevel converter technology and MCs can be used in applications such as induction machine, FACTS, motor drives, HVDC etc. There are various topologies for MC such as Cascade H Bridge, Neutral point clamped, the flying capacitor.

The modulation methods are classified according to switching frequencies in [16]. It is found that the emission from multilevel converter in the high frequency range is remarkably lower than that for two-level converter. Detailed experiment results in [17].

3.5. Primary and secondary emission

It is very important to differentiate between primary emission and secondary emission within supraharmmonic range. The Primary emission is the element of current that is consumed by the internal emission of the device itself. The Secondary emission is the element of current that is consumed by the internal emission from another device. Primary and secondary emission as shown in Figure 9. Detailed explanation on [18].

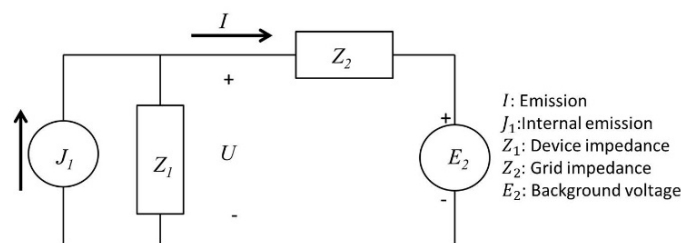


Figure 9. Primary and secondary emission

The primary emission is not dependent on time and location and is not similar to the emission that is calculated on a standard test. Controlled experiments can be done for distinguishing primary and secondary emissions. In these experiments, each separate device is calculated with a familiar source to develop the spectrum of emission. The data obtained from these experiments can be used in situation of mixed load. In [19]; several cases are discussed for primary and secondary emissions.

4. MEASUREMENT TECHNIQUES, CHALLENGES AND MITIGATION MEASURES

4.1. Measurement challenges

Generally, there are three analysis techniques such as time domain analysis, frequency domain analysis and time-frequency domain analysis [20]. Variation in magnitude levels can be easily identified using the time domain analysis technique. In order to identify the components of frequency in the signal,

frequency domain is ideally used. Representation of time frequency is a balance achieved in the middle of two desirable but incompatible features such as time domain and frequency domain representation. For time and frequency analyses techniques, there is a group of strongly acknowledged indices. For visual evaluation, time frequency techniques are more preferably used.

Due to the presence of harmonic frequencies [up to 9 kHz] in a non sinusoidal signal, it makes some difficulties to differentiate between them and “accurate” emission in signal between 2 kHz and 9 kHz frequency.

4.2. Time domain analysis

The Filtered and unfiltered current feeding a fluorescent lamp that is provided with higher frequency ballast is shown in Figure 4.

From unfiltered current, it can find that except for some notches, the waveform is rather sinusoidal. The filtered current is produced by the application of a Butterworth filter.

It shows recurrent oscillations at the end of the notches. The same oscillations can be seen in voltage waveform [21]. It is said to be “commutated oscillations”. These oscillations that occur during the commutation of a line-commutated is due to the sudden voltage sag by two phases short-circuit. Due to voltage sag, the system for feeding will started to fluctuates in its natural frequency and these frequencies in LV system are usually in the period of several kHz up to more than 10 kHz.

The source of notches and oscillations makes the active PFC converter inadequate to control the current approximated to its zero crossing and this disturbance is said to be “zero crossing distortion” [22, 23]. Due to the presence of electromagnetic-interference EMI filter between the terminals of devices, the distortion will not occur within the zero-crossing current completely. Both filtered and non-filtered shows high frequency non-damped oscillations between zero -crossing oscillations. Unfiltered and filtered current as shown in Figure 10. With the fundamental waveform, the production of the fluctuations is synchronized and due to multiple lamps, there will be an adding effect. The amplitude of oscillations increases with increase in lamps but the amplitude of High frequency signals that observable between notches cannot be increased

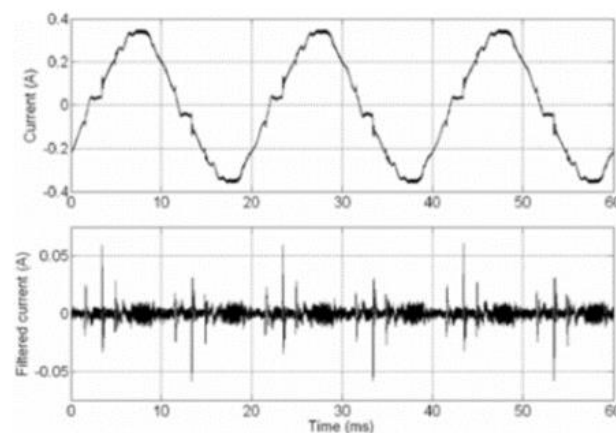


Figure 10. Unfiltered and filtered current [feeding a fluorescent lamp]

4.3. Time frequency domain analysis

Precise than time domain and frequency domain, a time-frequency domain is commonly used. Time Frequency Analysis is a signal processing tool which is widely used in field applications for extracting valuable information from non-stationary signals. Time-frequency indicate the change in spectral aspect [characteristics] of the signal which is the function of time. Non-stationary signals are signals where components of frequencies are absent all the times in the given signal. To analyze these signals such as a voltage or current, we need to use a multi-resolution technique which provides the TFR. These techniques decompose any non-stationary signal in terms of a joint time-frequency domain representation.

In order to calculate the data from domestic appliances and also from Central PV inverter, Short time Fourier transform [STFT] can be applied. The results from STFT are shown in a spectrogram and the Spectrograms used for signal processing owing to show the high frequency emissions. STFT has some disadvantages about magnitude and frequency bands representation [24].

4.4. Mitigation measures

Fuzzy logic controllers are one of the methods that are used to mitigate the high frequency emissions [25]. From a current signal, by using Uniform Random Noise method, supraharmonics can be reduced. But it has several disadvantages and it cannot reduce the harmonics completely. To overcome this limitation, Fuzzy Controllers are introduced. This method is simple when compared to other former methods. Fuzzy logic works on the basis of five rules:

- The first output will be negative, if the first input is lower and the second input is medium
- The first output will be negative, if the first input is lower and the second input is higher
- The first output will be positive, if the first input is medium and the second input is lower
- The first output will be positive, if the first input is higher and the second input is lower
- The first output will be zero, if the first input is lower and the second input is also lower

The data given by the operator is more important than the dynamic mathematical model of the system, while designing a fuzzy logic controller. For a control system, the output or error signal produced in its physical environment is considered to be a major problem. But this has an important role in the closed loop systems processes. The fuzzy logic controls are used to minimize the system fault or error to a minimum value.

For reducing the emission below 2 kHz, the conventional PWM techniques are used. The same result holds for another technique like the hysteresis control. Its leads to emission at Pulse width modulation switching frequencies and in Radio Frequency range. There are random switching PWM techniques such as carrier frequency modulation fixed duty, random carrier frequency modulation variable duty, random PWM, and random pulse position modulation.

RPPM is same as that of classical PWM. Instead of starting at the beginning of each cycle, the pulse position is sequentially within each period of switching. Thus, RPWM allows the change in width of the pulse but the required duty cycle is same as that the average pulse width. Today the most commercially available random approach is RCFMFD. This is commonly known as “spread spectrum technique” [15].

5. CONCLUSION

This paper reviewed about the high frequency emission in 2-150 kHz range. Disturbances due to high frequency emission are becoming an increasing concern in the industry, especially with the growth of distribute and embedded generation.

Supraharmonics, SH disturbances are not caused by the distortion of the fundamental frequency waveform. There are many sources for supraharmonics such as power converter, LED, CFL etc. The relevance of supraharmonics distortions is increased mainly due to vulgarization of the smart electric grids that persuade the use of Power Line Communication techniques.

The primary emissions are defined as the part of the current waveform that are driven from the internal emission from the device itself. Secondary emissions are defined as the part of current waveform which is driven from the internal emission of other devices. The major three types of analysis includes: the time domain, the frequency domain and the time- frequency domain. The time domain promotes, easy identification of the magnitude levels and also its variation. Frequency domain is ideally used to determine the components of frequency in the signal. Precise than time, frequency domain, a time frequency domain is commonly used.

Fuzzy logic controllers are one of the methods that are used to mitigate the supraharmonic emission. This method is simple when compared to other former methods.”Spread spectrum technique” is also used to reduce the high frequency emission. Power electronics can be considered as an important source of waveform distortion and it can act as a key to mitigate distortion

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