International Journal of Technology Engineering Arts Mathematics Science
Vol. 1, Iss. 1, January- June 2021, pp. 15~23

Indices for Harmonic Distortion in Power Transmission and Distribution Systems

Dr. S. M. Bakre, Mrs. A. D. Shiralkar, Prof. S.V. Shelar

[1]Associate Professor, Electrical Engineering Department, AISSMS IOIT, Pune, Maharashtra, India
[2]Head, Electrical Engineering Department, AISSMS IOIT, Pune, Maharashtra, India
[3]Assistant Professor, Electrical Engineering Department, AISSMS IOIT, Pune, Maharashtra, India

Corresponding Author: Dr. S. M. Bakre (shashikant.bakre@aissmsioit.org)

Article Information

Article history:

Received April 17, 2021
Revised April 25, 2021
Accepted April 25, 2021

ABSTRACT

Because of the exponential growth of non-linear loads during last two decades, the problem of power quality, particularly, harmonics has been aroused. Non-linear loads are the sources of harmonics that give rise to harmonic distortion. The harmonic currents generated by the non-linear loads generate harmonic voltages across lines and causes harmonic distortion of the system. The detrimental effects of high order harmonics are overheating of neutral wire, fire hazards, mal-operation and failure of equipments, rise in T&D losses, incorrect meter reading etc. The examples of non-linear loads are computers, AC and DC drives, Soft starters, arc discharge lamps, cycloconvertors etc. In brief, harmonics are generated when electricity is controlled by electronics. In order to mitigate harmonics, it is required to conduct their measurements. Harmonics are measured mainly by Harmonic Analyzers which are based on Fourier Series. However there are number of parameters which are not measured by Harmonic Analyzers. This paper discusses a novice method for computation of such parameters. Python is taken as a programming tool for computational algorithms.

KEYWORDS: Harmonics, Non-linear Loads, Harmonic Analyzer, Total Harmonic Distortion (THD), Total Demand Distortion (TDD), Point of common coupling (PCC)

1. INTRODUCTION

Harmonics are the integer multiple of a fundamental frequency. The standard fundamental frequency is 50 Hz in countries like India, United Kingdom whereas in United States, France etc. it is 60 Hz. The integer multiple of harmonics are 2,3,4,5… which are designated as second, third, and fourth harmonic components having frequencies 100 Hz, 150 Hz, 200 Hz, and 250 Hz respectively. The even harmonic components are periodic in nature having positive half cycles of equal and opposite nature and they cancel each other. Therefore normally, the system comprises of odd harmonic components such as 3, 5, 7, 9, 11… etc. Thus, generally odd harmonics are prevalent because of half wave symmetry [1].

There are other types of harmonics called inter harmonics and sub-harmonics. Inter harmonics are fractional harmonic components such as 1.4, 3.6, 5.2, 8.9 etc. The harmonic components having magnitude lesser than fundamental are sub-harmonics [2].

Up to early nineties, the system load was generally linear. However during the later period, there has been exponential rise in non-linear loads. It is important to note that the harmonics are generated when electricity is controlled by electronics. Non-linear loads are basically electronic devices and circuits. Fig.1 shows atypical performance of the non-linear resistor. The pure sinusoidal voltage wave results into a distorted non-sinusoidal load current wave because of the non-linear resistor. The various types of non-linear loads are listed below.

- Florescent lighting and other vapour lamps with electronic ballasts
- Switch Mode Power Supplies (SMPS)
- Computers, Copiers and Television sets
- Printers, Scanners and Fax machines
- High frequency welding machines
- Fans with electronic regulators
- Adjustable speed drives

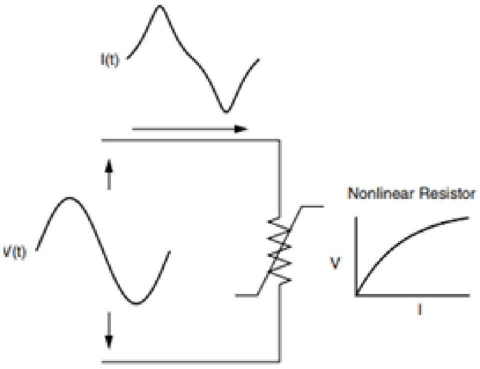

Fig. 1. Non-sinusoidal current due to non-linear load

- Static slip energy recovery schemes
- Wind and solar power generators
- Static VAR compensators
- HVDC transmission systems
- Magnetic Power Supplies
- Microwave oven and induction heating devices
- Xerox machines and medical equipments
- Various frequency based Heat Ventilation Air Conditioners (HVAC)
- Battery chargers and fuel cells
- Electric traction
- Arc furnaces
- Cycloconvertors
- Plasma power supplies
- Static field excitation systems

As shown in Fig. 2, the harmonic currents flowing through the system impedance give rise to harmonic voltages at the load. The symptoms of harmonics are listed below which cause detrimental effects [3].

- Nuisance in tripping operation of switchgear/ fuse.
- Power factor improvement not commensurate with capacitor addition
- Premature/ frequent failure of equipment

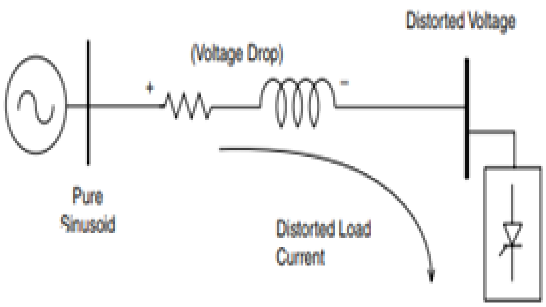

Fig. 2.Voltage Distortion Malfunction of equipment

- Overheating of cables and equipments
- Overheating/ burning of neutral wire
- Incorrect energy consumption
- Low power factor
- Memory loss in electronic equipments
- Poor quality of manufactured product
- Audible noise in cables
- Difficulties in installing compensating equipments

In the early 1800s, French mathematician, Jean Baptiste Fourier formulated that a periodic non-sinusoidal function of a fundamental frequency may be expressed as the sum of sinusoidal functions of frequencies which are multiples of the fundamental frequency [4]. The harmonically distorted wave is a non-sinusoidal but a periodic wave. Thus using Fourier series, the complex wave as shown in Fig.3 can be resolved into the sum of sinusoidal components. In this way, the Fourier series allows expression of non-sinusoidal periodic waveforms in terms of sinusoidal harmonic frequency components. This can be expressed in Fourier series as given in Eq. 1.

$$\mathbf{V_{(t)} = V_{(0)} + V_{(1)}\sin(\omega t) + V_{(2)}\sin(2\omega t) + \cdots + V_{(n)}\sin(n\omega t) + V_{(n+1)}\sin\left((n+1)\omega t\right) + \cdots} \quad (\mathbf{1})$$

Table 1. Effects of harmonics on equipments

Equipment	Effect
Capacitor	Overheating, Insulation failure
Motors	Overheating, increased noise level, increased vibrations
Transformers	Overheating, Possibility of resonance between winding and line capacitor
Reactors	Overheating
Protection equipment	False tripping, No tripping when required
Telephone	Noise at respective frequencies
Measuring instruments	Incorrect reading
Lines, Neutral wires, cables, bus bars	Overheating
Electronic devices	Wrong pulse on data transmission
Incandescent lamps	Reduced life, flicker
Generators	Harmonic pairs 5^{th} and 7^{th} have potential for creating mechanical oscillations in turbines

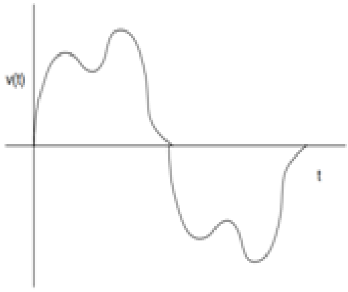

Fig. 3. Harmonically distorted wave

Fig.3 shows non-sinusoidal voltage waveform. The Fourier series allows expression of non-sinusoidal periodic waveforms in terms of sinusoidal harmonic frequency components [5]. Fig. 4 shows harmonic measurements at HT consumer metering installation. The detrimental effects of harmonic distortion are as follows-

- Failure of capacitor banks
- Overheating of neutral wires
- Distortion in communication
- Higher T&D losses
- Meter and relay contacts become sluggish and insensitive
- Series and Parallel Resonance

The measuring equipments for harmonics namely Cathode Ray Oscilloscope (CRO), Numeric Meters and Harmonic Analyzers are based on Fourier series [2]. The detailed harmonic analysis can be conducted by the Harmonic Analyzers or Power Quality Analyzer.

1.1 TOTAL HARMONIC DISTORTION (THD)

The main parameter for calculation of harmonic distortion is Total Harmonic Distortion (THD). THD is the measure of effective value of harmonic components in a distorted waveform. THD is calculated, both for current and voltage. The expressions for computation of THD are given in Eq. 2 and Eq. 3.

$$I_{THD} = \left[\sqrt{\left(\sum \frac{I_n^2}{I_1^2}\right)}\right] \quad (n = 2,3,4,5 \ldots.) \qquad (2)$$

$$V_{THD} = \left[\sqrt{\left(\sum \frac{V_n^2}{V_1^2}\right)}\right] \quad (n = 2,3,4,5 \ldots.) \qquad (3)$$

Where, I_{THD} is the Total Harmonic Distortion for current, V_{THD} is the total harmonic distortion for voltage, I_n and V_n are the n^{th} harmonic components of current and voltage and I_1 and V_1 are the fundamental components. Thus the index THD is calculated in terms of voltage or current. THD indicates potential heating value of the harmonics with respect to the fundamental. We can also express THD in terms of total and fundamental quantities as follows [3].

Fig. 4. Harmonic Measurements at site

Other parameters are Current Distortion Power (CDP), Voltage Distortion Power (VDP), Harmonic Apparent Power (HAP), Fundamental Apparent Power (FAP), and Non-linear Apparent Power (NAP).

1.2 TOTAL DEMAND DISTORTION (TDD)

TDD is the distortion index where current is taken as fundamental during peak demand and calculated using Eq. 4.

$$I_{TDD} = \frac{I_H}{I_{1peak}} \qquad (4)$$

It should be noted hare that current I_{1peak} is taken as fundamental during peak demand and not fundamental current at any other instant. Harmonics are measured at the Point of Common Coupling (PCC). PCC is the common point for linear and non-linear loads. Fig. 6 illustrates PCC for harmonic measurements.

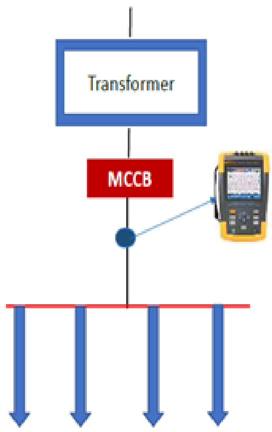

Fig. 6. Point of Common Coupling (PCC)

1.3 STANDARDS ON HARMONICS

Guidelines, PCC location, recommended practices and limits of harmonic distortion have been specified in various national and international standards. The primary objective of these standards is to provide a common ground for harmonic measurements and analysis. Some of the commonly used standards referred worldwide are discussed below [1].

- **IEEE 519-1992**

It is commonly accepted standard all over the world. This standard has defined PCC where harmonic measurements are recommended. The short circuit ratio is defined by this standard as a ratio of maximum short circuit current at PCC to the fundamental component of maximum demand load current at PCC itself.

- **IEC 61000**

The International Electrotech Commission (IEC) have released their standard numbered IEC 61000. They have developed Electromagnetic Compatibility (EMC) standards as applicable to power quality. The limits for harmonic current emissions from equipment drawing current upto 16 Ampere per phase and more than 16 Amperes per phase are defined in IEC 61000-2-3 and IEC 61000-3-4 parts of the standard respectively.

- **NRS 048-02**

It is the South African standard dealing with power quality. It covers minimum standards of Quality of Supply (QOS), measurements and guidelines.

- **EN 50160**

It is the European national standard on power quality issues. It specifies voltage characteristics for a system or load which is to be followed. The harmonic voltage limits are given in percentage of fundamental.

The objective of this paper is to measure the main indices harmonic distortion THD and TDD. However, this paper proposes additional indices for harmonic measurements. The Python based approach is proposed in this paper for computation of these indices.

2. IMPACT ON BILLING

The apparent power S has two components namely real or active power (P) and reactive power (Q). Mathematically, it is expressed as Eq. 5

$$S = \sqrt{P^2 + q^2} \tag{5}$$

This represents a right angle triangle as shown in Fig.7. This triangle is called as power triangle. In kVAh based billing system, the fixed charges or demand charges are levied on apparent power (kVA) and energy charges are based on apparent energy (kVAh). Because of kVAh billing system, Real and Reactive energies need not be charged separately. Fig 8 shows the pattern of energy consumption. It is expressed in form such as heating, lighting, motion etc. The other component kVArh is required to provide magnetic flux to equipments such as motors. The very little amount of reactive current is required in magnetic circuits.

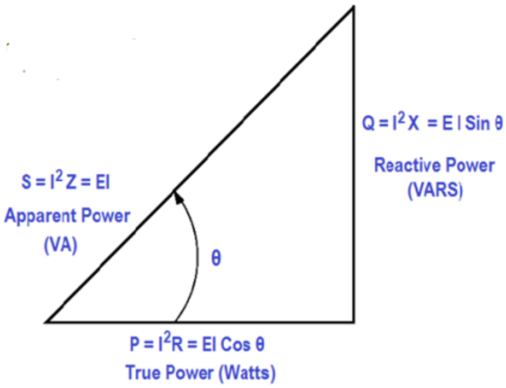

Fig. 7. The power triangle

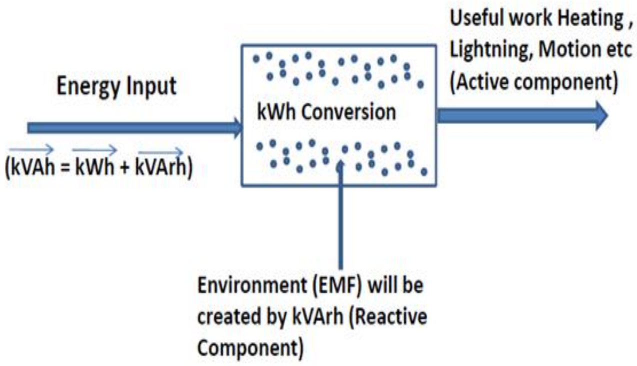

Fig. 8. Energy diagram

The surplus amount current flows through wires, switches and contacts and deteriorates them. The kVArh comes with kWh whether you want it or not. Total kVAh for computing power factor is computed as Eq. 6.

$$kVAh = \sqrt{kWH^2 + (kVAHRh.lag + kVARh.iead)^2} \tag{6}$$

However, more kVAh will be billed in case the load is non-linear. In case of non-linear load, the additional component of power namely distortion power (D) will come in picture.

Under the circumstances, the conventional power triangle will not give correct apparent power. The total apparent power would be expressed as Eq. 7

$$S = \sqrt{P^2 + q^2 + d^2} \tag{7}$$

Accordingly, the triangle would be revised as shown in Fig. 9. The parameter D is an important harmonic index. Therefore the billed amount would be more due to harmonics. In order to reduce billed amount of electricity bill, the compensation would be required for heavy reactive load and harmonic mitigation for non-linear load.

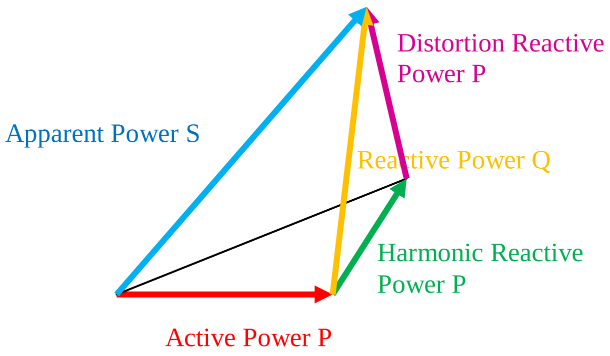

Fig. 9. Revised power triangle

2.1 HARMONIC RESONANCE

The phenomenon of resonance occurs on matching of frequencies. For example, solders performing parade disperse when they come near the bridge. Because, when the frequency of feet matches with frequency of vibration of bridge, the bridge would collapse. Electrical resonance is classified as series resonance and parallel resonance. Table 2 shows comparison between series and parallel resonance.

Fig.10 shows harmonic series resonance. The harmonic series resonance occurs when high harmonic currents flow through the series combination of transformer inductance and customer power factor correction capacitor. The series combination of transformer inductance and capacitor bank is very small (almost negligible) and only limited by resistance.

The complex network of series resonance is simplified by its equivalent circuit as shown in Fig 11. Harmonic currents are the source of harmonics. This is represented by a current course.

Table 2. Series & Parallel resonance

Particulars	Series RLC	Parallel RLC
Condition	Xl=Xc	Yl=Yc
Impedance	Minimum	Maximum
Current	Minimum	Maximum
Power Factor	Unity	Unity
Phase Angle	Zero	Zero
Effect	V & I in Phase	V and I in phase

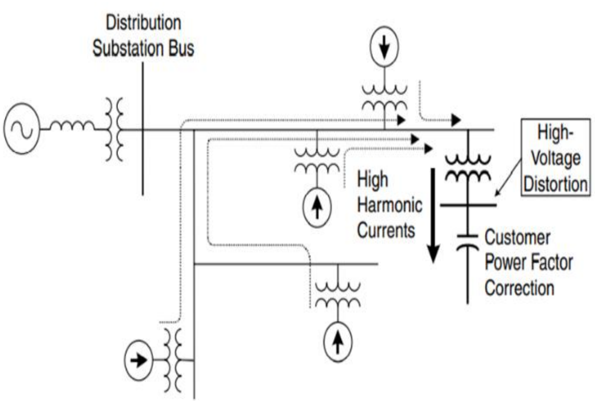

Fig. 10. Series Harmonic Resonance

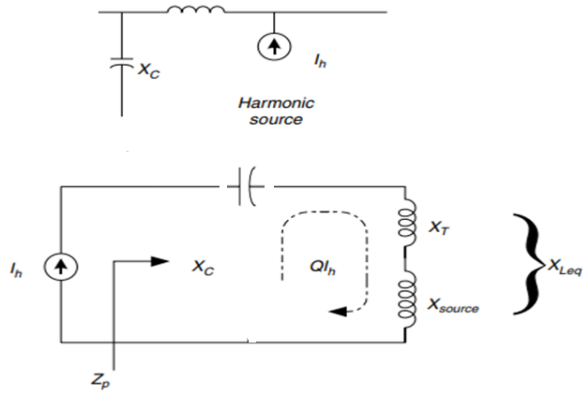

Fig. 11. Equivalent circuit

Harmonic current corresponding resonant frequency will flow freely in this circuit. The voltage at power factor correction capacitor is magnified and highly distorted, given by the Eq. 7.

$$V_s\,(at\ power\ factor\ capacitor\ bank) = \frac{X_c}{X_T + X_C + R} V_k \approx \frac{X_C}{R} V_k \quad (7)$$

Where Vh is the harmonic voltage corresponding to harmonic current I_h. Resistance R is series resonance resistance. Fig.12 shows harmonic parallel resonance formed between transformer winding inductance and shunt capacitor. Parallel resonance occurs when the reactance of X_C and distribution system cancel each other. At higher frequencies, the shunt capacitor bank appears in parallel with system inductance. Fig 13 shows simplified circuit and Fig. 14 shows simplified distribution network.

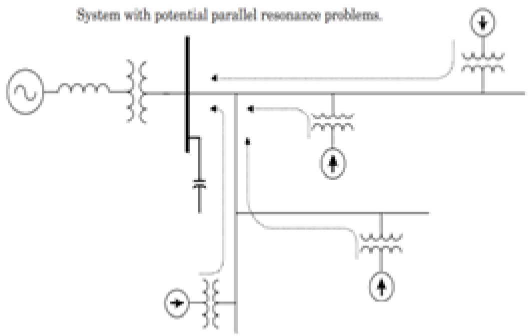

Fig. 12 Parallel harmonic resonance

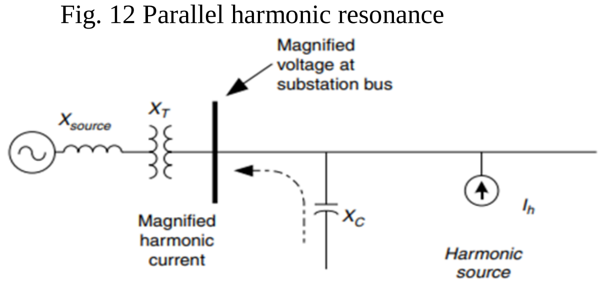

Fig. 13 Harmonic parallel resonance

The Fig. 15 shows series and parallel resonance as seen from harmonic source. The harmonic indices h_r and h_s indicate the degree of resonance as given in Eq. 8 and Eq. 9. It is therefore required to include these indices in harmonic studies.

$$h_r = \sqrt{\frac{X_C}{X_T + X_{Source}}} \quad (8)$$

$$h_s = \sqrt{\frac{X_C}{X_T}} \quad (9)$$

3. OTHER HARMONIC INDICES

The Eq. 10 of voltage can be written as follows.

$$V_T = V_0 + \sqrt{2}\sum_{h=0}^{\infty} V_h \sin(hwt + \alpha_h) \quad (10)$$

where, V_T (t) is the instantaneous voltage, $V_0$is the average value of the voltage, $V_h$is the rms value of h^{th} harmonic voltage and $\alpha_h$is the phase angle of h^{th} harmonic voltage. Similarly, the equation of current can be written as Eq. 11.

$$I_T = I_0 + \sqrt{2}\sum_{h=0}^{\infty} I_h \sin(hwt + \alpha_h) \quad (11)$$

Where, I_T (t) is the instantaneous current, $I_0$is the dc component, I_h is the rms value of h^{th} harmonic current and β_h is the phase angle of h^{th} harmonic current.

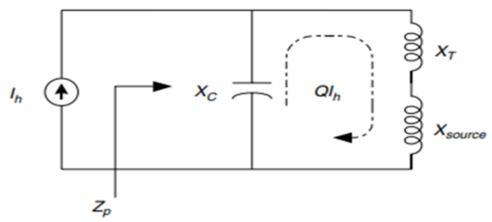

Fig. 14 Equivalent Circuit

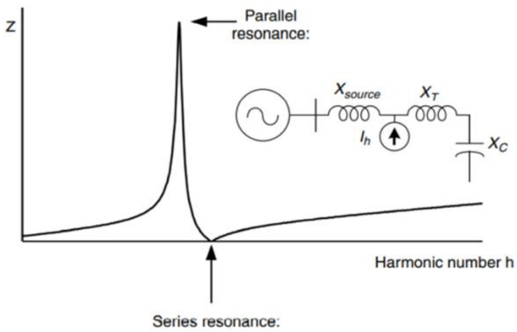

Fig. 15. Series parallel resonance

The current I flowing through load will be given by the Eq. 12.

$$I^2 = I_1^2 + I_H^2 \quad (12)$$

Where I_1 is the fundamental component of current and I_H is the harmonic component of current such that Eq. 13.

$$I_H^2 = I_2^2 + I_3^2 + I_4^2 + \cdots + I_n^2 \quad (13)$$

It may also be stated that Eq. 14 or Eq. 15.

$$I_H^2 = \sum_{i=2}^{n} I_i^2 \quad (14)$$

$$I_H = \sqrt{\sum_{i=2}^{n} I_i^2} \quad (15)$$

On similar lines, we can find out expression for total l harmonic voltage $V_H$as follows. The voltage V Across the load would be expressed as Eq. 16.

$$V^2 = V_1^2 + V_H^2 \quad (16)$$

Where V_1 is the fundamental component of voltage and V_H is the harmonic component of voltage such that Eq. 17 or Eq. 18.

$$V_H^2 = V_2^2 + V_3^2 + V_4^2 + \cdots + V_n^2 \quad (17)$$

$$V_H = \sqrt{\sum_{i=2}^{n} V_i^2} \quad (18)$$

The Fundamental Apparent Power (FAP) would be calculated as follows.

$$P_i A = V_i I_i \cos\theta_i \quad (19)$$

$$Q_i = V_i I_i \sin\theta_i \quad (20)$$

$$Where\ \theta_1 = \alpha_i \beta_i \quad (19)$$

In this way, the Fundamental Apparent Power (FAP) is resolved into Fundamental Real Power (P_1) and Fundamental Reactive Power (Q_1). The Total Apparent Power (TAP) has two components - Fundamental Apparent Power (FAP) as discussed above and Non-Linear Apparent Power (NAP) [7]. Thus TAP can be calculated as Eq. 20.

$$TAP^2 = FAP^2 + NAP^2 \quad (20)$$

The Non-Linear Apparent Power (NAP) has following three components - Current Distortion Power (CDP), Voltage Distortion Power (VDP) and Harmonic

Apparent Power (HAP). These parameters are expressed in terms of the following Eq. 21, Eq. 22 and Eq.23.

$$CDP = V_1 \times I_H \tag{21}$$

$$VDP = V_H \times I_1 \tag{22}$$

$$HAP = V_H \times I_H \tag{23}$$

Using Eq. 23, the Non-Linear Apparent Power (NAP) can be expressed as Eq. 24,

$$(NAP)^2 = CDP^2 + CDP^2 + CDP^2 \tag{24}$$

The Harmonic Apparent Power (HAP) is further divided into Real part and Reactive parts, as Eq. 25.

$$(HAP)^2 = (V_H \times I_H)^2 = {P_H}^2 + {N_H}^2 \tag{25}$$

Where P_H is Total Harmonic Active Power and N_H is Total Harmonic reactive Power. Now, dividing above Eq. 25 as Eq. 26.

$$(NAP/FAP)^2 = \left(\frac{I_H}{I_L}\right)^2 + \left(\frac{V_H}{V_2}\right)^2 + \left(\frac{V_H . I_H}{V_2 . I_1}\right)^2 \tag{26}$$

The ratio I_H/I, known as Total Harmonic Distortion for Current (I_{THD}). Similarly the ratio V_H/V is known as Total Harmonic Distortion for Voltage (V_{THD}). Thus Eq. 27 can be written as,

$$(NAP/FAP)^2 = (I_{THD})^2 + (V_{THD})^2 + V_{THD} . I_{THD} \tag{27}$$

Generally, the V_{THD} pertains to utility. It is usually less than 3%.

The I_{THD}, on other hand pertains to the consumers. In case of high non-linear load, the I_{THD} is very high as compared to V_{THD} as Eq. 28.

$$I_{THD} \gg V_{THD} \tag{28}$$

If V_{THD} is neglected then in equation becomes as Eq. 29,

$$\frac{NAP}{FAP} = I_{THD} \tag{29}$$

In this way, the parameter current THD is the main measure of harmonics. The ratio of Harmonic Apparent Power (HAP) to the Fundamental Apparent Power (FAP) is given by the expression as Eq. 30.

$$\frac{NAP}{FAP} = I_{THD}\ V_{THD} \tag{30}$$

The value of V_{THD} being very small as compared with I_{THD}, the ratio HAP/FAP is very small.

The power factor can be calculated using following expression as Eq. 31.

$$Power\ Factor = \frac{(P_H + P)}{TAP} \tag{31}$$

Under linear load conditions, the values of P_H and NAP would be zero and the power factor would be improved. If the total harmonic apparent power is denoted by S_H, then it can be stated as Eq. 32 and Eq. 33.

$$(S_H)^2 = (V_H \times I_H)^2 = {P_H}^2 + {N_H}^2 \tag{32}$$

$$P_H = \sum_{h=0}^{\infty} V_h I_h \cos(\theta_h) = \alpha_h - \beta_h \tag{33}$$

P_H is the total Harmonic Active Power. The remaining component N_H is the Total Harmonic Reactive Power. It can be recognized that while a direction of flow could be assigned to P_1 and Q_1 , no direction of flow could be assigned to the three components of the non-fundamental apparent power, S_N. They are only the products and they have no physical meanings. Nevertheless, such formal components can serve as useful indicators of operation of network.

This equation may be re-written as a function of Total Harmonic Distortion of voltage and current as Eq. 34.

$$\left(\frac{S_n}{S_1}\right)^2 = (I_{THD})^2 + (V_{THD})^2 + (I_{THD} . V_{THD})^2 \tag{34}$$

Typically $0.01<V_{THD}<0.03$. Electrical utilities generally strive to maintain $V_{THD}<0.05$. In contrast, I_{THD} is generally much higher than V_{THD}. In typical medium and low voltage systems, $0.05< I_{THD}< 0.09$. Some low power non-linear loads may operate with I_{THD} as high as 1.5 and clusters of non-linear loads may push I_{THD} in excess of 0.9.

The error due to approximation is than 1% for I_{THD} greater than 40%. Even better approximations obtained with the following expression as Eq. 35.

$$\left(\frac{S_n}{S_1}\right)^2 \approx \sqrt{[(I_{THD})^2 + (V_{THD})^2]} \tag{35}$$

Using the approximation of normalized non-fundamental apparent power given in the above equation, for $V_{THD}< 5\%$, the error is less than 0.15 % .The normalized harmonic apparent power S_H / S_1 can be calculated as Eq. 36.

$$\left(\frac{S_H}{S_1}\right) = \frac{V_H I_H}{V_1 I_1} = I_{THD} . V_{THD} \tag{36}$$

For example, for $I_{THD} = 0.4$ and $V_{THD} < 0.05$, $S_H / S_1 < 0.02$. Because the component P_H is less than or equal to S_H, $\frac{P_H}{S_1}$ has in general, a very low value. In practical situations, $\frac{P_H}{S_1}$ will rarely exceed 0.015. It is important to note that a distinction has been drawn between non-fundamental apparent power and harmonic apparent power. The harmonic apparent power is much smaller than S_N and does not convey enough information about non-linear load.

The measurement of P_H or $\int P_H\,dt$ (harmonics kWh) is not an effective way to evaluate harmonic power flow, because some harmonics may generate power while others dissipate power in the observed load or cluster of loads, leading to mutual cancellation in the P_H term. Only a complete listing of harmonic currents and voltage phasors (magnitude and phase) can lead to a clear understanding of contribution made by each harmonic to the electric energy flow. Such measurements however may carry so much information as to be unwieldy for everyday load monitoring.

Generally, the value S_N and the normalized values S_N/S_1 are much better indicators of the level of harmonic "pollution "than the value of P_H . A well-filtered non-linear load will be characterized by a low ratio of S_N/S_1. Increased current distortion will not necessarily increase the value of P_H but it will always increase the normalized value of S_N/S_1. The most expedient figure of merit to quantify the effectiveness of electrical energy flow in the system is, Total Power Factor (PF) can be written as Eq. 37.

$$Power\ factor = \frac{P}{S} = \frac{(P_1 + P_H)}{S} \qquad (37)$$

Where P is the real power and S is the apparent power. However, isolating P_1, Q_1 and S_1 from the non-fundamental power, makes it easy to follow the uncorrupted fundamental power flow of the electrical energy and makes the application of engineering economic techniques (such as power factor correction capacitors), easier. Displacement Power Factor (DPF), given by the following Eq. 38, retains a significant value for this concept where the fundamental powers are monitored separately from the non-fundamental.

$$Displacement\ Power\ factor = \frac{P_1}{S_1} = \cos\theta_1 \qquad (37)$$

3. 1 THE PYTHON PLATFORM

Traditionally speaking the Java language is mostly used in electronic devices. However because of comparative benefits, the Python language is preferred now-a-days in number of applications. Python is a high level, open source, platform independent, objects oriented programming language. Python was developed in early eighties by Guido Van Rossum at National Research Institute for Mathematics and Computer Science at Netherlands [8]. As compared to C/C++/Java programming languages, Python is simple but powerful programming language. Therefore Python is widely used in graphics, animation, desktop, palmtop, mobile, and web and database management systems. Python is used as an embedded scripted language for electronic devices and circuits. The Python language is found to be quite suitable for new upcoming technologies such as IoT, Machine Learning, data science and deep thinking.

3.2 SERIAL INTERFACE

The fundamental and other harmonic components of current and voltage (I_1, I_H and V_1, V_H) are received from the output port of the main processor of numeric meter or harmonic analyzer.

The output data is sent from the microcontroller of smart meter/analyzer to the embedded system via the serial link. The Python script running on the computer will read and display it on console. It may be noted that this code will work with versions Python 2.7 and above.

The output of smart meter/harmonic analyzer is given to the embedded system through a serial communication such as RS282 or RS485. The embedded system reads the values of fundamental and other harmonic components of current and voltage (I_1, I_H and V_1, V_H). As per Psudo code shown in Fig.17, the indices viz. CDP, VDP, HAP, FAP, NAP,DI etc are computed. It should be noted here that the basic parameters are calculated by ALP/ C++/Java based processor of smart meter/analyzer.

4. CONCLUSION

The increasing trend of use of non-linear loads may lead to severe problems such as overheating of lines and equipments, burning and failure of equipments, undue tripping of lines and transformers, noise and distortion in data and voice communication systems, high T&D losses and incorrect meter reading. Higher harmonic currents also lead to higher kVAh consumption. Under the circumstances, the conventional power triangle will not give correct apparent power. The deviation between kVAh and kWh can be minimized through harmonic mitigation in case the reactive compensation techniques do not show improvement. Use of detuned capacitors does not suppress harmonics. The other undesired events such as overheating of neutral wire and equipments, undue trappings, PCB failures are also stopped. THD and TDD are the traditionally used indices to measure harmonic distortion. This paper proposes additional indices for harmonic measurements namely CDP, VDP, HAP, FAP, NAP, D, DI, h_r, h_s,

S_H / S_1,P_H / S_1,S_N/ S_1 and DPF. The Python based approach is proposed in this paper for computation of these indices. Compared to conventional assembly language based programming and C++/Java based embedded platforms, the Python based approach for serial interface and computation of these indices is found to be simple, convenient and feasible.

REFERENCES

[1] Roger C. Dugan, Mark F. McGranaghan, Surya Santoso, H.W. Beaty, “Electrical Power Systems Quality”, *McGraw-Hill Professional Engineering, Second Edition*

[2] C. Sankaran, “Power Quality’, *CRC Press, Third Edition*

[3] Bhim Singh, Ambrish Chandra, Kamal Al-Hqddad, ‘Power Quality-Problems and Mitigation’, *Wiley Publishing, Second Edition*

[4] Dr. S.M. Bakre, ‘Electrical Harmonics in Easy Steps’, *Amazon KDP Publishing, First Edition*

[5] Potomanski, P. Kawelek, ‘Application of Fourier Series to determine measurement error of harmonics with selected harmonic ahalysers’ , *IEEE 201711thInternational conference on measurements.*

[6] L. Siequira, A.M. Carneiro, M. Oliveira,’Assessment of harmonic measurements in power and energy measurements’,*2000-IEEE International Conference journal volume I.*

[7] Sasa Mahinic, Dilbor Brnobic, Nino Stojkovic, ‘Indices for harmonic distortion monitoring for power distribution systems’, *2008 IEEE International Conference*.

[8] Dr. Shashikant Bakre, ‘Python Programmingin easy steps’, *Amezon KDP Publishing*