HIOKI

# Application Note

## What is Harmonics and How to Identify the Harmonics Sources in your Facility with Hioki PQ3198?


### What is Harmonics and How is it Generated?

In an ideal AC circuit with a sinusoidal voltage waveform, the corresponding current through the linear resistor will also be in sinusoidal waveform [1]. This waveform is called the *fundamental waveform* (or $1^{st}$ order harmonics) and corresponds to the single supply frequency called the *fundamental frequency*, which is the lowest frequency.

However as most electrical loads have non-linear voltage-current characteristics [2] (current is not proportional to voltage and fluctuates with the alternating load impedance), the resulting sinusoidal wave will have a frequency that is an integer multiple of the fundamental frequency. If the frequency is n multiples of the fundamental frequency, it is the *nth* order harmonics of the fundamental frequency. For a 50 Hz voltage, the 2nd order harmonics frequency is 2x50 = 100 Hz, $3^{rd}$ order harmonics frequency is 3x50 = 150 Hz, and so on.

**The superimposition of these multiple frequency waveforms with the fundamental frequency will result in a distorted non-sinusoidal waveform called harmonics. Figure 1.0 below illustrates the concept of voltage harmonics for a 50 Hz fundamental frequency voltage.**

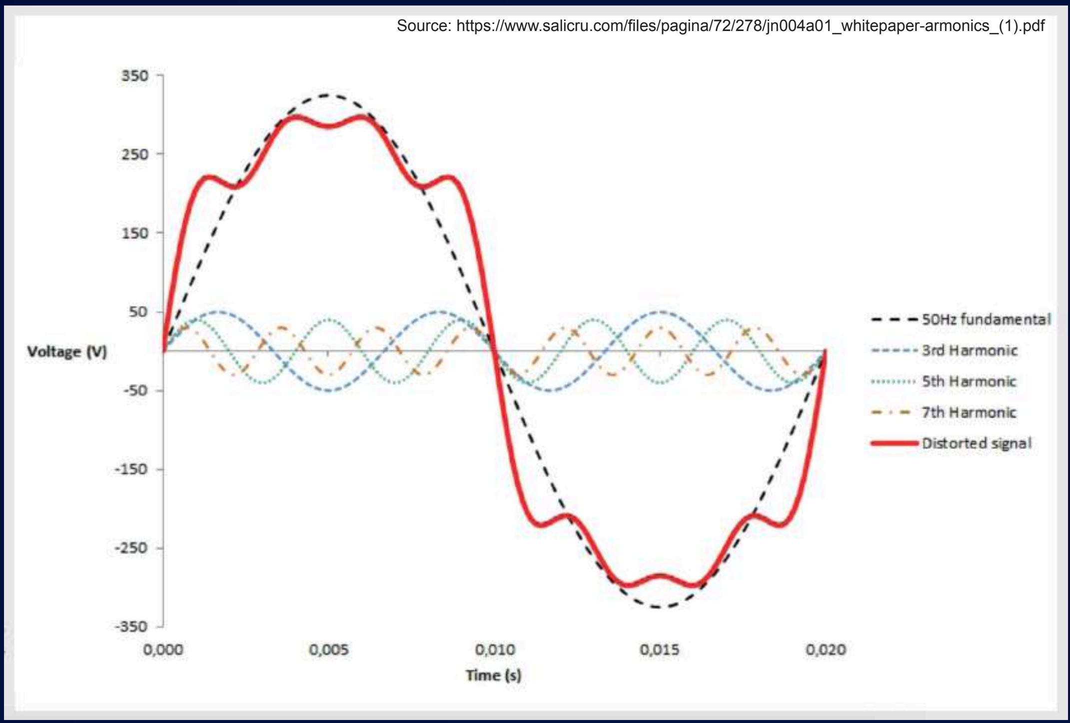



**Figure 1.0 Voltage Harmonics Waveform for a 50 Hz Fundamental Frequency Voltage**

## Common Sources of Harmonics

**Non-linear loads are common sources of harmonics in power systems, where the current is not proportional to the voltage [3]. Examples of non-linear loads are:**

**IT Equipment Power Supply Unit (PSU) component**
***(To convert AC to DC)***

**Lighting with Power Factor Correction (PFC) Circuit**
***(To increase energy efficiency)***

**Variable Frequency Drive (VFD) and Variable Speed Drive (VSD)**
***(To control motor speed)***

## Effects of Harmonics

**Table 1.0 below lists examples of the effects of harmonics on various equipment.**

| Equipment | Effects |
|---|---|
| Conductors | Overheating, nuisance tripping (in MCCB) |
| Capacitors | Heating, premature aging and destruction of capacitor |
| Transformers and Motors | Overheating of the windings, thermal insulation loss, reduced efficiency |
| Power Generators | Loss in automatic synchronization and switching capability |
| Communication System Equipment | Interference leading to loss in data |

Source: https://www.electrialindia.in/harmonics-causes-effect/

**Table 1.0 Harmonics Effect on Various Equipment**

**Generally, harmonics reduce the overall electrical system's Power Factor (PF), which is represented by the ratio of real power (usable electricity) to apparent power (demand power). A PF that is lower than 1 indicates low power efficiency.**

## Harmonics Measurement

**Harmonics are measured in terms of Total Harmonic Distortion (THD) and Total Demand Distortion (TDD). Table 2.0 compares both parameters from different aspects.**

| Items | Total Harmonics Distortion (THD) | Total Demand Distortion (TDD) |
|---|---|---|
| Parameter Indication | Percentage of voltage/current distortion due to harmonics with reference to fundamental frequency [4] | Percentage of voltage/current distortion due to harmonics with reference to maximum load demand [4] |
| Representation | $\frac{\text{Sum of powers of all harmonics component}}{\text{Power of } \mathbf{Fundamental\ Frequency}}$ | $\frac{\text{Sum of powers of all harmonics component}}{\text{Power of } \mathbf{Maximum\ Load\ Demand}}$ |
| Value Indication | Higher value indicates lower Power Factor, higher current peaks, higher cost [5] | Higher value indicates higher impact of harmonics distortion on the system |
| Limit Standard | IEC 61000-3-2 | IEEE 519 |

**Table 2.0 THD and TDD comparison**

**For current, the TDD current gives a better insight into the impact of harmonics distortion on the power system e.g. the THD current value might be very high but if the load is low, the impact of the harmonics on the system is also low (low TDD). For voltage, however, the THD index is the preferred parameter to describe voltage harmonics distortion by the power quality industry [7].**

## Hioki PQ3198 for Harmonics Measurement and Source Identification

The Hioki PQ3198 is equipped with a simple vector diagram display that helps to ensure correct connection for harmonics measurement. This colour-coded ‘needle-and-box’ display shows both voltage and current measurements. A correct connection is denoted by the same colour in the needle and box, as shown below in Figure 2.0.


Figure 2.0 Vector diagram display on PQ3198 for connection

The PQ3198 can also determine the harmonics measurement load type (inductive or capacitive load) using the Power Factor (PF) sign, shown in Figure 3.0 below.


Figure 3.0 Power Factor value display on PQ3198 to determine type of load

Inductive load, indicated by a positive (+) PF value, causes the current rate to be blocked. Thus, the current wave shifts horizontally and lags behind the voltage wave. Inductive loads mainly consist of devices with wire coils or function based on the Magnetic Induction Principle (Figure 4.0); inductive loads consume active power and produce reactive power. [8]


Figure 4.0 Examples of Inductive Loads

Capacitive load is indicated by a negative (-) PF value, with the current wave leading the voltage wave instead. Capacitive loads consist of any electrical device that can absorb electrical energy in a moment (capacitance) (Figure 5.0).


Figure 5.0 Examples of Capacitive Loads

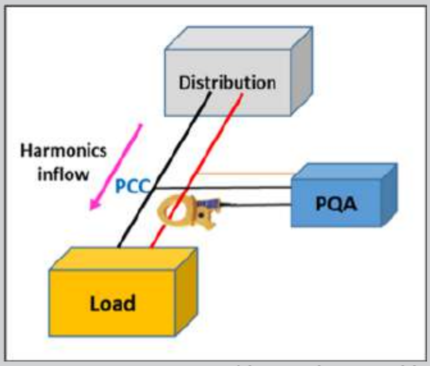
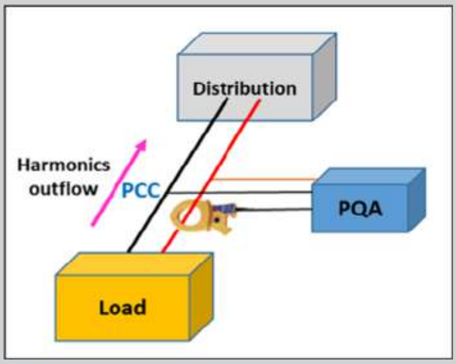
**Users can also determine the <u>direction of harmonics flow</u> based on the harmonics power sign and harmonics phase angle values. Figure 6.0 shows an example of measurements for both parameters on the PQ3198, for 3rd order harmonics.**


**Figure 6.0 Harmonics Power (left) and Phase Angle (right) for a 3rd Order Harmonics**

**However, the harmonics power value decreases with higher harmonics orders, making it difficult to judge polarity. Hence, the harmonics power phase angle acts as a second parameter to determine the direction of flow (Figure 7.0).**


**Figure 7.0 Harmonics Power (left) and Phase Angle (right) for a 11th Order Harmonics**

**Table 3.0 summarizes the methods used to determine the direction of harmonics flow based on the harmonics power sign and phase angle values.**

| Harmonics Flow | Inflow | Outflow |
|---|---|---|
| Harmonics Flow Direction | Distribution to Load<br><br><br>**Harmonics measured at Point of Common Coupling (PCC)* | Load to Distribution<br><br><br>**Harmonics measured at Point of Common Coupling (PCC)* |
| Harmonics Power Phase Angle Value | -90° to 0° **OR**<br>0° to 90° | -90° to -180° **OR**<br>90° to 180° |
| Harmonics Power Sign | Positive (+) | Negative (-) |

*Disclaimer:*
*The flow direction should only be used as a reference and not a conclusive indication for the source of harmonics.*
*For multiple harmonics, which is a vector made up of amplitude and phase, it is not easy to determine the source of harmonics based solely on flow direction as most power supply contains some form of harmonics.*

**Table 3.0 Harmonics Power and Phase Angle to Determine Harmonics Flow Direction**

The THD and the TDD values can be measured using PQ3198. These values can then be analyzed and displayed using the PQ One software (Figure 8.0).

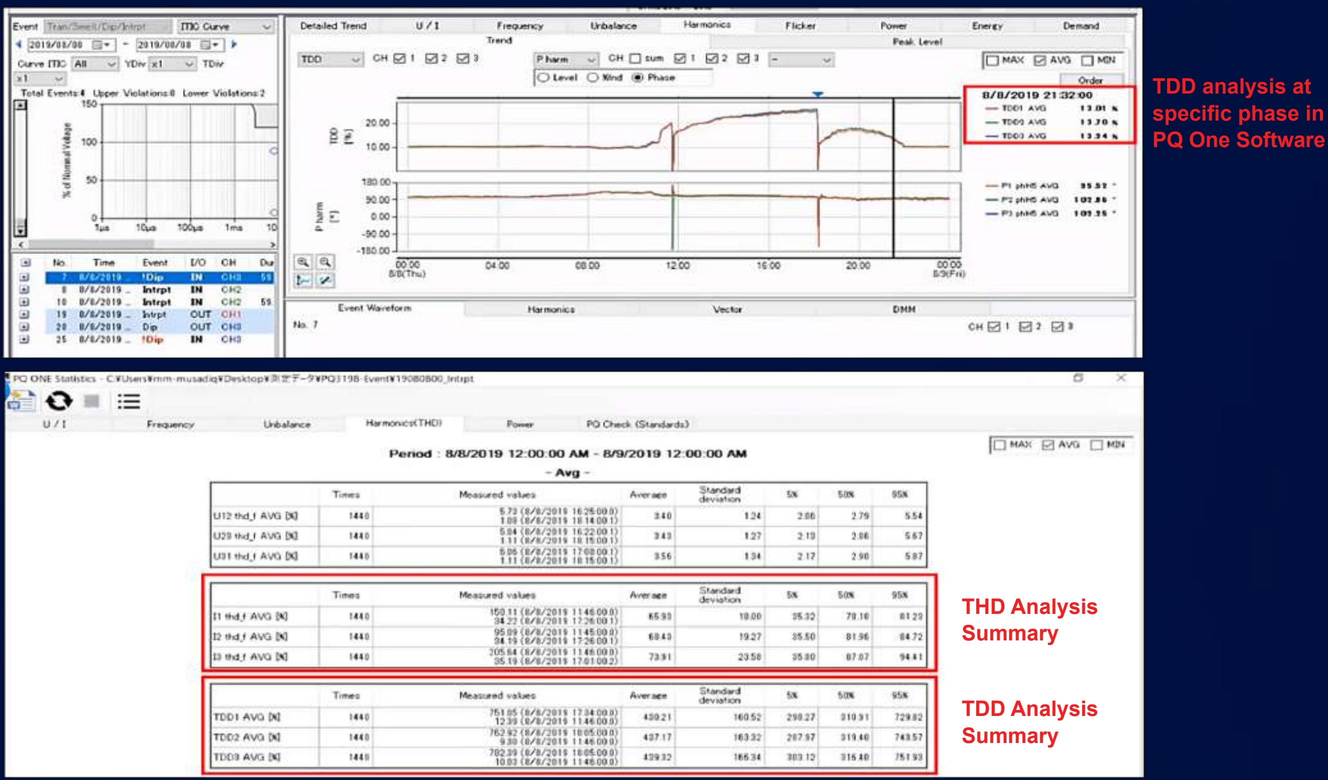



Figure 8.0 THD and TDD Analysis using PQ One Software

There's also an option to view the vector of harmonics in Linear and Logarithmic view, which is useful for viewing low phase angle vector values (Figure 9.0).

**Linear Vector Display**

**Logarithmic Vector Display**
Helps in viewing the phase angle more clearly for low phase angle vector values ( I2 in this case)


Figure 9.0 Vector View of Harmonics in Linear (left) and Logarithmic (right)

**The PQ3198 is also capable of capturing high-order harmonics waveform up to 80 kHz (this is mostly generated by electronic components in Power Supply Unit (PSU) installed in semiconductor devices) (Figure 10.0).**

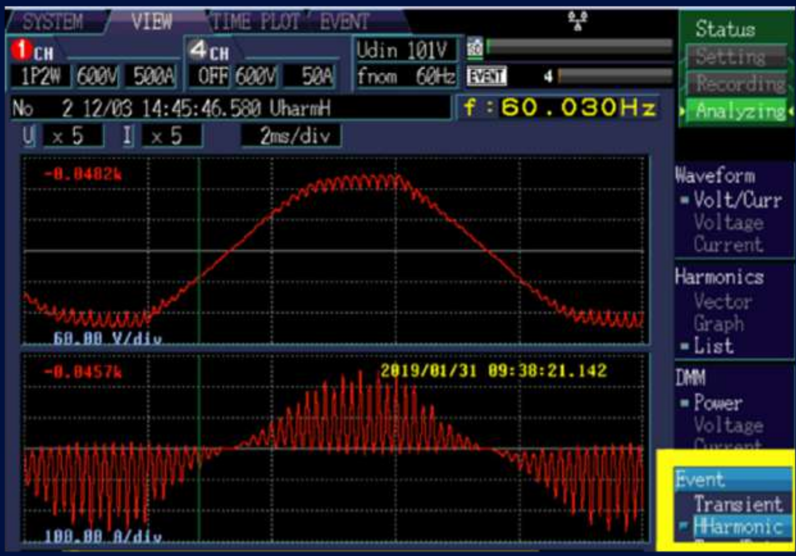
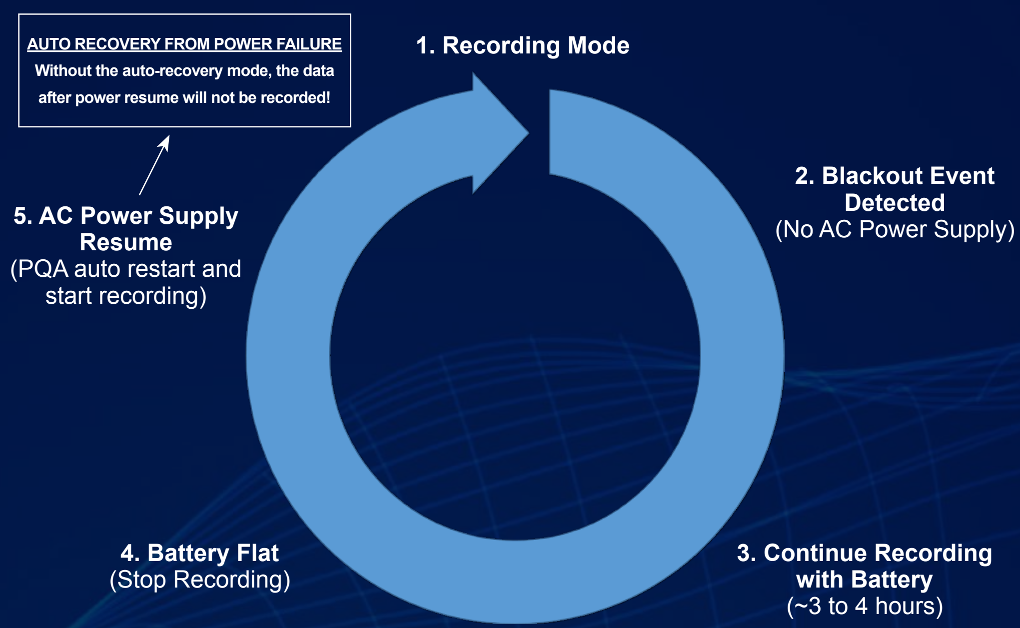



**Figure 10.0 Screenshot of a High Order Harmonics Waveform**

**Other key features of the PQ3198 for harmonics measurement include:**

- **Compliance with IEC 61000-4-30 Ed. 3 Class A standard**
- **Auto-recovery mode from power source depletion where the PQ3198 will automatically restart and start recording when the AC power source resumes, ensuring continuous data logging**



- **Built-in HTTP server function which allows user to check the results and configure the PQ3198 using a browser**
- **Built-in FTP function which allows user to retrieve the data at any time and place**
- **Integrate with GENNECT One freeware for multiple devices (maximum of 15 instruments) logging of up to 512 parameters and also stand-alone BMS function**
- **Synchronization to the UTC Standard time by using Hioki PW9005 GPS Box (useful for multiple PQ3198 data comparison)**


**Since harmonics is a measurable parameter, it can also be controlled using several basic methods [9]:**

- **Reducing harmonics currents in loads i.e. by adding a line reactor or transformer in series**
- **Adding filters to siphon or block the harmonic currents from the system i.e. shunt filters which work to short-circuit harmonics currents as close as possible to the source and active filters that electronically supply the harmonic component of the current into a non-linear load**
- **Modifying the frequency responses of the system to harmonics i.e. changing capacitor size, moving or removing capacitor, and adding a reactor to detune the system**

**In conclusion, harmonics measurement is crucial as it impacts the power efficiency, functionality and lifespan of equipment; the source(s) of harmonics need to be identified and controlled before it brings harm to the equipment. The PQ3198 is equipped with multiple features that enable correct and meaningful harmonics measurement and source identification.**

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**HEADQUARTERS**
81 Koizumi
Ueda, Nagano 386-1192 JAPAN
www.hioki.com

**HIOKI SINGAPORE PTE. LTD.**
(For South East Asia, Oceania & Bangladesh markets)
33 Ubi Avenue 3, #03-02 Vertex, S408868
TEL: +65-6634-7677
www.hioki.com.sg
www.facebook.com/HiokiSingapore

**Thailand Representative Office**
202 9th Floor, Room 906, Le Concorde Tower
Ratchadapisek Road, Huay kwang
Bangkok 10310, Thailand
TEL +66-2-051-5323
www.hioki.com.sg
www.facebook.com/HiokiThai

**PT HIOKI ELECTRIC INSTRUMENT**
Gedung Graha MIR, 1st Floor, Zone C
Jl. Pemuda No. 9, Rawamangun, Pulogadung
Jakarta Timur 13220, Indonesia
TEL +62-21-2956-9853
www.hioki.com.sg
www.facebook.com/HiokiIndonesia