Power Quality issues resulting from Energy Saving Initiative- New Revenue Opportunity for the Building Automation Community

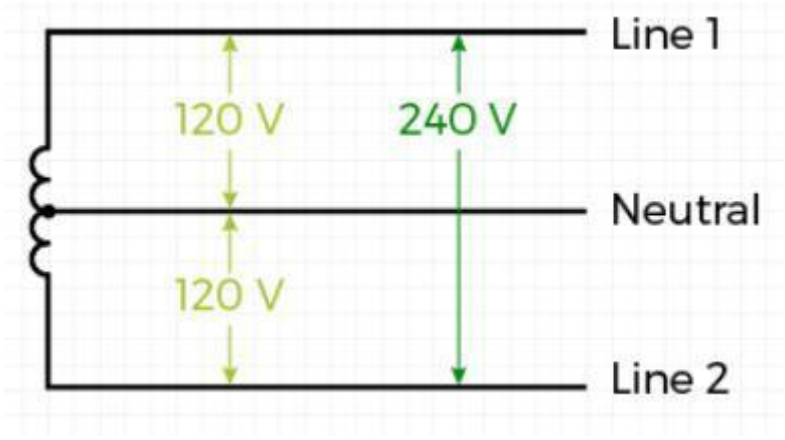
Abstract:

Energy saving and green energy initiatives are changing the energy economy for more carbon free and cost-effective power production. However, introduction of energy efficiency measures like LED lights, VFD (Variable Frequency Drives), EV (Electric Vehicles) charging stations, and smart solar grids also pollute the power lines by introducing current and voltage harmonics, voltage/current imbalance and many other deleterious power quality issues. Therefore, with the adoption of energy efficiency measures, there is an increased need to analyse the resulting power quality since the measures may adversely impact expensive machines such as HVAC systems, pumps, motors, CT scanners, MRIs, and many others. It may also increase the fire hazards from current imbalances. Consequences of resulting poor power quality from energy efficiency measures may outweigh any financial or practical gains of Energy saving projects. This paper shows one of such case studies done on an office building with five floors and having different offices in different floors.

1. Introduction:

This article first explains the sources of current/voltage harmonics and imbalance. Further, it demonstrates how modern Power expert system (in this case from Machinesense) can be used to understand degrading power quality of the buildings. All of the Machinesense system data can be tapped from Modbus on TCP. This offers a new revenue opportunity in Building automation projects since EV charging, UPS and energy saving measures are ubiquitous everywhere. Machinesense expert system can be used as a smart energy meter as well as power quality auditor.

2. Typical power distribution in a large commercial building in USA/Canada:



Single phase three wire system with hot lines and a neutral. Heavy-duty single-phase loads in commercial premises run from 240V L-L system (2 #Hot wires) and lower power equipment runs from 120V L-N system.

- Typical single-phase loads in 120V system (#Hot wire to # Neutral):
  - **Power outlets for mobile/laptop chargers etc**
  - **CFL lamps or other LED lights**
  - **Fans**

- Whereas heavy-duty single-phase loads in 240V system (#Hot wire 1 to #Hot wire 2):
  - **Refrigerator**
  - **Air Conditioner**
  - **Dryers**
  - **Water heater**
  - **Electric vehicle charger**
  - **Electric Stoves**

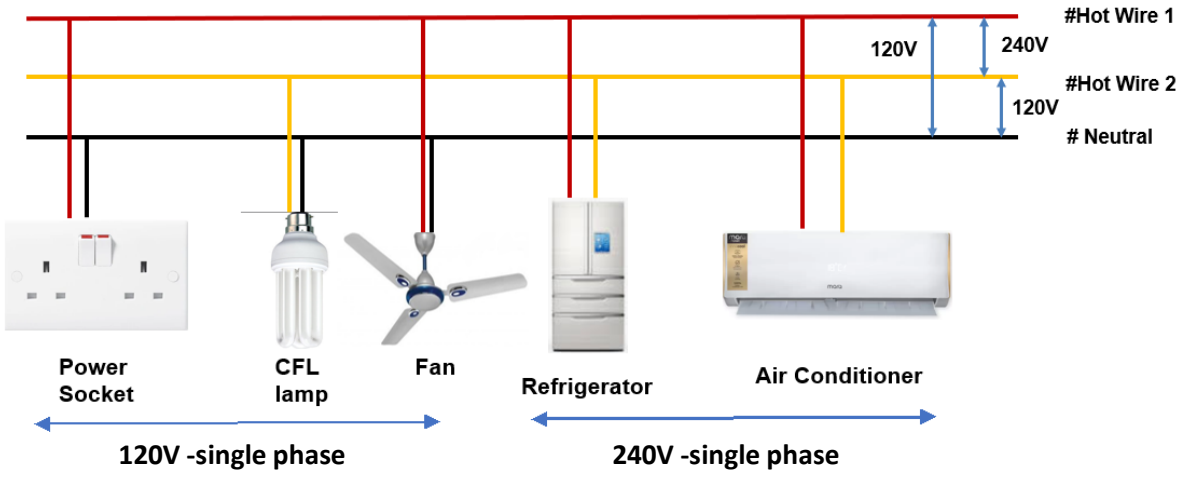


Fig. 1 Uneven distribution of low power (@120V) loads in a commercial building

As low power single phase loads like fans, lights, power outlets are connected between any Hot wire and Neutral, there is always a chance of getting poor load distribution among two #Hot wires w.r.t #Neutral. This will create neutral imbalance and makes it overloaded. But heavy-duty single-phase loads like AC, refrigerators, water heaters, dryers etc run from two #Hot wires. So, the system is always safe w.r.t distribution of these kind of loads.

3. Sources of current imbalance & other power quality issues

3.1 Imbalance in connection of single-phase loads

In split phase or single phase three wire (2 # Hot wire and a neutral) system does have two lines with 180-degree
phase shift. If the loads were guaranteed to be balanced (Fig. 2), then the neutral conductor would not carry any current and the system would be equivalent to a single-ended system of twice the voltage with the line wires taking half the current. This would not need a neutral conductor at all, but would be wildly impractical for varying loads; just connecting the groups in series would result in excessive voltage and brightness variation as lamps are switched on and off.

If the loads are not properly distributed (Fig. 3) among two #hot wires and neutral, severe current imbalance may result overload on one or two phases. This over in any phase may reduce its thermal capacity.

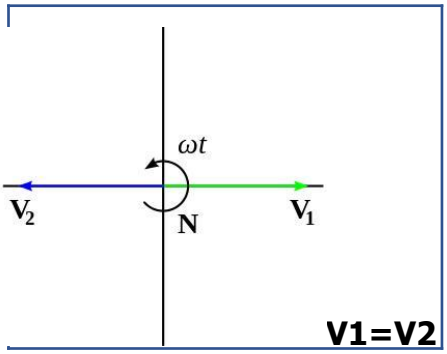


Fig. 2 Phasor diagram of split phase or single phase three wire system with balanced load.

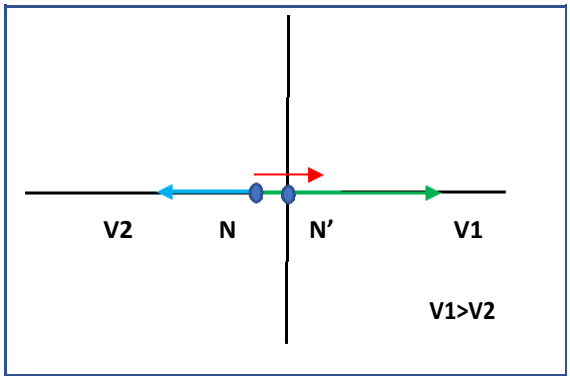


Fig. 3 Phasor diagram of split phase or single phase three wire system with unbalanced load.

3.2 Effects of high frequency inverters and other nonlinear devices- SMPS (laptop, mobile chargers etc.)

Nonlinear loads introduce significant harmonics in phase currents. These harmonics effectively change the power factor of the overall load as indicated by the true power factor.

3.3 Harmonic distortion

Current Imbalance creates harmonics and induced harmonics creates imbalance too.

3.4.1 Harmonic distortion

Nonlinear loads connected to power lines always generates harmonics because of its non-linear nature. Most of the AC-DC power conversion using diode (uncontrolled device) in any electrical home appliances creates majority of the 5^{th} and 7^{th} harmonics in the order of 40-60%. Modern day's low-cost mobile chargers or laptop chargers always use nonlinear AC-DC power conversion generating high harmonics which circulates in the wire and affect other critical equipment which is unprotected at the same line. High harmonic is one of the reasons of the equipment failure.

3.4.2 Burn-out of Single-phase loads (lighting, power adapters etc.)

When the amount of nonlinearity in the power line is excessively high, the presence of high harmonics increases true rms of the Amperage in the conductor and started generating more I^2 R loss. It eventually deteriorates thermal capacity of the conductor insulation and more often power lines get affected significantly. If neutral gets damage due to this then all the low power single phase loads which are running from 120V system will be isolated from the source utility and loads like LED/CFL lamp, power adapter may burn out experiencing high voltage as neutral is isolated.

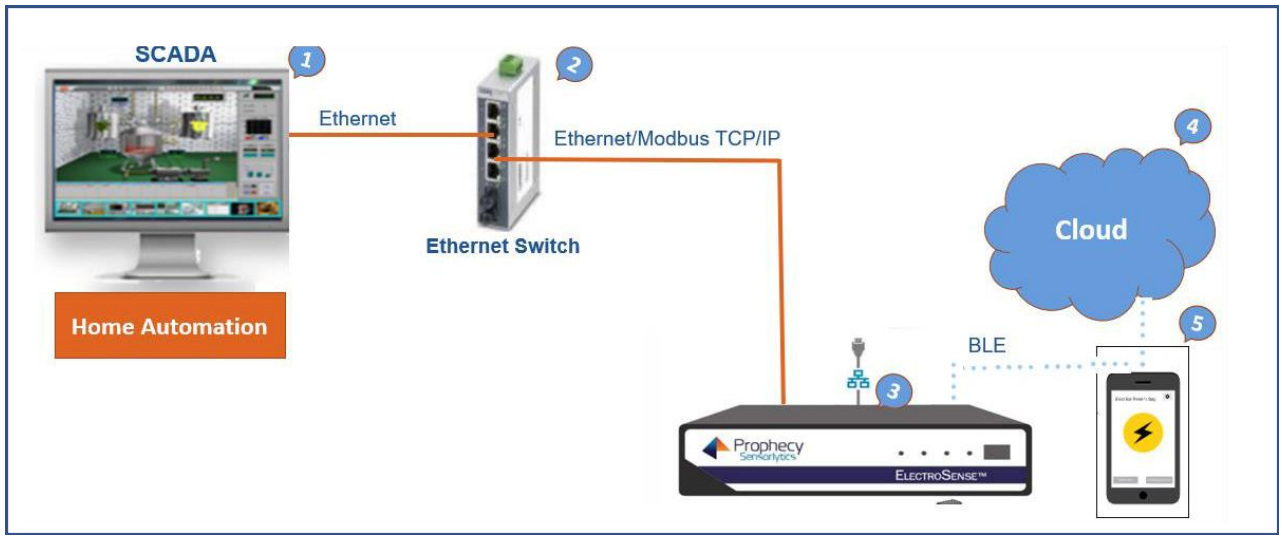
4. A hybird way to capture all the power quality data!

We have used Machinesense Expert System which can distribute power quality data to HMI via Modbus and to cloud via Ethernet and WiFi. Therefore, the system is flexible and it works with both legacy automation system as well as new IoT systems.

4.1 Consideration for Networking & Automation

- When it comes to select any network to work with existing devices or sensors, Modbus TCP/IP gives many advantages compared to other solutions.

- **Simplicity**: It is simpliest of all. It only requires Modbus instruction set to wrap TCP/IP around it. Modbus driver is to be installed which is a few steps process and then knowledge of using Ethernet and TCP/IP sockets makes modbus running and communicating to remote PC very easily.
- **Standard Ethernet**: Standard PC ethernet card can be used to communicate with remore devices.
- **Availablity**: Interoperability among different vendors' devices and compatibility with a large installed base of Modbus-compatible devices makes Modbus an excellent choice.
- **Cost effective**: As it requires minimum hardware change so cost and execution time will be very less.

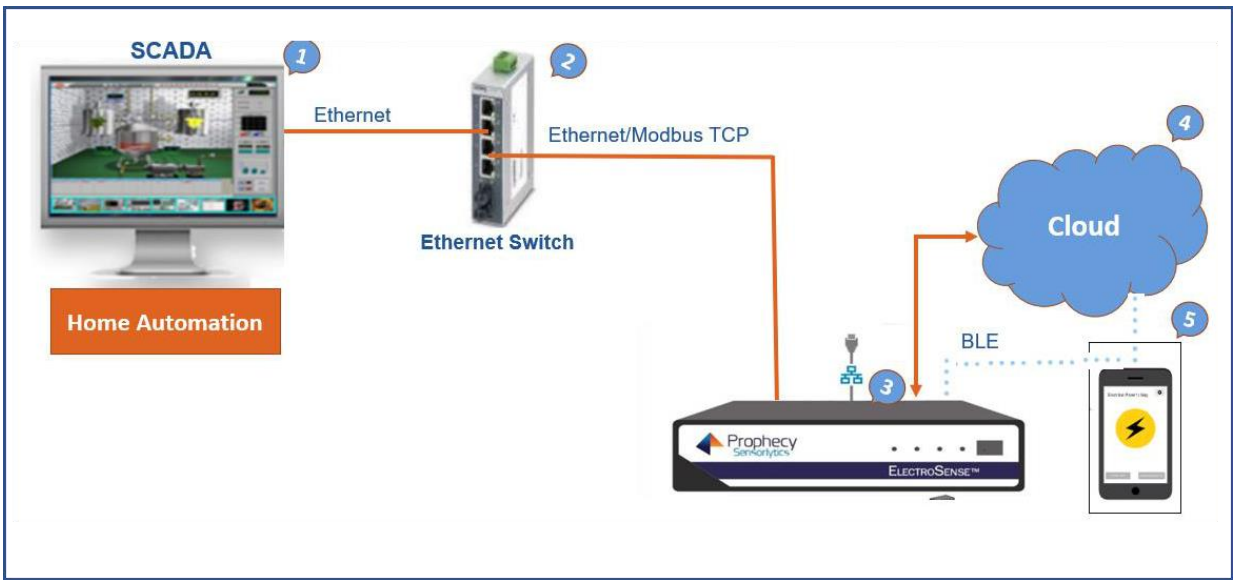


4.2 Component list:

1. Home Automation SCADA
2. Ethernet Switch
3. MachineSense Power Analyzer with inbuilt SSD for local storage
4. Cloud – only for device onboarding
5. Mobile App ---- dual fucntion App for fetching sensor details from cloud and pushing back to MW through BLE.

In this architecture, Power Analyzer should not be connected to cloud at all. Third party front end visualization can be intergrated through Modbus over ethernet.

4.3 Cloud based architecture for Modbus over ethernet conncetivity: ON line version

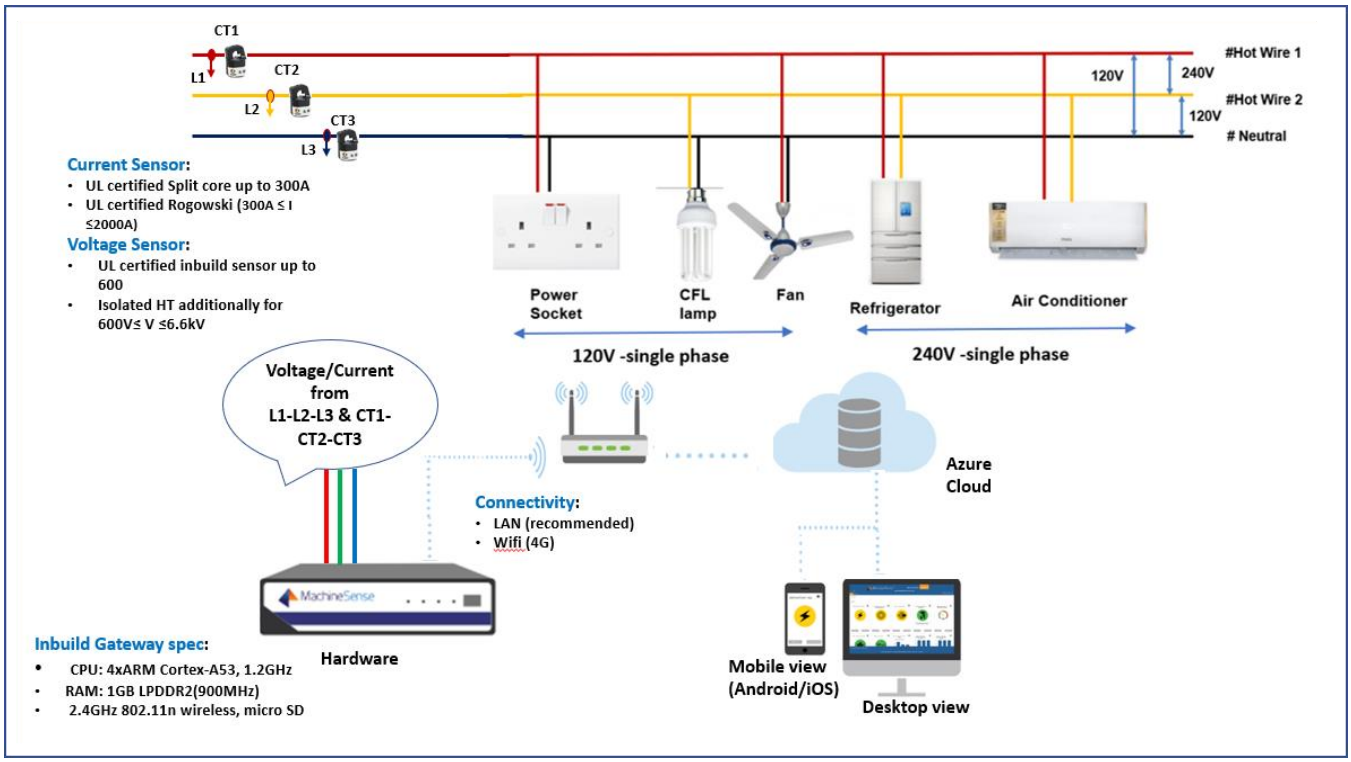


Component list:

1. Home Automation SCADA
2. Ethernet Switch
3. MachineSense Power Analyzer without SSD. Power Analyzer should be connected to the cloud over dediacted ethernet for online remote monitroing.
4. Cloud – used for data visualization
5. Mobile App ---- dual fucntion App for fetching sensor details from cloud and pushing back to MW through BLE.

In this architecture, both MachineSense data visualization (Crystalball) and local visualization over Modbus will be available.

5. Typical System Installation:



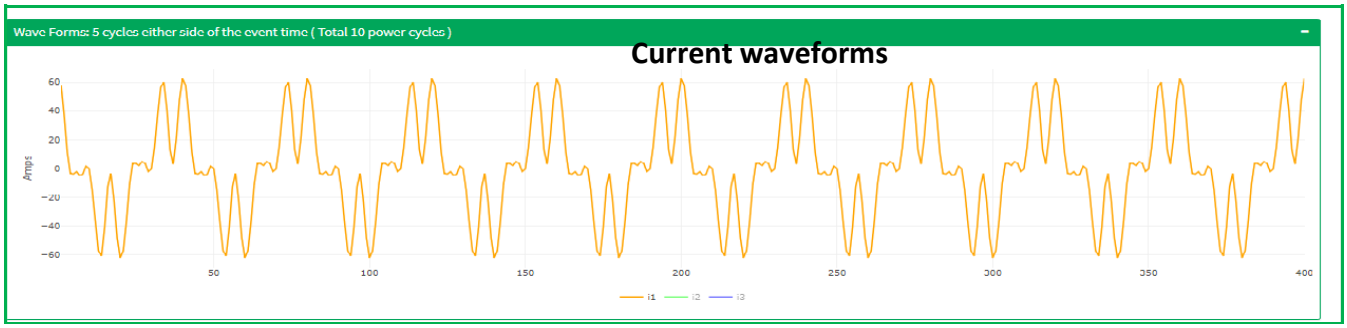
6. Description of the installation for case study:

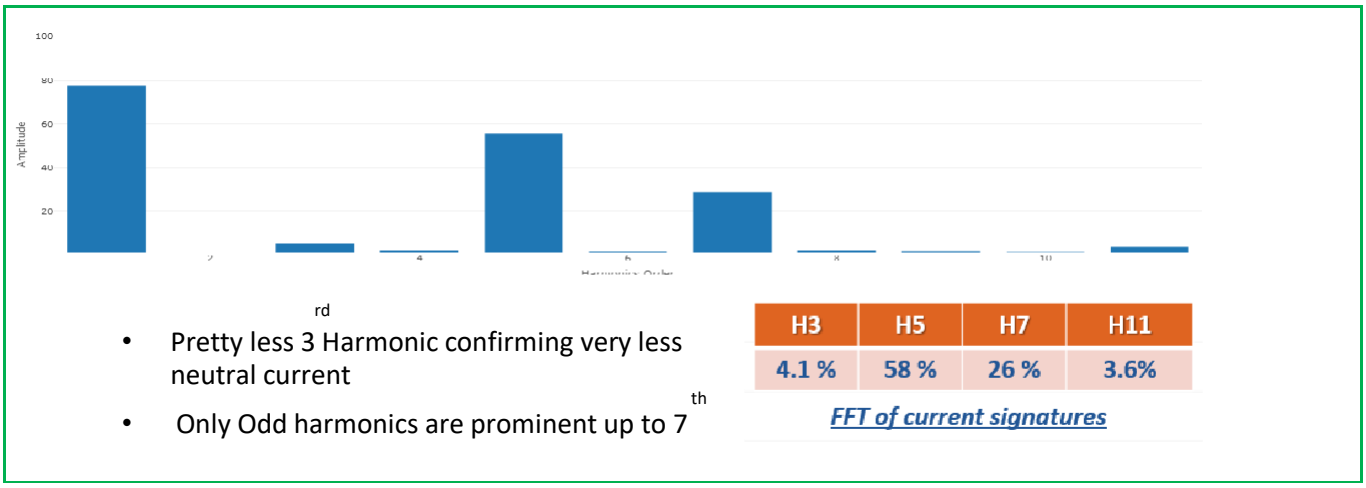
We have selected a five storied office building for a typical case study. MachineSense Power Analyzer is installed at the outgoing terminal of the Main incoming DB (Distribution Box) on the ground floor so that characteristic of overall load connected to different floor can be measured and a proper analysis can be made to show how non-linear loads and improper distribution of such load degrades power quality.

- **Voltage/Current tapping**: MachineSense Power Analyzer can measure both 3-phase 4-wire (with neutral) and 3-phase 3-wire system. Voltage up to 600V can be measure nominally but in case of high voltage up to 6.6kV, an additional isolated step-down transformer can be used. A wide range of current up to 2000A can be measured using Rogowski otherwise simple split core CT can be used for the measurement up to 300A.
- **Power Supply**:
  - 110-270V AC @50/60Hz or
  - 24V DC
- **Connectivity medium:**
  - Ethernet drop (recommended) or 4G router for Azure connectivity
  - Modbus over ethernet for third party integration
- **Visualization**:
  - Web App or Mobile App for MachineSense visualization
  - Third party HMI communicated over Modbus

Few steps installation procedure doesn't kill much time and it also make sure there is no down time required for installation.

Web View for Expert visualization: (Real time analysis of any event)



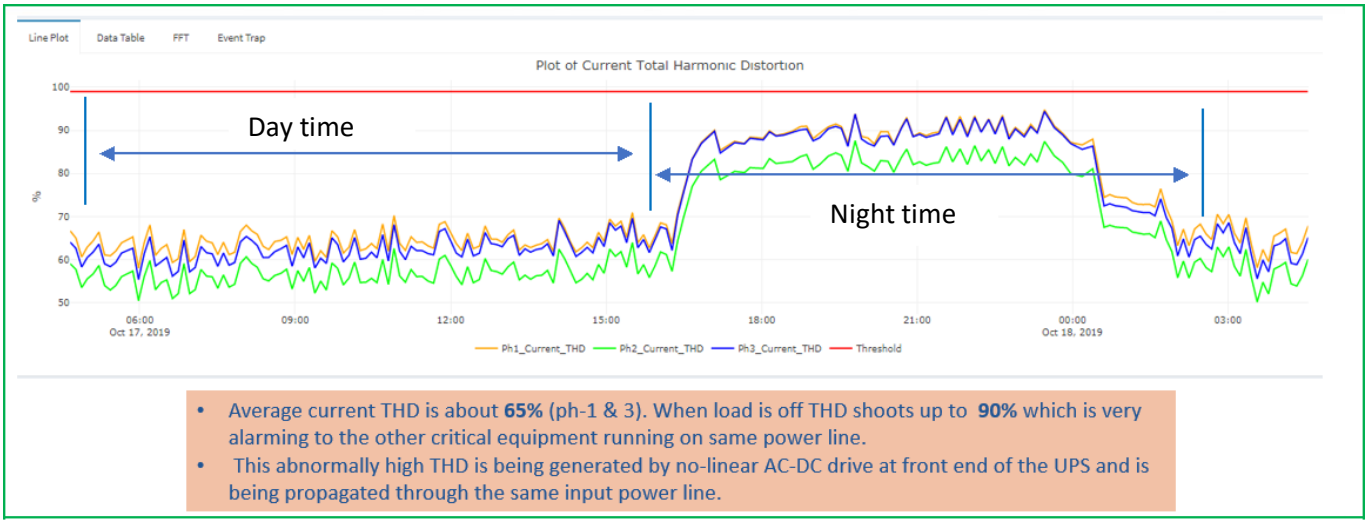


- Pretty less 3rd Harmonic confirming very less neutral current
- Only Odd harmonics are prominent up to 7th

H3	H5	H7	H11
4.1 %	58 %	26 %	3.6%

FFT of current signatures

Current THD plot over 24 hrs- Day vs Night



- Average current THD is about **65%** (ph-1 & 3). When load is off THD shoots up to **90%** which is very alarming to the other critical equipment running on same power line.
- This abnormally high THD is being generated by no-linear AC-DC drive at front end of the UPS and is being propagated through the same input power line.

MachineSense' data monitor for Predictive and Preventive Analysis

- **Conclusion:** In this article we have shown different sources of poor power quality in a typical office building and how they will erode the energy saving measure if not properly mitigated in due course of time. We also show how Building Automation Community can add Machinesense Expert System Data to their HMI and thus expand the scope of the project as power quality issues in a building can't be ignored anymore. This doesn't add to any new hardware cost as the Machinesense expert system also works as a Energy Meter.

  To receive a 5% Discount on any MachineSense Power Quality Analyzers go to: http://esquaredenergyadvisors.com/machinesense/