Power Quality Assessment Report & Proposal

for

[redacted]

[redacted]

Wednesday, May 8, 2024

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Table of Contents

Introduction

Basic Power conducts power quality surveys to better understand the system in order to prescribe solutions to existing power quality issues. This document explains the methodology and the specific reasons for certain measurements. In short, this is a detailed guide to understanding power quality issues and ways to identify them in your system.

Pre-Screen Process

Starting off with basic information, we need to know the location, the type of operation, ownership, and age of the building.

The operation type of the building is an important piece of information because we can make early assumptions judging strictly on the expected technologies within the system. For example, an office building would have large inductive motor loads from the HVAC system and elevators while a supermarket would focus more on just HVAC.

The building's age is also important to us because we realized that older buildings are under-engineered due to the change in load-types throughout the years. Perhaps during the building's early ages, the specifications met some standards, however, with newer inductive and nonlinear loads, we expect those same wiring specifications to perform poorly.

Afterwards, we will request documents that help us profile the power quality of the site.

List of Documents:

- *Power Quality Measurements*
- *Energy Consumption Bill*
- *Line Diagram*
- *List of Recent Changes or Upgrades*
- *Transformer Specifications*
- *Grounding Test Results*
- *Previous or Existing Filter Specification (if applicable)*
- *Previous or Existing Capacitor Bank Specification (if applicable)*

To begin, we'd like to know if power quality measurements were made. If we have this information and deem it useful for our analysis, then we'll use this information to diagnose the problem. However, from our experience, power quality reports we receive are often short and missing necessary information for a proper diagnosis, so we prefer performing our own power quality measurements. More details on the power quality report later.

The energy consumption bill is usually the most readily available document for most facilities. Depending on the provider, we can extract some surface level information about the power quality. The important values are real power (kWh), apparent power (kVA), and reactive power (kVAr). From these values, we can calculate the current output of the system, power factor, and estimate the losses. Although the electricity bill reports these values, they are often an average over the course of the month, which isn't an accurate depiction of the actual energy profile.

The line diagram is a schematic of the site that we can use to identify potential problems and areas of interest. For example, in large industrial plants, variable frequency drives (VFDs) are used in conjunction with motors to save energy. However, VFDs are switch-type controllers, meaning that it will connect and disconnect energy at high speeds to control the speed and orientation of the motor. This switching mechanism causes transients as well as harmonic issues within the motor. Almost all inductive motors behave with a dependency on the harmonic frequency. Suppose the negative direction is considered as a counter-clockwise signal while the positive direction is considered as clockwise signal. The 5th order harmonic determines the negative direction while the 7th order harmonic determines the positive direction. When the AC waveform becomes nonlinear due to the VFDs, both signals of positive and negative from the 5th and 7th harmonic are sent to the motor. This causes the motor to stutter or vibrate, at times even completely lock up. Although VFDs can save energy, it can build up harmonics within the system and end up damaging the motor itself. The line diagram gives us an idea of where to measure to identify potential problems.

Similar to the point above, we'd like to know about any recent changes to the system. Perhaps a newly added VFD is causing the motor to stagger during its operation. Sometimes adding an additional inductive load without proper reactive power compensation can reduce the overall power factor which increases energy loss through the wires, transformers and motors. The efficiency of the system decreases as the power factor decreases, so it's best to maintain a high power factor.

Another detail we need in the pre-screening process is the operation hours of the building. If the site appears to be steady across the week, we'll most likely conduct a simple 24-hour power quality survey for an accurate energy profile. However, if the operation varies throughout the course of the week, we'd like to conduct a 7-day power quality survey to accurately capture the energy profile of the site. Through this method, we can calculate a proper solution that fits the operation demands.

The rest of the documents on the list is for us to calculate potential energy savings from the solutions we plan to propose. This way, as the client, you can make an informed decision from all the information we extract from these documents.

The following chart displays the status of the pre-screening documents as of Wednesday, May 8, 2024:

Available Documents	Missing Documents
• Line Diagram • Power Quality Measurements	• Energy Consumption Bill • Transformer specifications • Grounding test results • Previous or existing filter(s) information • Capacitor bank(s) information

Based on the information we receive from the pre-screening process, we will decide on which locations to measure and what to look for. Before we conduct any measurements, we first scout the location to identify the characteristics of the operation. For example, if an office building is heavily using its HVAC system or lights throughout the day, we can note that in our initial scout. During this procedure, we'll take a look at a few things:

- Wire gauge in the main distribution panel
- Existing equipment failure
- Major load areas

The importance of wire gauge specifications within the building is that it can contribute to the losses of energy within the wire. For larger wire gauges, there' less resistance, resulting in more efficient energy transmission from point A to point B. However, older buildings were engineered for smaller and less complicated loads, so the resistance of the wires are probably not optimal for today's standard. This information helps quantify the energy losses and allows for energy savings calculations.

If there were any recent equipment failures, we'd like to know about it. Depending on the load-type, we can use it as supporting evidence when determining the main cause of these issues. If the equip was old, internal components might have been the cause of the failure. However, if newer equipment continuously fails, it is most likely the cause of poor power quality.

In the analysis, we'd like to measure the major load areas to generate a proper energy profile of the building. Suppose the main issues only account for half of the total energy profile, then any adjustments or fixes will at most account for half of the total energy profile. However, for us to quantify the amount, we'd need to know the main loads of the establishment and where to measure them.

Depending on the situation, we'll offer a 24-hour or 7-day power quality measurement. This process will document the real power (kWh) consumed, as well as the reactive (kVAr) and apparent power (kVA). This process will also record the power factor, any transient events, sags/swells within the system, harmonic contents, etc. During this time, maintain the same level of operation as if the device was absent.

After receiving this data, our engineers will process the information and evaluate the situation. The processed data will be summarized in detail with the recorded findings from the meter. The report will contain the following content:

- Voltage
- Current
- Power (kWh, kVAr, kVA)
- Power Factor
- Frequency
- Waveforms
- Harmonic Distortions
- Sags/Swells
- Transient Events

Since the report is designed to educate the client on issues that they may not be aware of, the engineers will explain and provide a power quality solution to those problems.

Power Quality Report Summary

Measured Report Details

During the 214 hour power quality survey, we measured an active power of 11 kW. According to our findings, the apparent power (kVA) is 14 which is below the installed capacity and not causing any problems.

We detected no voltage unbalance of any concern or cases of current imbalance, which is good. In accordance with GB/T 15543-2008, the standard for current unbalance is anything below 30%. The measured current unbalance is on average 5.35%. As for the voltage unbalance, the allowable standard limit is 2%. We measured a 0.31% voltage unbalance which passes the regulation standards of the GB/T 15543-2008.

There were no anomalies detected with the frequency and the measured deviation of the frequency is within the standard limit of ±0.20 Hz according to the GB/T 15545-2008.

During this power quality survey, we did not observe any concerning voltage harmonics and all measurements comply with the IEEE 519 standard.

Phase A:	Phase B:	Phase C:
There are no harmonics of major concern	There are no harmonics of major concern	There are no harmonics of major concern

During this power quality survey, we measured the following harmonic currents that are considered too high according to the IEEE 519 standard:

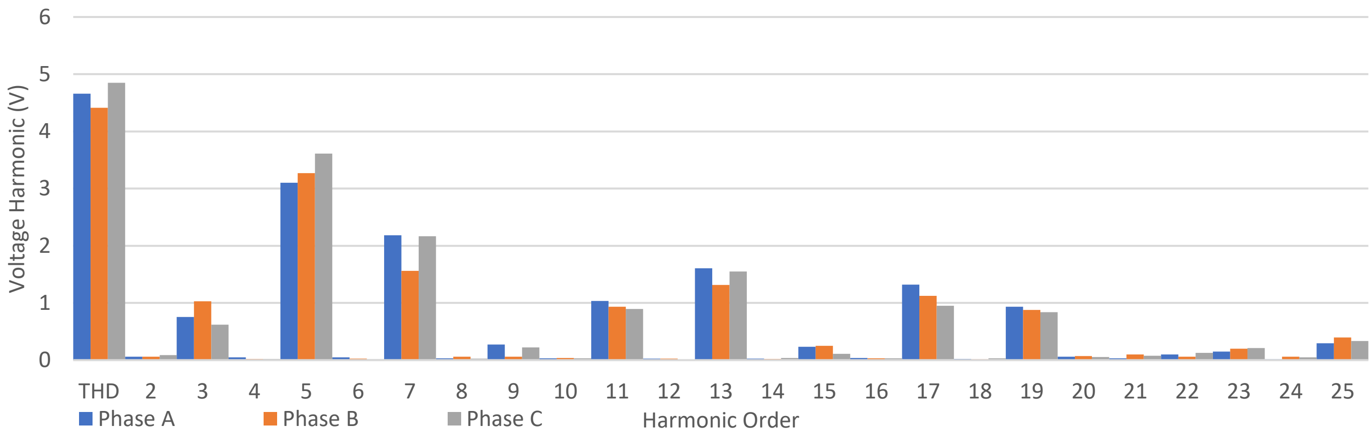
Phase A:	Phase B:	Phase C:
- H05 at 19.73%	- H05 at 19.38%	- H05 at 19.41%
- H07 at 8.51%	- H07 at 7.55%	- H07 at 7.34%
- H11 at 10.23%	- H11 at 10.16%	- H11 at 10.48%
- H13 at 5.45%	- H13 at 5.63%	- H13 at 5.28%
- H17 at 6.85%	- H17 at 6.63%	- H17 at 6.56%
- H19 at 4.91%	- H19 at 4.38%	- H19 at 4.26%
- H23 at 6.43%	- H23 at 6.85%	- H23 at 6.5%
- H25 at 6.02%	- H25 at 5.64%	- H25 at 5.43%

According to the report, no voltageevents were detected during the power quality survey. This snapshot indicated a trigger in Phase B. Transients could be a result of switching events, such as capacitor bank switching, operation startup, surges, etc.

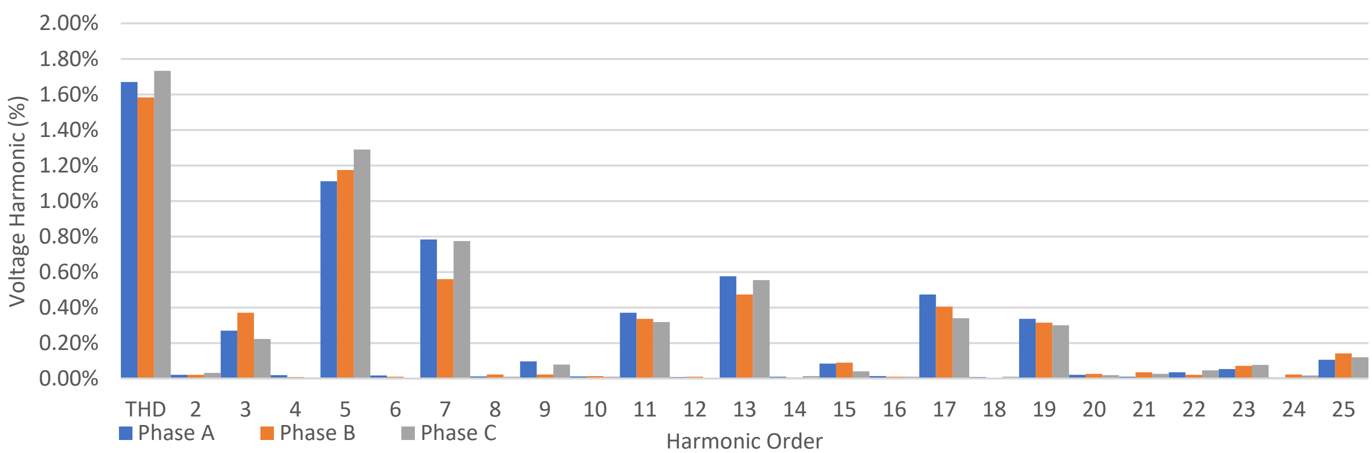
Voltage Harmonic Distortions

During this power quality survey, we did not observe any concerning voltage harmonics and all measurements comply with the IEEE 519 standard.

Phase A: There are no harmonics of major concern	Phase B: There are no harmonics of major concern	Phase B: There are no harmonics of major concern

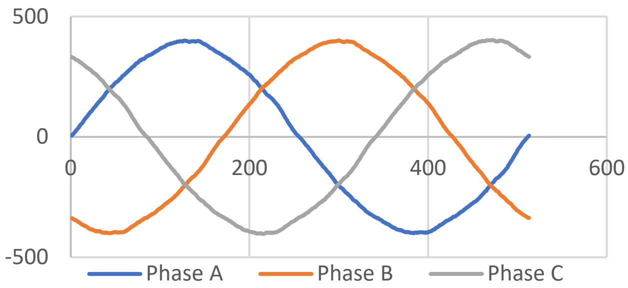


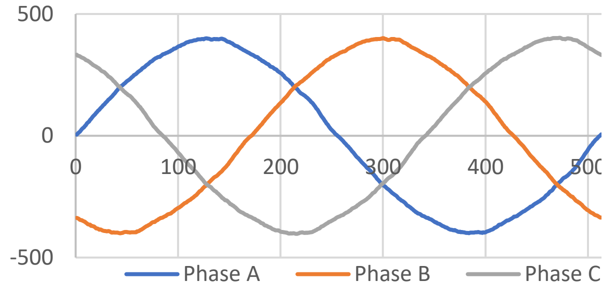
Displayed above is the harmonic content measured with your system. The measure harmonics are within IEEE 519 standards and should not harm the operation and its equipment.



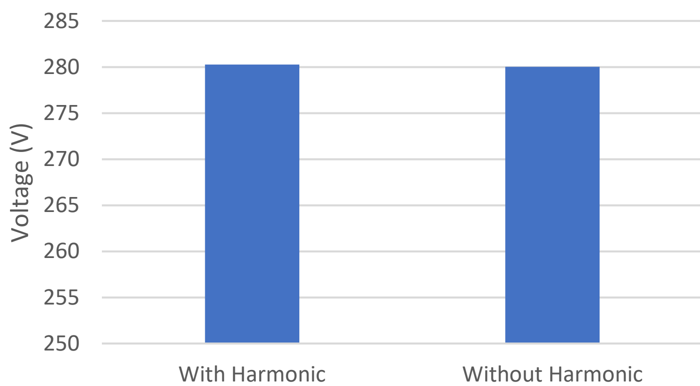
The graph above shows the voltage value as a percent of the total voltage measured, which in this case is 278.95V. Again, as you can see, there are no dangerous harmonics within your system.

Using the harmonic data, we can recreate the voltage waveform. Since the harmonic values change throughout the measurement, the following waveform is an illustration of the waveform based on the average harmonic content.





Suppose we remove the small amounts of harmonic we measured, the resulting waveforms (on the right) would resemble near perfect sine waves.

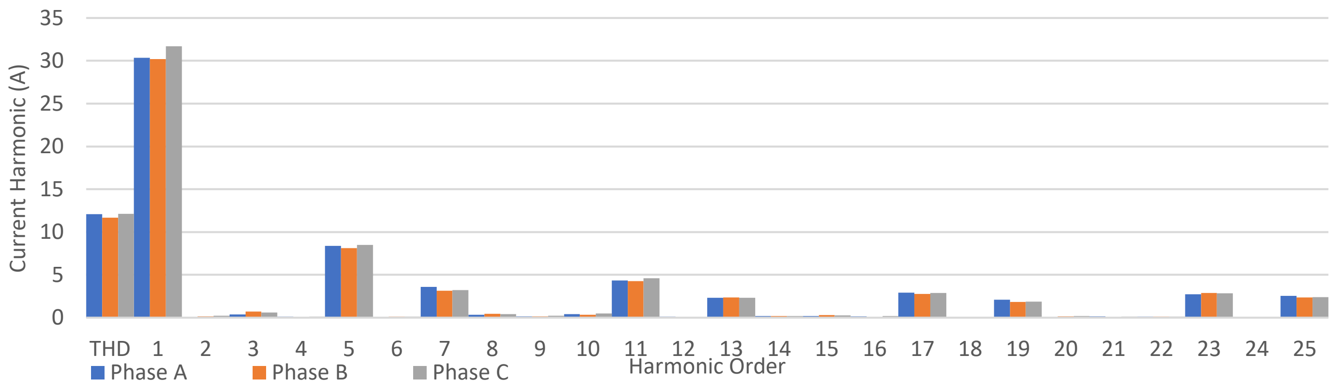


The graph above shows the voltage per phase. As you can see,The phases are less balanced most likely due to some resonance in the current harmonics.

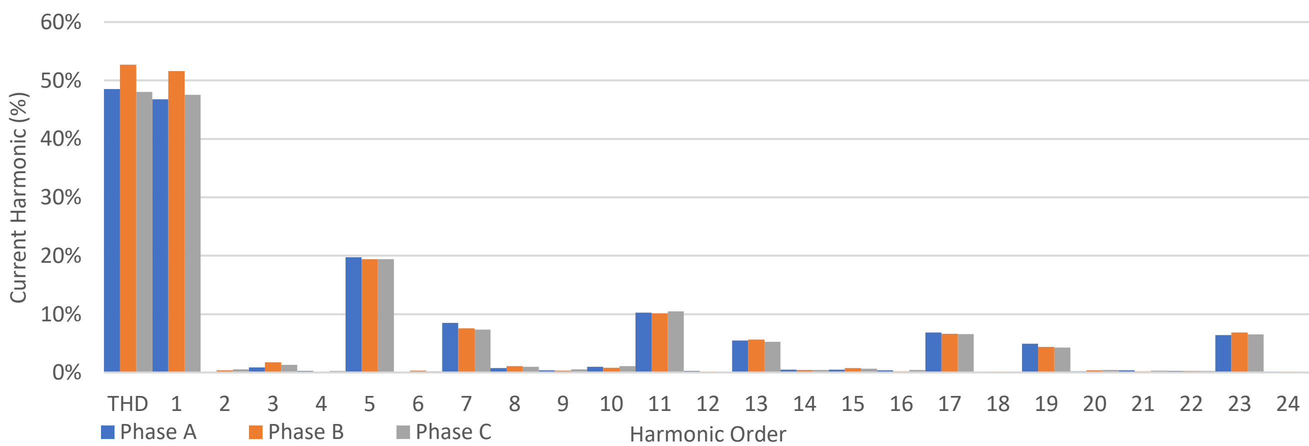
Current Harmonic Distortions

During this power quality survey, we measured the following harmonic currents that are considered too high according to the IEEE 519 standard:

Phase A:	Phase B:	Phase C:
- H05 at 19.73%	- H05 at 19.38%	- H05 at 19.41%
- H07 at 8.51%	- H07 at 7.55%	- H07 at 7.34%
- H11 at 10.23%	- H11 at 10.16%	- H11 at 10.48%
- H13 at 5.45%	- H13 at 5.63%	- H13 at 5.28%
- H17 at 6.85%	- H17 at 6.63%	- H17 at 6.56%
- H19 at 4.91%	- H19 at 4.38%	- H19 at 4.26%
- H23 at 6.43%	- H23 at 6.85%	- H23 at 6.5%
- H25 at 6.02%	- H25 at 5.64%	- H25 at 5.43%

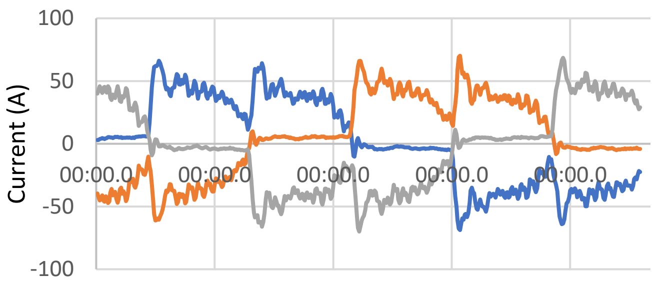


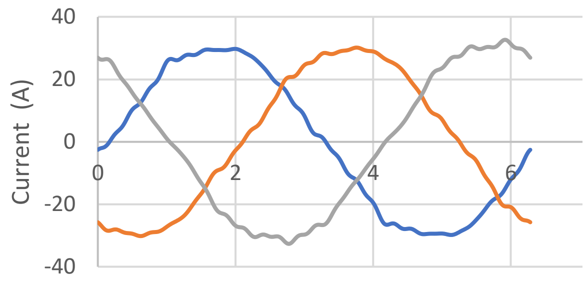
As you can see, the 5th, 7th, 11th, 13th, 17th, 19th, 23rd and 25th harmonic is high relative to the other voltage harmonics. Having high voltage harmonics can cause extra load consumption since the peak voltage with harmonics will be greater. Another common harmonic issue is that it will cause voltage unbalance between the phases. The motor's life span will reduce as a result due to either overloading or irregular voltage signals.



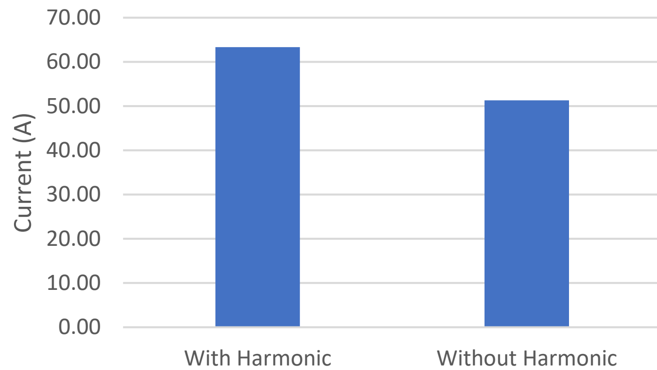
The graph above shows the current value as a percent of the total current measured, which in this case is 63.36A. Again, as you can see, the 5th, 7th, 11th, 13th, 17th, 19th, 23rd and 25th harmonic is the highest harmonic in the system.

Using the harmonic data, we can recreate the current waveform. Since the harmonic values change throughout the measurement, the following waveform is an illustration of the waveform based on the average harmonic content.





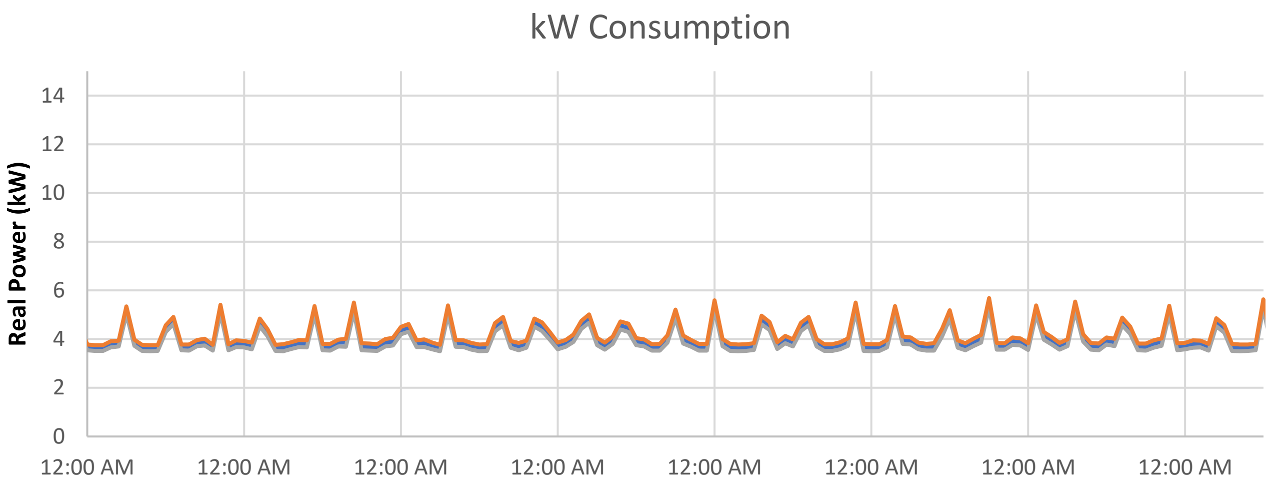
Suppose we remove the small amounts of harmonic we measured, the resulting waveforms (on the right) would resemble near perfect sine waves.



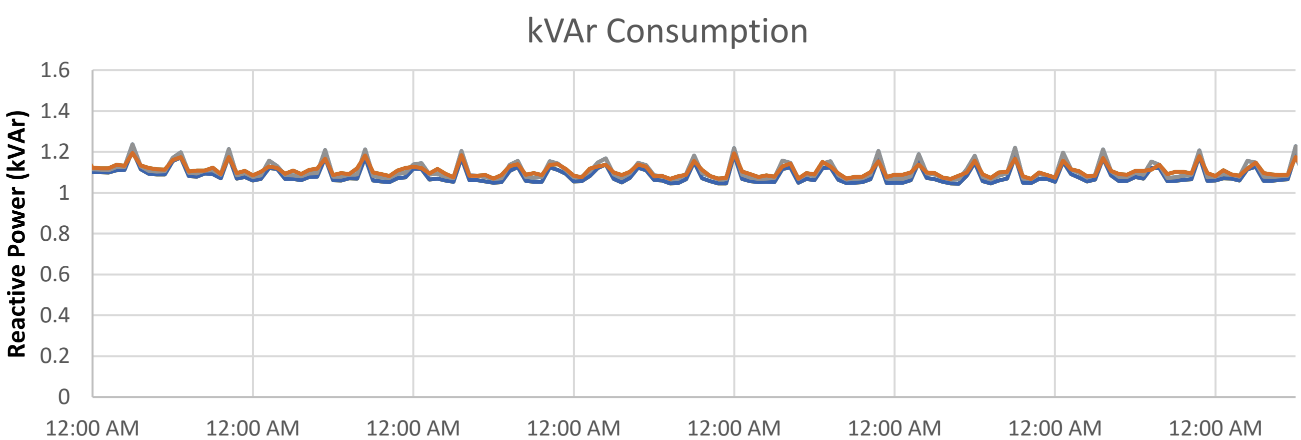
Graph above shows the difference in current between the peak current with harmonics and the without harmonics. It appears that the filtered harmonic has a lower current due to the reduction in current harmonics.

Power of the System

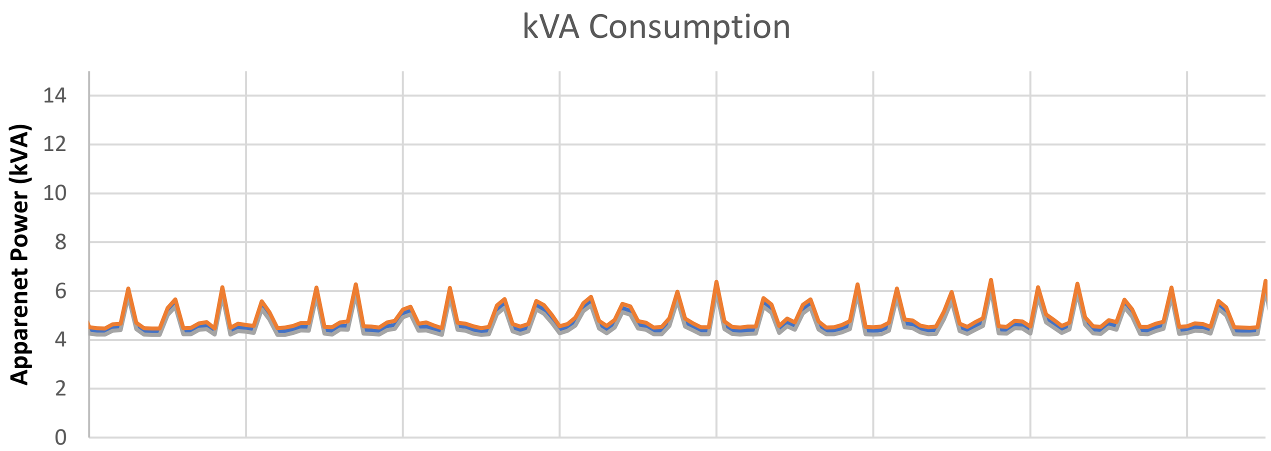
Within the 214 hour measurement, we collected data on the system's active, reactive and apparent power.



The kW consumed every hour is averaged to be 17 kWh. This is an energy value drawn from the load of the system. However, this value also includes the inefficient energy drawn due to losses and harmonics. Suppose kW is an amount of water and the load is drawing that water from a source, if there are leaks within the pipes or turbulance affecting the current, the efficiency of the system decreases.The importance of power quality is that it could increase the efficiency of the system and reduce unnecessary losses within the system.

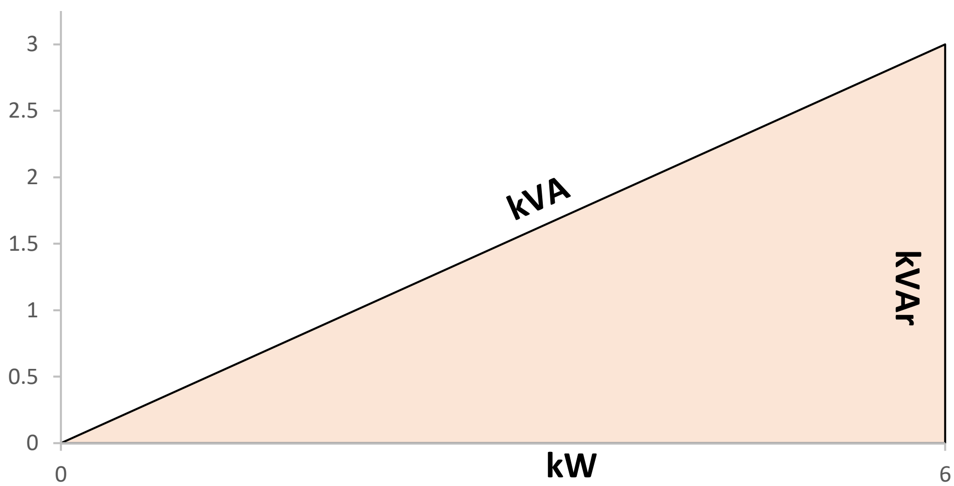


The maximum kVAr absorbed or returned by the load is 4 kVAr. This value represents the total power absorbed by the load or returned to the utility. To understand reactive power more clearly, let's first establish the relationship between reactance and reactive power. Reactive power is directly proportional to reactance with the current being theproportionality constant. If we lower the reactance of the load, we can lower the kVAr of the load as well. Later in the Power Factor section, we'll discuss the importance of reducing this value.



The total kVA consumed by the load is 20 kVA. This value represents to total power flowing, both power used by the load and absorbed/returned. In other words, kVA is the result of both the kVAr and kW. This relationship can be further explained with a power triangle.

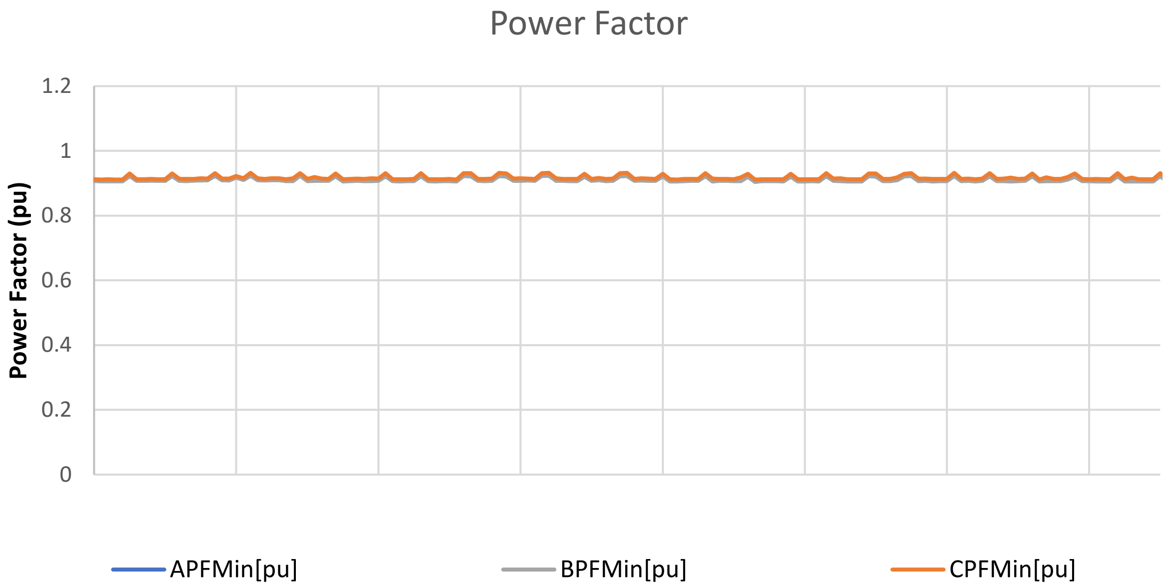
Power Factor



On the left is a power triangle, which illustrates the relationship between each power. As you can see, the kVA is just a result of a kVAr and kW value. Most utility companies charge a flat kVA capacity, which is the expected power distributed and returned. However, if the load overdraws this dedicated amount, the utility company will charge penalty fees. A good indicator on the system's load is a ratio called the power factor. It is the ratio of the real power to the apparent power. It can also be used to determine the phase angle, which is important to balance to prevent harmonics.

The average power factor of the system during regular operation times is 91.28%. To improve this value, either decrease kW consumed by the load or decrease kVA by reducing the kVAr needed in the system. Improving the power factor will improve the efficiency in power flow within the system. As a result, it can also reduce energy losses within the wires and the transformer. This will also reduce some harmonics, however, since a kVAr compensation solution doesn't necessarily tune into a specific harmonic frequency, the harmonics may still persist, but at a slightly less damaging amount. To reduce a significant portion of the harmonic distortions, you will need a harmonic filter tuned to the highest harmonic frequency in the system.

The following graph is the measured power factor at each phase of the system. As you can see, there's an uneven load in the phases, causing the power factor to vary per phase.

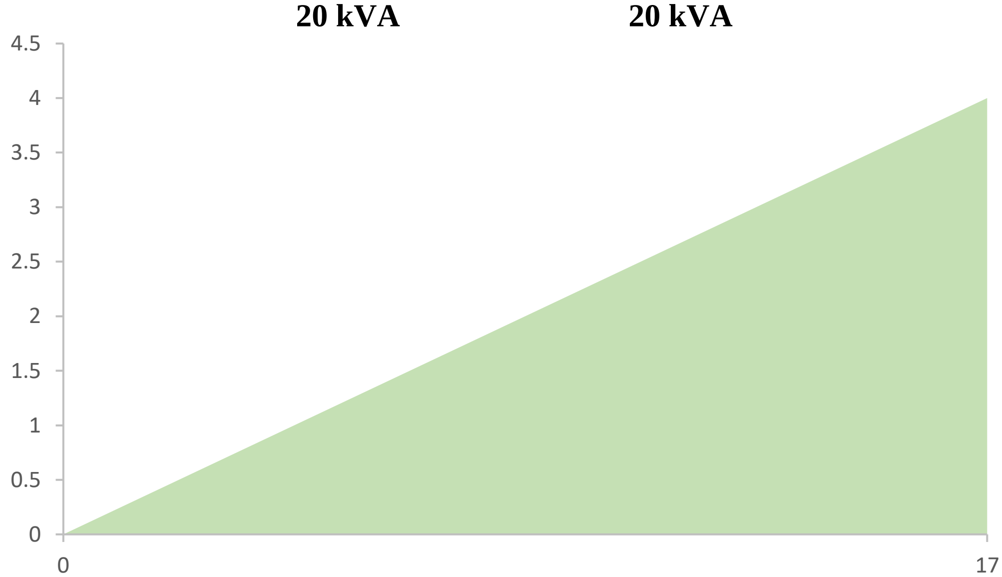


Suppose we correct the power factor to 95%, this would reduce the following values:

Old kVAr **4 kVAr** → **New kVAr** **0 kVAr**

Old kWh **17 kWh** → **New kWh** **17 kWh**

Old kVA **20 kVA** → **New kVA** **20 kVA**



As shown above, there is a change in the power triangle. The green represents the old power triangle with its kVAr, kW, and kVA. The orange is the new power triangle, noticeably smaller than the previous power triangle. This illustration shows the reduction of energy consumed by the system simply due to changes in the power factor.

Triggered Events

The following report is conducted with triggers, meaning if the conditions are met, a snapshot of the energy profile will be taken.

Of 1 total VOLTAGE SAGS

CRITERIA	PHASE	CATEGORY	DATA	DATE/TIME
Lowest Magnitude	A	SUSTAINED	35.0V, 6887 Sec.	3/28/24 4:35

Of 0 total VOLTAGE SWELLS

CRITERIA	PHASE	CATEGORY	DATA	DATE/TIME

Of 2 total VOLTAGE INTERRUPTIONS

CRITERIA	PHASE	CATEGORY	DATA	DATE/TIME
Longest Duration	A	MOMENTARY	0.6V, 2.372 Sec.	3/28/24 6:29

Of 27 total VOLTAGE TRANSIENTS

CRITERIA	PHASE		DATA	DATE/TIME
Largest Magnitude	B		866.1V, 0.002 Sec.	3/28/24 5:58

According to the report, no voltageevents were detected during the power quality survey.

Sags occur when there's a short circuit, an overvoltage, lightning strike, or insulation fails within the system. This cause the a decrease in the RMS voltage, making it lower than the nominal voltage, hence the term sagging.

Interruptions could be a result of a malfunctioning switching device or a response by a fuse, circuit breaker, or recloser. This suggests an overload occured and the operation was interrupted by a protection mechanism.

Transients could be a result of switching events, such as capacitor bank switching, operation startup, surges, etc. The spikes of energy can cause disturbances in the equipment, power them off or even permanently damage it.

Engineer Summary

During the power quality survey, we observed that the 5th, 7th, 11th, 13th, 17th, 19th, 23rd and 25th current harmonic is high relative to the other current harmonics. Having high current harmonics can cause extra load consumption since the peak energy with harmonics will be greater. Another common harmonic issue is that it will cause current unbalance between the phases. The motor's life span will reduce as a result due to either overloading or irregular voltage signals. It is recommended that you install a harmonic filter at the line side of the load to mitigate the harmonic.

Based on the measurements, the site has a power factor of 91.28%. This is good and improvement is optional. Any additional kVAr compensation would just further optimize the system and reduce the remaining losses. There is a diminishing return in the upper ranges of the power factor, and if the compensation isn't adaptive, the system could go leading, and send unnecessary and extra energy back into the grid. The current power factor is in a good range and doesn't require much kVAr compensation to reach 95% power factor.

According to the report, several voltage events were detected during the power quality survey.

Sags occur when there's a short circuit, an overvoltage, lightning strike, or insulation fails within the system. This cause the a decrease in the RMS voltage, making it lower than the nominal voltage, hence the term sagging. To fix voltage sag, power is injected via a backup power source. This will boost the voltage back to the nominal voltage and essentially mitigating the sag.

Interruptions could be a result of a malfunctioning switching device or a response by a fuse, circuit breaker, or recloser. This suggests an overload occured and the operation was interrupted by a protection mechanism. We recommend checking the fuses, switching devices, and breakers to ensure that it still performs as expected. This will help isolate the issue as either an intended consequence of the protective devices or a malfunction.

Transients could be a result of switching events, such as capacitor bank switching, operation startup, surges, etc. The spikes of energy can cause disturbances in the equipment, power them off or even permanently damage it. We recommend getting surge protection devices to shunt the transients and protect the system from getting affected.

Engineer Contact Information

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Email: Cedric@BasicPower.Energy

Engineer Proposal

Please refer to page 7 & page 8 for the current harmonic distortion graphs. As shown on those pages, the current harmonic distortion is too high. Out of the max current draw, about 40% is the result of harmonic distortion as well as the DC offset current. To reduce the harmonic distortion, we recommend installing a harmonic filter between the variable frequency drive (VFD) and the feed from subpanel [redacted] We recommend installing an active filter with power electronic switching to inject the opposite harmonic waveform - similar to noise cancelling. We advised the faculty electrician to stray from using passive harmonic filters due to the additional capacitance it will add to the system. The power factor is already at a good value, any additional capacitance will risk the system going into leading, which increases both voltage and current usage.

Both air compressors have similar current waveforms as well as power power draw, so this recommendation also applies to the air compressor tied to the subpanel [redacted].

We would also like to note that the measurement occurred on the breaker outputting to the air compressor - meaning it was a single load measurement for each compressor. Based on my observation from the site survey, there are multiple installed VFD units without any sign of harmonic filtration. This is concerning knowing that the new VFD units for the air compressor exhibit high current harmonic distortion and we recommend conducting a harmonic analysis on the substation as a whole rather than on every load.

We would also like to notify the team about the voltage transient and voltage sag event. This took place around early morning on March 28, 2024. Please investigate if anything tripped during this time as the readings indicated an electrical spike occured, leading to a temporary down time event.