Power Quality Assessment Report & Proposal

for

[redacted]

[redacted]

Friday, September 15, 2023

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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 Friday, September 15, 2023:

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 165 hour power quality survey, we measured an active power of 118 kW. According to our findings, the apparent power (kVA) is 128 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 3.38%. As for the voltage unbalance, the allowable standard limit is 2%. We measured a 0.36% 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 measured the following harmonic voltages that are considered too high according to the IEEE 519 standard:

Phase A:	Phase B:	Phase C:
- H03 at 4.92%	- H03 at 3.9%	- H03 at 4.98%

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

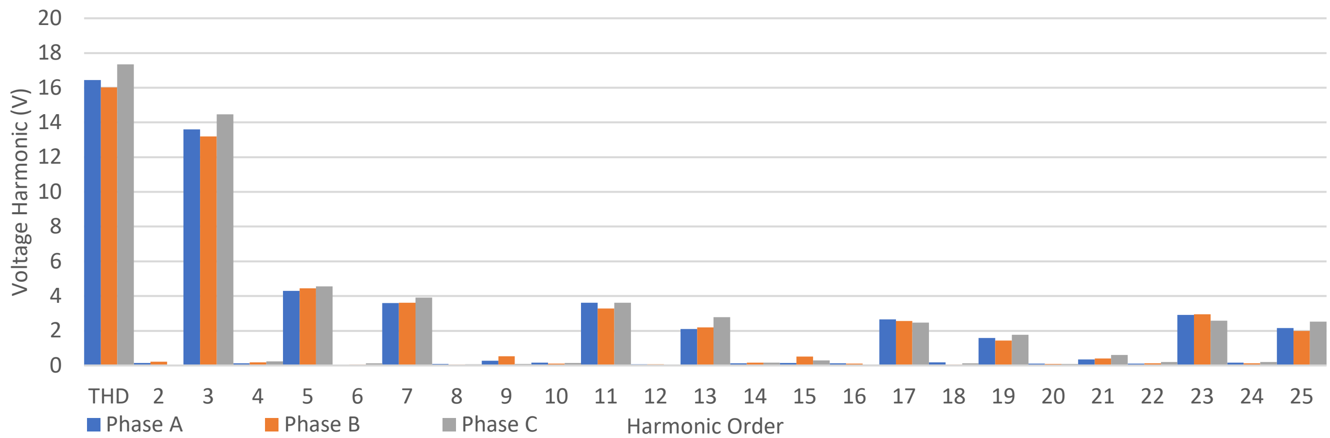
Phase A:	Phase B:	Phase C:
- H05 at 13.29%	- H05 at 12.35%	- H05 at 12.13%
- H07 at 4.23%	- H07 at 4.18%	- H07 at 4.13%
- H11 at 3.35%	- H11 at 3.07%	- H11 at 2.96%
- H13 at 1.85%	- H13 at 1.8%	- H13 at 2.02%
- H17 at 1.79%	- H17 at 1.72%	- H17 at 1.54%
- H19 at 1.28%	- H19 at 1.22%	- H19 at 1.42%
- H23 at 1.43%	- H23 at 1.21%	- H23 at 1.02%
- H25 at 1.01%	- H25 at 0.97%	- H25 at 1.15%

According to the report, voltage sag and transient events were detected during the power quality survey. This snapshot indicated a trigger in Phase A. Transients could be a result of switching events, such as capacitor bank switching, operation startup, surges, etc.

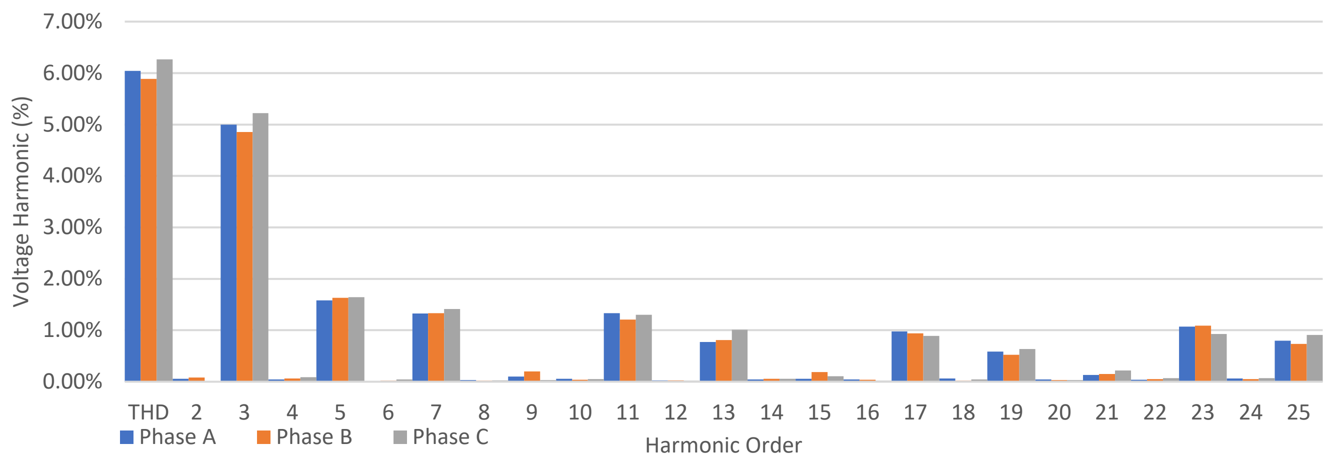
Voltage Harmonic Distortions

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

Phase A:	Phase B:	Phase C:
- H03 at 4.92%	- H03 at 3.9%	- H03 at 4.98%

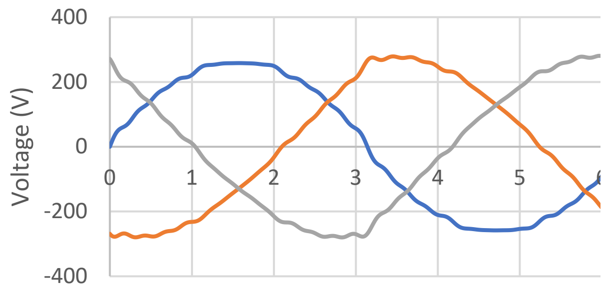


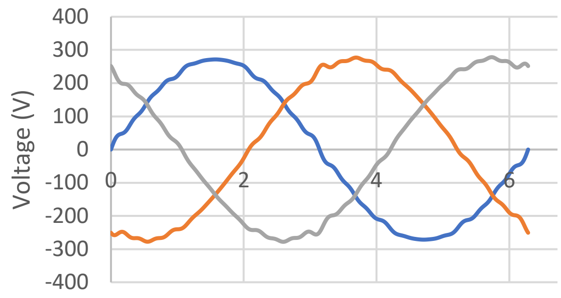
As you can see, the 3rd harmonic is high relative to the other voltage harmonics. Having high voltage harmonics can cause extra load consumption since the peak voltage with harmonics will be greater. Another common harmonic issue is that it will cause voltage unbalance between the phases. The motor's life span will reduce as a result due to either overloading or irregular voltage signals.



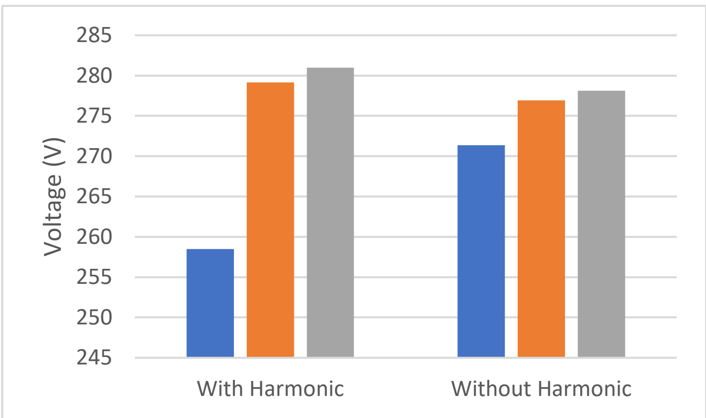
The graph above shows the voltage value as a percent of the total voltage measured, which in this case is 272.09V. Again, as you can see, the 3rd harmonic is the highest harmonic in the system.

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 3rd harmonic, the waveform on the right would be the result of the harmonic filters.



The graph above shows the voltage per phase. As you can see, the voltage levels are more balanced due to correcting the voltage harmonics. In fact, this is a direct cause in reducing the current harmonics, which extends the life of your motors and other electronic equipment.

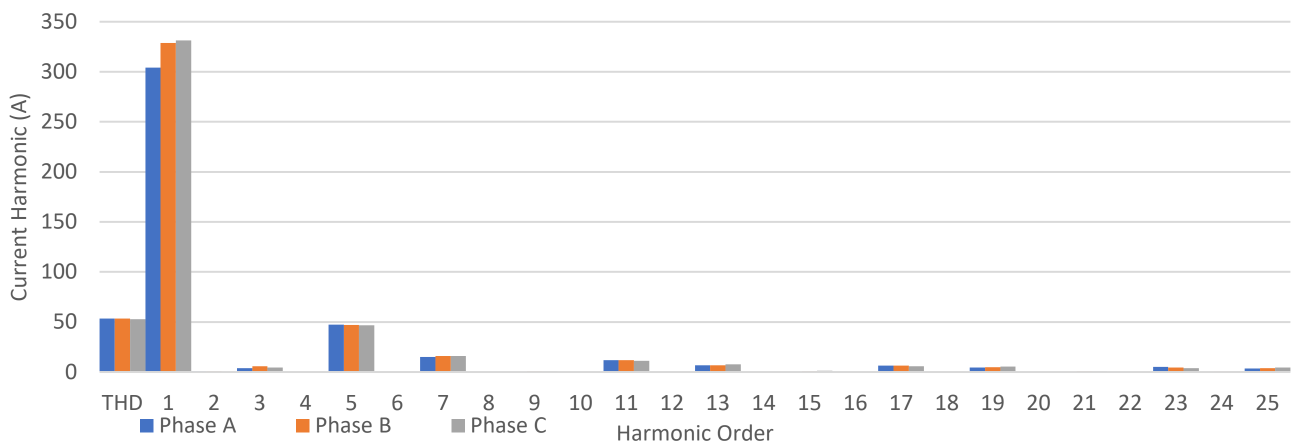
Current Harmonic Distortions

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

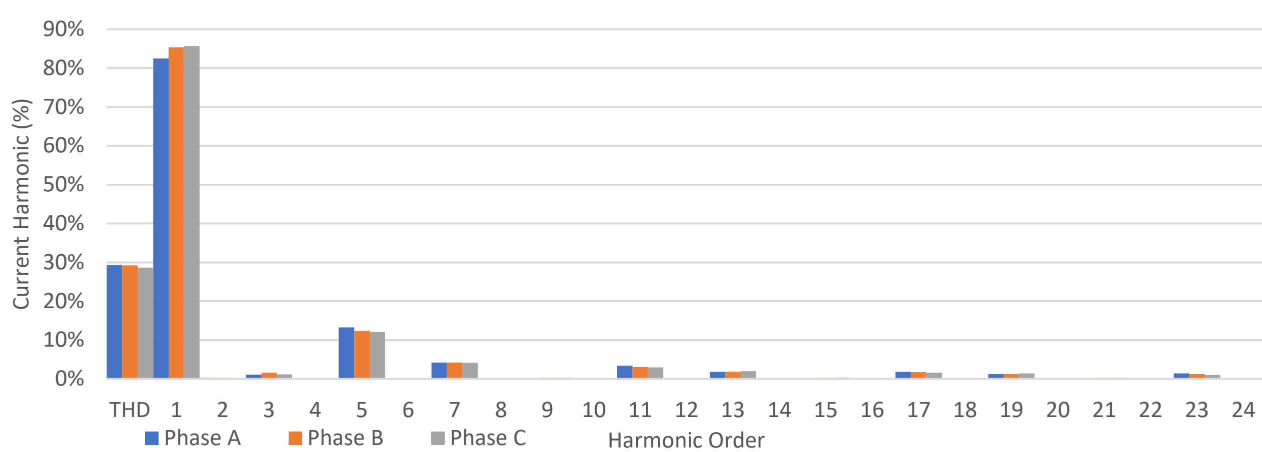
Phase A:
- H05 at 13.29%
- H07 at 4.23%
- H11 at 3.35%
- H13 at 1.85%
- H17 at 1.79%
- H19 at 1.28%
- H23 at 1.43%
- H25 at 1.01%

Phase B:
- H05 at 12.35%
- H07 at 4.18%
- H11 at 3.07%
- H13 at 1.8%
- H17 at 1.72%
- H19 at 1.22%
- H23 at 1.21%
- H25 at 0.97%

Phase C:
- H05 at 12.13%
- H07 at 4.13%
- H11 at 2.96%
- H13 at 2.02%
- H17 at 1.54%
- H19 at 1.42%
- H23 at 1.02%
- H25 at 1.15%

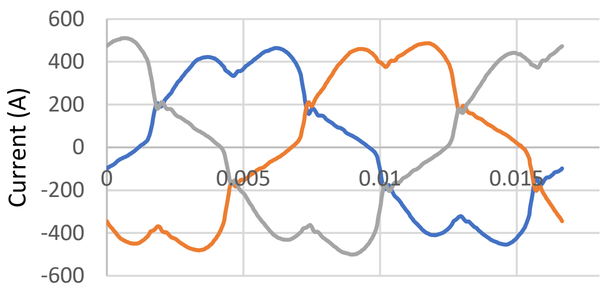


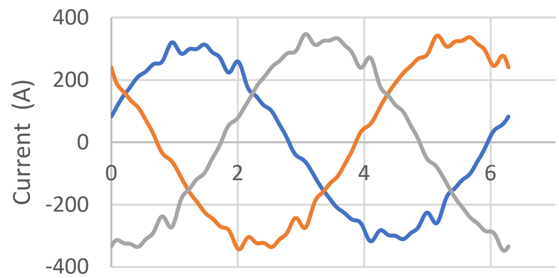
As you can see, the 5th, 7th, 11th, 13th, 17th, 19th, 23rd and 25th harmonic is high relative to the other voltage harmonics. Having high voltage harmonics can cause extra load consumption since the peak voltage with harmonics will be greater. Another common harmonic issue is that it will cause voltage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



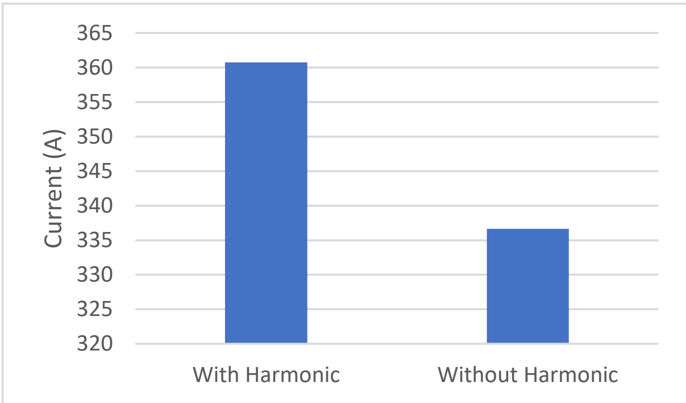
The graph above shows the current value as a percent of the total current measured, which in this case is 158.92A. Again, as you can see, the 5th, 7th, 11th, 13th, 17th, 19th, 23rd and 25th harmonic is the highest harmonic in the system.

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.





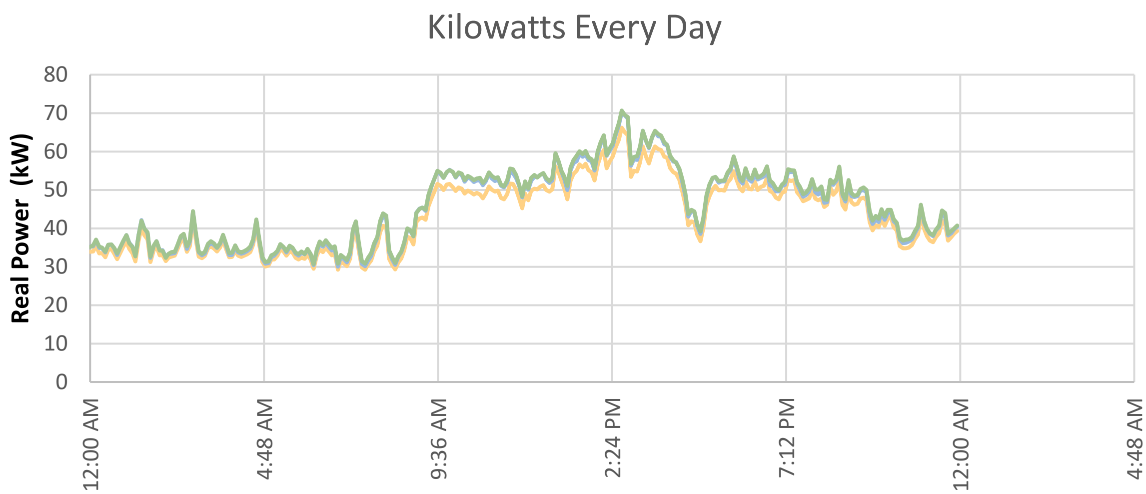
Suppose we remove the small amounts of harmonic we measured, the resulting waveforms (on the right) would resemble near perfect sine waves.



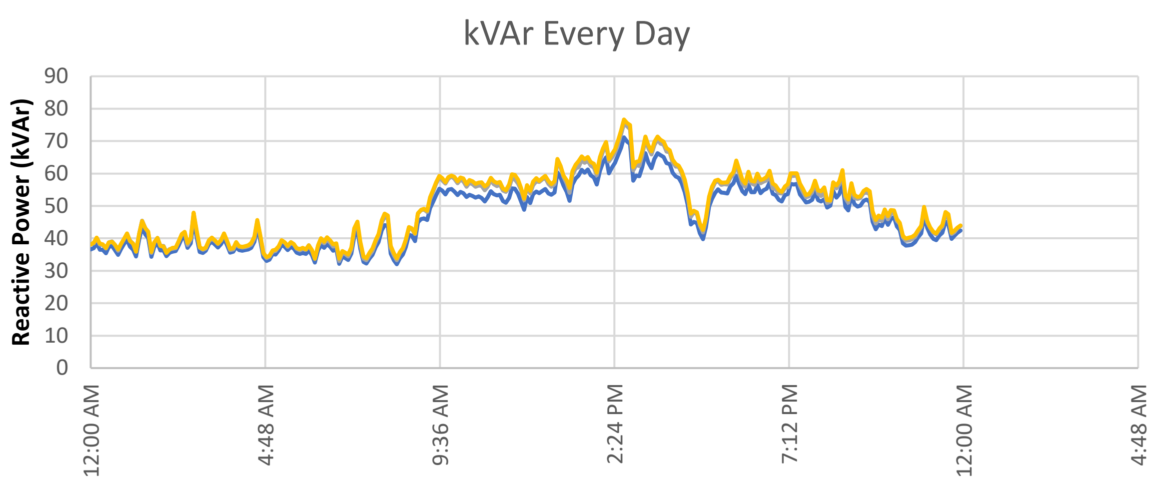
Graph above shows the difference in current between the peak current with harmonics and the without harmonics. It appears that the filtered harmonic has a lower current due to the reduction in current harmonics.

Power of the System

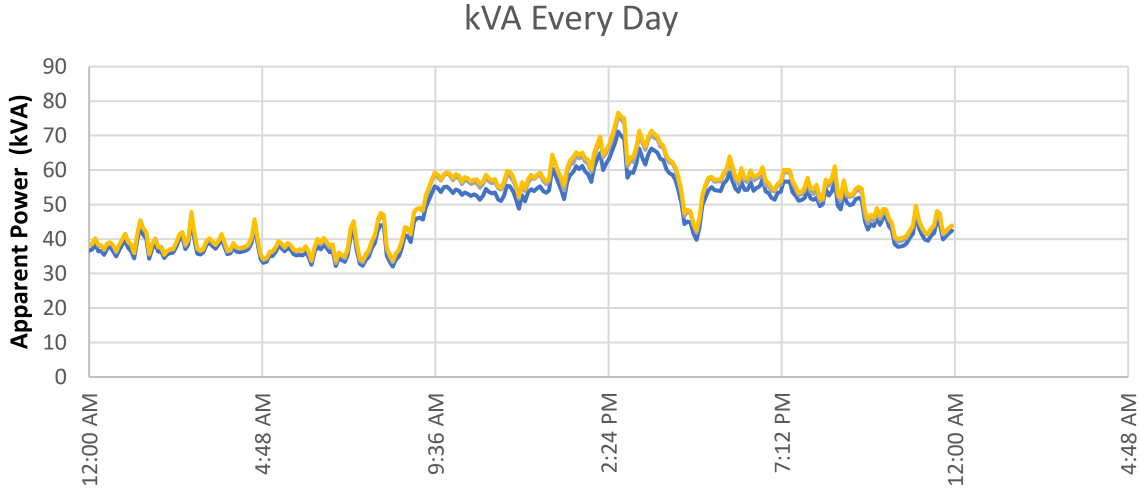
Within the 165 hour measurement, we collected data on the system's active, reactive and apparent power.



The kW consumed every hour is averaged to be 118 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.

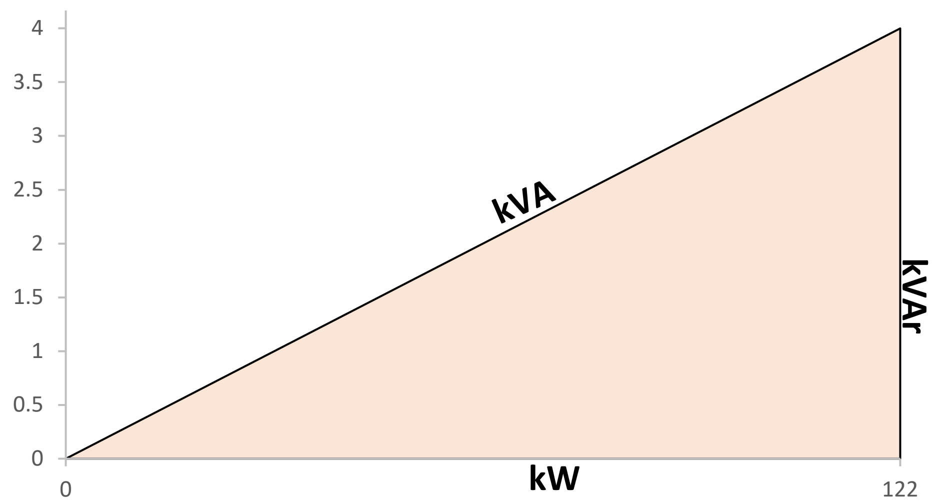


The total kVAr absorbed or returned by the load is 25 kVAr. This value represents the total power absorbed by the load or returned to the utility. To understand reactive power more clearly, let's first establish the relationship between reactance and reactive power. Reactive power is directly proportional 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 128 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.

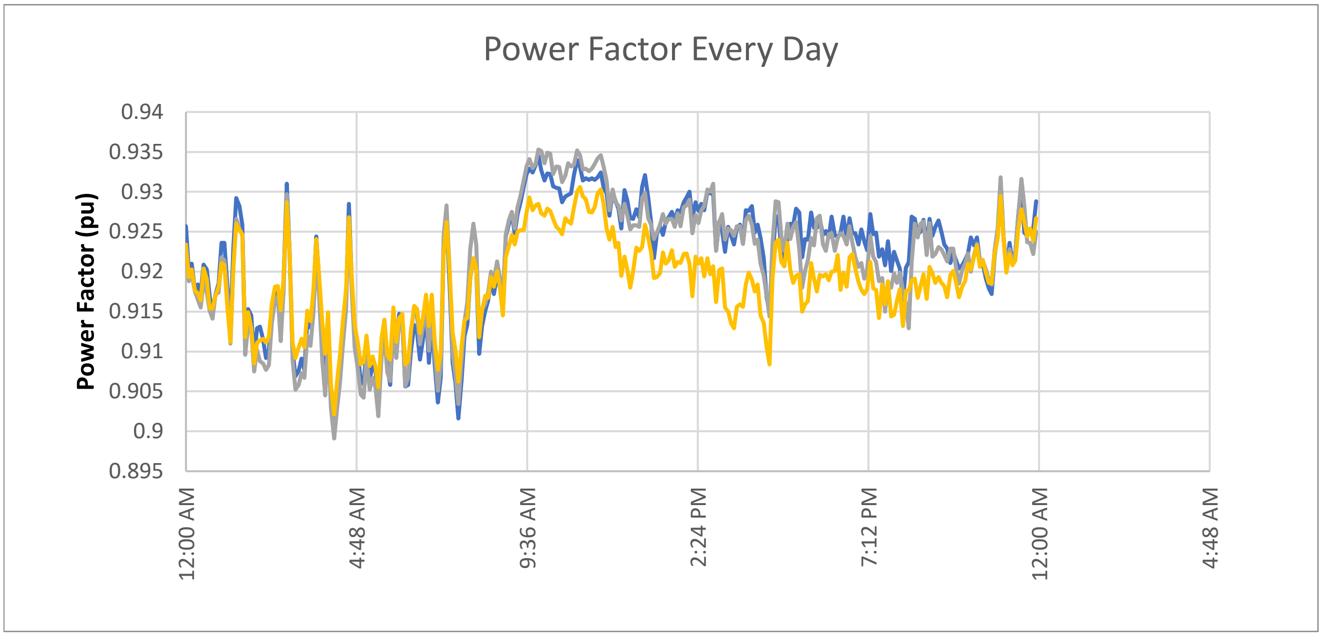
Power Factor



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 91.22%. 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.

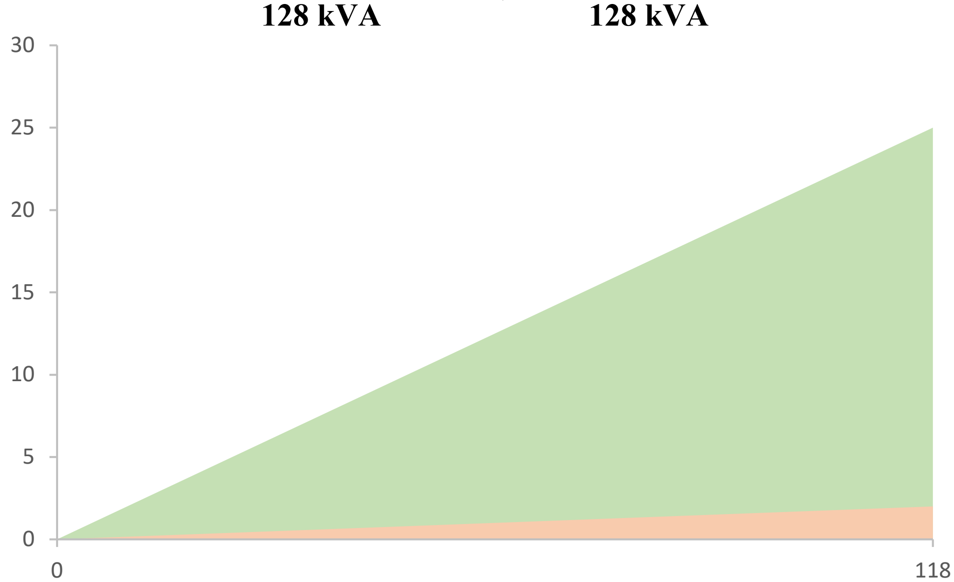
The following graph is the measured power factor at each phase of the system. As you can see, there's an uneven load in the phases, causing the power factor to vary per phase.



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

Old kVAr 25 kVAr → **New kVAr 2 kVAr**   **Old kWh 118 kWh** → **New kWh 118 kWh**

Old kVA 128 kVA → **New kVA 128 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 2 total VOLTAGE SAGS

CRITERIA	PHASE	CATEGORY	DATA	DATE/TIME
Lowest Magnitude	A	Sustained	19.5V, 5955.289 Sec	9/9/2023
Lowest Magnitude	B	Sustained	19.5V, 5955.289 Sec	9/9/2023

Of 0 total VOLTAGE SWELLS

CRITERIA	PHASE	CATEGORY	DATA	DATE/TIME

Of 0 total VOLTAGE INTERRUPTIONS

CRITERIA	PHASE	CATEGORY	DATA	DATE/TIME

Of 1 total VOLTAGE TRANSIENTS

CRITERIA	PHASE	DATA	DATE/TIME
Largest Magnitude	A	819.8V, 0.003 Sec.	9/9/2023

According to the report, voltage sag and transient 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.

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.

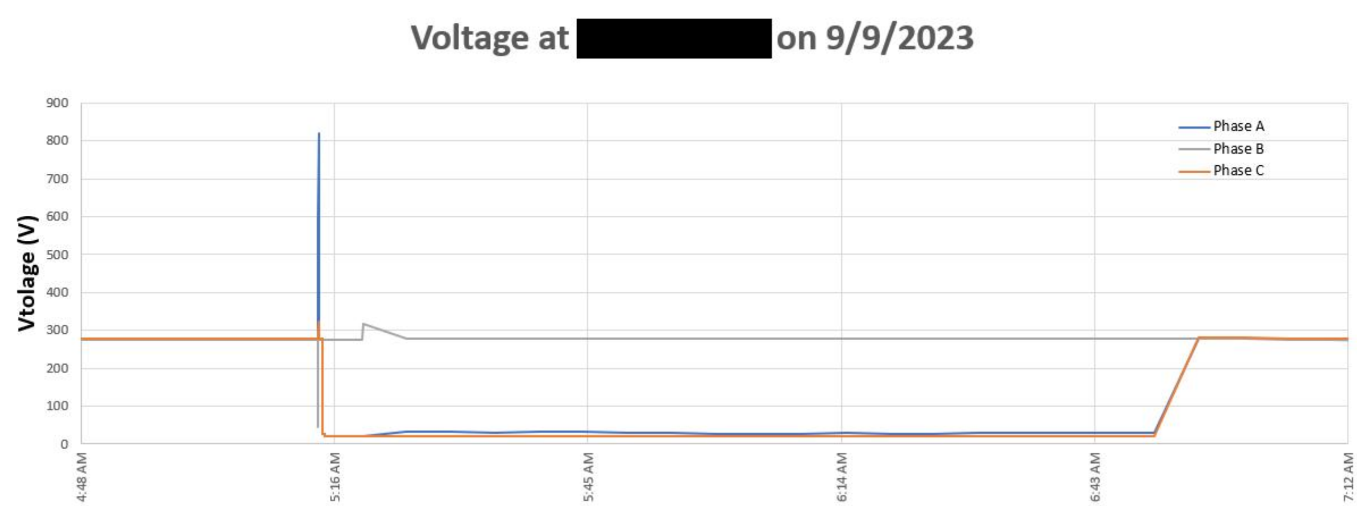
Engineer Summary

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.

Based on the measurements, the site has a power factor of 91.22%. 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.

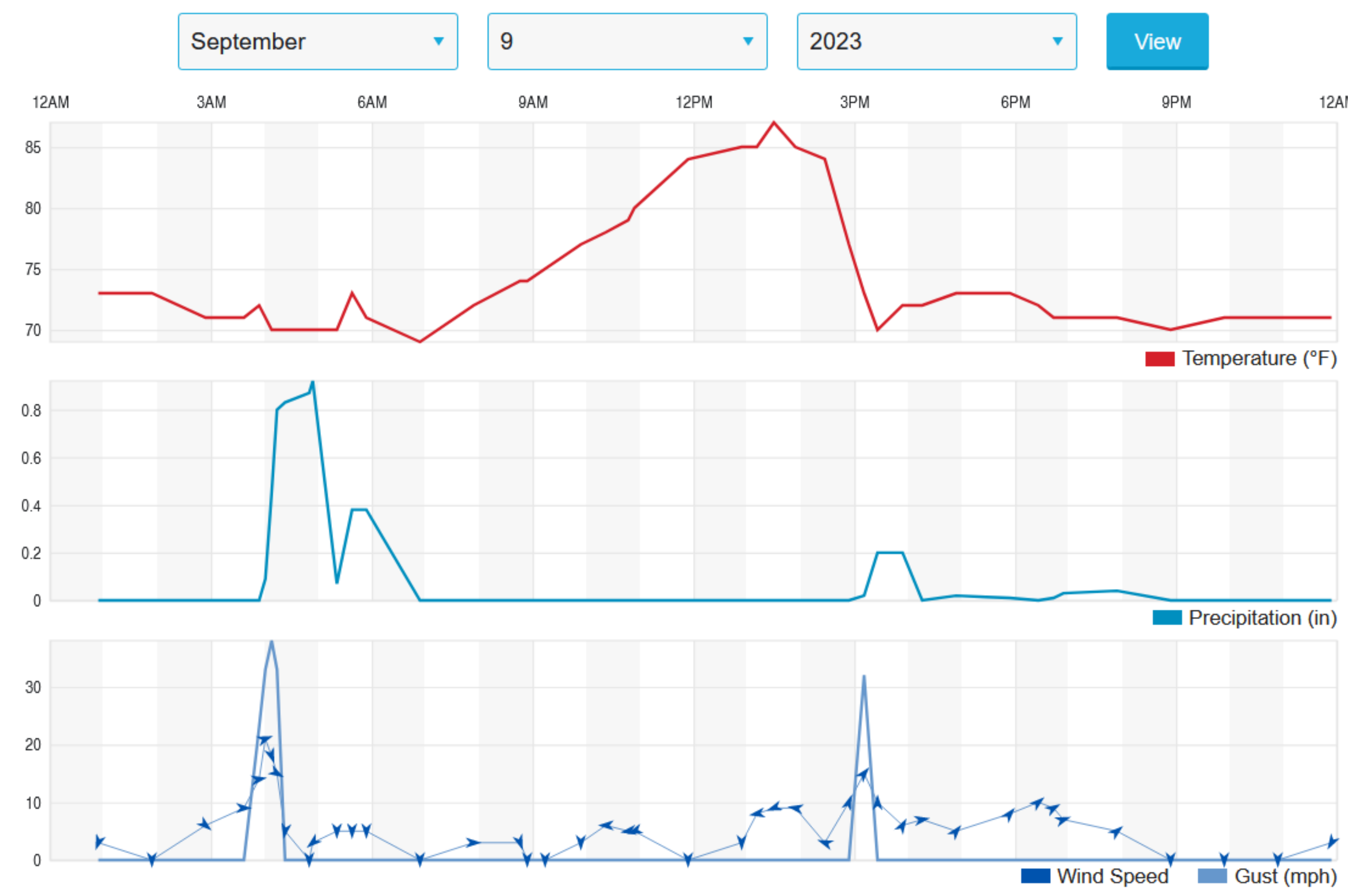
According to the report, voltage sag and transient events were detected during the power quality survey.

A voltage event occurred on September 9, 2023, between 5:00AM to 7:00AM. Weather reports show that a storm was active in the area during this time. Phase A and Phase C experienced a voltage surge event that caused a safety system to trip, causing phase A and Phase C to lose power through a sustained time. During this event, most 3-phase equipment stopped working - likely due to the safety features installed to prevent equipment from running only on one phase.



As shown in the graph above, a voltage spiked was detected, followed by a voltage drop. Using the data collected by Weather Underground, we conclude that this voltage event is likely the caused by a storm during the morning. This event likely happened at the substation or at a distribution center that feeds power into the school. The events that were measured does not seem to come from internal equipment malfunction.

Engineer Summary



As shown above, the weather data collected on September 9, at the [redacted]

Other than the measured transient/sag event, we also detected a concerning amount of harmonic distortion within the system. The reason for this concern is the additional heating and potential timing errors in the control circuits. A study conducted by the National Institute of Standards & Technology (NIST) demonstrated the effects of timing errors caused by low frequency harmonic distortion. In our measurement, we detected a large magnitude of low frequency harmonic distortion (between 3rd order to 19th order).

The cause of harmonic distortion comes from the conversion of AC to DC in the variable frequency drive (VFD). Although the harmonic distortion of a particular drive doesn't directly impact the motor it is paired with, the harmonic distortion goes back to the source and circulates to other equipment. If a building has several VFDs, they may negatively impact one another and cause a cascade of power quality issues. According to our measurements, 18% of the current measured is harmonic distortion, meaning 18% of the power flowing through the sub panel housing all the HVAC equipment is added noise. This additional current can cause nuisance tripping of breakers or fuses, hence causing other equipment to fail.

Engineer Recommendations

Basic Power was brought in to identify the causes of HVAC equipment failure, so we recommend conducting a power flow simulation of the system to identify any pain points. We also identified harmonic distortion within the system. Our simulation can provide a harmonic analysis on the HVAC system. This information will be useful in future installations since we can directly see the effects of new equipment on the system prior to installation.

For the voltage sag event, we determined a few things during our power quality survey. The safety system to protect the equipment worked by cutting off power before the surge damages the load. However, power was lost during that time without any backup power. We spotted a generator in the open area outside of the Main Electrical Room that was last tested by [redacted] on April 19, 2022. We did not see any voltage support during the sag event, meaning no source at 480V was active to support the load of the system - including the generator. To prevent downtime during surge events like this, we recommend using an interruptible power supply (UPS) to temporarily maintain power while the source is being maintained.

Generally, if the UPS is paired with a surge protection device (SPD), sensitive equipment, can be protected while still maintain power during surge events.

For the harmonic distortion in the system, we recommend installing harmonic filters for [redacted] on the rooftop to mitigate the damaging harmonics from affecting other equipment. We were told that [redacted] were down due to a fuse being blown. This may also be an effect of harmonic distortion as it can cause nuisance tripping of equipment due to the additional harmonic current circulating in the system.

While we conducted our survey, we noticed that despite the dedicated outdoor air system (DOAS) [redacted] being switched on, it was the only unit not operating during one of the hottest days of the year while nearing peak temperatures. DOAS [redacted] may require maintenance or servicing.

During our power quality survey, we noted a few concerns regarding the safety of the electrical room. According to **NEC NFPA 70, Article 110.26(C) - 2(a)**:

> *Unobstructed Egress. Where the location permits a continuous and unobstructed way of egress travel, a single entrance to the working space shall be permitted.*

We noticed debris and obstructions to a safe working environment within the rooftop electrical room housing the [redacted]. The working space in the area is concerning and we recommend following the National Electrical Code's (NEC) NFPA 70 which is is the benchmark for safe electrical design, installation, and inspection to protect people and property from electrical hazards.

Images of the mentioned safety concerns will be attached in the section labeled Survey Images.

Engineer Recommendations

In the Main Electrical Room, certain objects should be cleared from the room due to safety risks. We also recommend following the NFPA 70B: Standard for Electrical Equipment Maintenance. We noticed debris and dust accumulating in the room with a potential ventilation issue. For safety, the Main Electrical Room should be cleaned annually and should not be used as storage for anything else. Images will be provided in Survey Images.

We recommend following both the NFPA 70 and NFPA 70B for safety in the electrical work space. Especially for [redacted], should an inspector inspect that particular electrical room, they may find it in violation with the cited NFPA 70 Article 110.26.

Basic Power can provide the following:

1. A power flow analysis on the system to identify potential pain points of the system as well as harmonic analysis
2. Help size and select a UPS system to prevent power downtimes
3. Provide harmonic filters to lower harmonic distortion in [redacted]

Additional Note

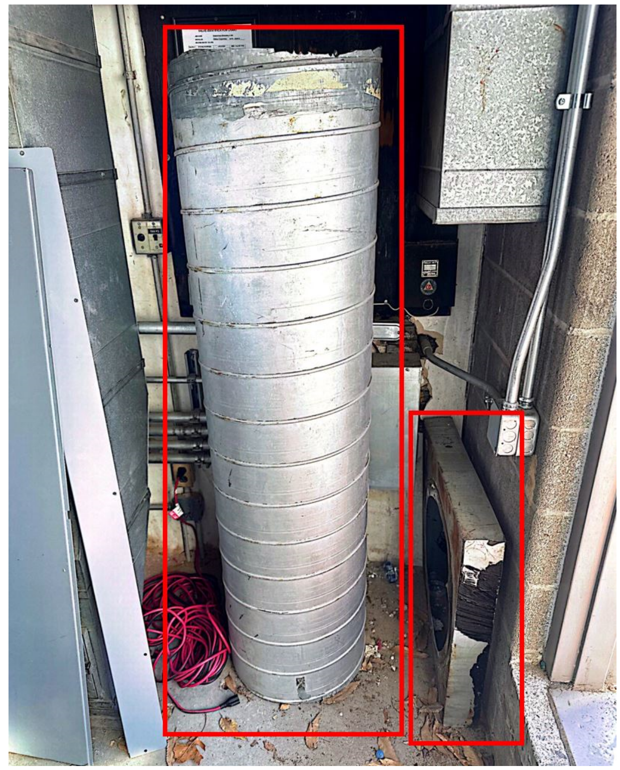
While retrieving the power quality meter, we discovered that the elevator key hole on the ground floor may have been damaged. The key cannot fit properly to operate the elevator and the elevator was stuck on the ground floor. We recommend having that serviced.

Engineer Contact Information
Cedric Wang, Electrical Engineer

Phone: 646-595-6236
Email: Cedric@BasicPower.Energy

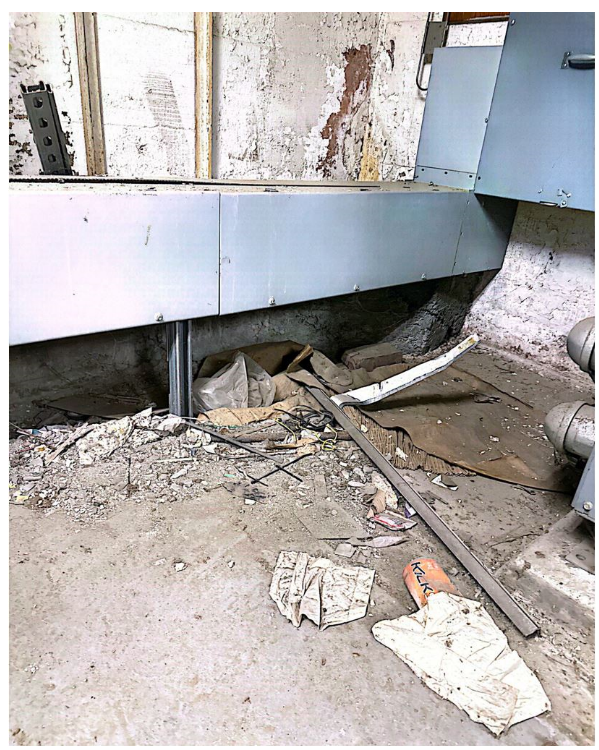
Survey Images

Rooftop Electrical Room housing [redacted]:
As you can see in the images below, unwanted clutter that obstructs the exit was found. These objects should not be placed in the electrical room and may violate NFPA 70 Article 110.26.



Survey Images

Main Electrical Room (MDP):
As you can see in the image below, unwanted clutter and dust is present in the electrical work space.



Survey Images

Main Electrical Room (MDP):
As you can see in the image below, unwanted clutter and dust is present in the electrical work space.