Power Quality Site Surveys for Industrial and Commercial Buildings

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Abstract

This paper describes a process of surveying facilities to identify power quality concerns. Harmonic mitigation and wiring and grounding issues pertaining to industrial and commercial customers are discussed in detail.

Introduction

This paper is to provide guidelines for those providing services for PQ Surveys. It may also aid plant personnel in doing preliminary work to narrow down the cause of apparent problems. Information discussed is based on personal work and that of other engineers that I have worked with. The subject matter discussed is broad and the intent is not to go into depth, but how to locate and identify the problems in the field. References are outlined for those readers interested in learning more detailed information about specific topics.

Identifying the Objective

Often times when a client makes first contact, they are not sure what the cause of the problem is. Almost always they can explain the observations that have been made. Based on this information an objective for the survey should be agreed upon. Through its development, the solution may take on different directions, but the objective always remains the same.

Take the following situation:

> *The customer calls and explains that he thinks he has a harmonics problem. He has read an article that indicates that harmonics often cause nuisance tripping of circuit breakers. Each time the breaker trips, eight hours is required to get production back on line.*

The client may or may not have a harmonics problem, but it is clear that his concern is that a breaker is tripping. Identifying a remedy to avoid nuisance tripping of the breaker is the objective of this survey.

Preliminary Information

It is important to understand as much of the problem as possible before showing up on site. In the situation above, the breaker may be tripping due to harmonics, but it also may be overloaded, trip due to a large inrush current, be located in a high ambient temperature, or several other causes.

Information that needs to be requested will vary from project to project, but the list below are typical items:

- Floor plans with trouble areas identified
- Panel schedules
- Riser diagrams and transformer information
- Lighting plan
- Topology of computer network

Floor Plans

These help identify the problem areas ahead of time and give a feel for the building layout. This saves time once on site, especially if it is a large office building or industrial plant. If a floor plan is not available, the customer should take the time to draw a rough sketch of the pertinent areas. Panels, electrical services, computer equipment, and any other critical equipment should be identified on the floor plan. Sometimes a video tape may help, but unless a lot of thought is put into the items to tape it may be a waste of time.

If the floor plans are drawn to scale, it is possible to estimate cable lengths. It also allows a picture to develop, showing the physical relationship of critical equipment. This in it self may give insight on the problem, whether it is transients, harmonics, or radiated fields.

For instance:

> *An employee began having problems with their computer monitor after rearranging their office. While discussing the problem with the person, it is realized that the monitor had been moved from the north to the east wall. On the other side of the east wall was a 2500 kVA dry type transformer. The magnetic field from the transformer was great enough to distort the screen.*

This situation could easily be identified from the layout diagrams.

Panel Schedules

What floor plans do to show physical layouts, the panel schedules do for electrical relationships. Equipment that wouldn't likely be on the same circuit, often is. If an employee notices interference with their computer each day, maybe that is the time the cleaning crew vacuums or a specific process may start up on the production floor. Looking at outlets and equipment sharing circuits and panels may enlighten the problem at hand.

Riser Diagrams

Riser diagrams typically contain information about the type of service, transformers, and impedance information. For many projects this information will have to be pieced together. It is important to obtain the data, for these are indicators to how severe the problem may be. Fault duty and capacitor switching procedures from the utility can give an indication of transient concerns. Local transformer size and impedance will give an idea of expected harmonic voltage distortion.

Lighting Plan

More so than switch-mode power supplies, this is where over loading due to zero-sequence third harmonic currents is observed. It is important to get an idea of how the lighting load is distributed and identify possible areas of overheating. Once again it will be easier and quicker to take relevant measurements if the locations to do so are identified before going on site.

Topology of Computer Network

Most PQ surveys incorporate problems with the computer network. This makes sense since most computer equipment ties the power system ground and the network ground together. Most complex networks have a network administrator. While it will be beneficial to understand the basics of computer networking, the network administrator should be relied upon for the brunt of the system testing. As a minimum the different topologies and types of wire should be understood. Two of the more common are the token ring utilizing 10baseT, twisted pair with a terminating impedance of 85 - 110Ω, and thin wire ethernet 10base2, RG-58 coaxial with a terminating impedance of 50Ω.

Using the Resources Available

Measurement equipment and other engineers are typically thought of as adequate resources in problem solving. The most important though, may not have any technical background at all. When a doctor examines a patient, many questions are asked so that they can narrow the list of test that need to be administered. The same should be done with the site operators and maintenance personnel. Beware though, if the facts of a discussion are easy to verify, do so!

> *A consultant was called in to investigate medium voltage capacitor fuse clearings. Only a select few fuses clear on a regular basis and it was determined that the problem began about the same time that an arc furnace tap changer experienced arcing problems. Immediately, a transient problem was suspected. After lengthy analysis, it was found that the replacement fuses being used were the wrong type. Even though questions about fuse size and type were asked repeatedly, the information was never verified.*

During the initial contact, all pertinent information should be requested. Key personnel that have witnessed the problems should also be identified. If possible, interview them over the phone or at minimum prepare a list of questions that may give some insight to the problem. Keep in mind that individuals not familiar with PQ problems may have information that they don't believe to be relevant. Before the interviews are conducted, the cause of the problem should be narrowed so that very specific questions may be asked, but not so much that important information may be missed. This inquiry of personnel is more of an art than a science and will develop as more surveys are completed.

It should be strongly suggested that site personnel keep very detailed records of equipment failures and other problems. If possible, actual components that have been replaced should be saved. Looking at a power supply that only has a damaged capacitor leads to a transient concern; whereas a melted terminal may indicate a loose connection or harmonic condition.

Once on site, meetings with employees reporting the problems should be done before and after the site survey. This will give insight to what they feel the most serious problems are and the follow up meeting will give yourself an opportunity to ask follow up questions.

Equipment to be Utilized

For most site surveys, the following list of equipment should be adequate. If more equipment is necessary than that outlined, the survey has found a special problem. The following will handle transients, harmonics, loose termination's, and verification of documented system information.

- Circuit Tracer
- Infrared Temperature Gun
- Digital Oscilloscope, two channel minimum
- Harmonic Spectra Analyzer
- Transient Analyzer

Circuit Tracer

A circuit tracer is a device that injects several high frequency signals onto a power circuit. It is possible to do this with the circuit either energized or not. The receiver is then used to identify the circuit at any other location.

This will soon become your most valuable tool. While the floor plans, panel schedules, and lighting plans should detail enough information, they are often incorrect. For many job sites, the only information available is written on the panel covers. Due to limited space, this information is typically abbreviated to the point that it is not understood.

Infrared Temperature Gun

These have been incorporated into nearly every preventive maintenance program. They may be as sophisticated as a video camera that produces a color spectra on a monitor or a simple gun that indicates a temperature. The main idea is to chart trends and to locate abnormally high temperatures. If twenty bus splices were recorded at 50^{o}C and the twenty-first at 90^{o}C, it would be wise to inspect and torque the splice plate.

Digital Scope Meter

If a preliminary survey is being done, it is often nice to have a scope meter. While simultaneous three-phase measurements will not be possible, it will allow for indicating spot checks. Most have software that make it possible to obtain spectra data from the captured wave form. For a few thousand dollars it is feasible to own a tool that will provide harmonic and transient information. Two channels are desired so that simultaneous voltage and current measurements may be performed. Observation of a drives DC bus and the system voltage simultaneously is also convenient when transients are of concern.

Spectra Analyzers

For serious harmonic analysis, an analyzer designed for those measurements is required. If a simple summary of harmonic magnitudes are desired, the above scope meter is suggested. Otherwise use a device that will take simultaneous measurements of voltage and currents for a three-phase four-wire system. If computer simulations are to be performed, it is critical to record phase angles.

Transient Analyzers

Unlike harmonics, transients are not steady-state and may be unpredictable in occurrence. For this reason it is desirable to have an instrument designed to capture events based on deviation of wave shape or upon exceeding a peak value. These instruments can also determine the frequency and energy associated with a transient.

Once on Site

As part of the preliminary work, a scheduled approach should have been developed. The time scheduled for the survey is most likely tight and the customer will want you to investigate as many problems as possible. If an agreed upon schedule is in place, it will be easier to accomplish the necessary tasks. As seen in Figure 1, the schedule doesn't need to be detailed or structured. The thought that goes into creating the schedule is what is important.

Day One
1. General Inspection of Problem Areas
2. Meet with staff.
3. Measurements in third floor electrical rooms.
4. Meet with building superintendent and inspect the building primary electrical service rooms.
5. Detailed inspection and measurements of third floor problem areas.
6. Review of building drawings and initial measurements.

Day Two
1. Detailed inspection and measurements of fourth and fifth floor problem areas.
2. Detailed inspection and measurements of computer room.
3. Meet with Director of Information services, to access work completed.

Figure 1 - Site Schedule

Panel Board Connections

The major concern with panel boards is when they incorporate an isolated ground bar. Recently a survey was performed in a building with six special panels equipped with isolated ground bars. Not a single panel board was installed like the others, even though they were put in at the time of construction.

As soon as a panel board is identified as a computer panel or anything else that may elude to the fact that it may contain an isolated ground, take extra care in examining it. The case above had problems ranging from the "green wire" located outside of the conduit to an isolated ground bar with no "green wire" back to the system ground. A common finding is "green wire" isolated ground conductors that are routed separate from the feeder conductors. As per the NEC Article 250 Part J, the equipment grounding conductor must be routed with the feeders. This is done to minimize the impedance between a faulted conductor and ground. This impedance is directly proportional to the distance between the conductors. Remember that a fault within the equipment is relying on the "green wire" to allow fault current to trip the protective device, see Figure 4. Be certain to identify both ends of the isolated ground, many times it may not even go back to the service ground.

A second concern is with broken or loose connections. this is particularly true with the neutral termination's. When unbalanced voltage magnitudes are measured from phase to neutral, look for a suspect neutral connection. An unusual case describing this situation is discussed below:

> *A gentleman was receiving poor reception from his TV, so he disconnected the coaxial cable from the back. When he did this, there was a spark and the TV and living room light went out. When the cable was reconnected, the TV and light came back on. It was later discovered that the branch circuit neutral connection had come apart and was using the sheath of the coaxial cable for a neutral. See Figure 2 above.*

Another common problem in panel boards are neutral to ground connections. These connections should only be done in service panels and at transformers. This may be at the buildings main supply or at a panel being fed from a separately derived source. All sub panels should not have a neutral connection to ground. The primary concerns are:

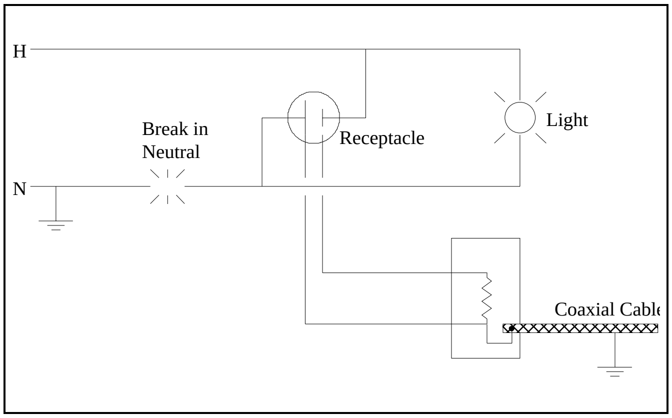

Figure 2 - Broken Neutral Conductor

earth fault protective devices may not see enough fault current to trip and loop currents may flow in the neutral and ground conductors.

Transformer Connections

In the struggle to prevent interference from line noise, plant personnel have tried many different installations to electrically isolate equipment. Figure 3 shows the correct way to install an isolation transformer. Just because the transformer is for isolation, doesn't exclude it from the requirements of the National Electrical Code. Quite often these transformers are found with no connection to the building ground system. This was the case in a situation discussed in EC&M's January 1993 PQ Corner:

> *At a food processing plant, harmonics were suspected as the cause for nuisance tripping of conveyor adjustable speed drives. Current distortion with in the plant was found to be less than 2%. While taking measurements at the drive, a 35V neutral to case voltage was discovered. Investigation of the drives isolation transformer revealed that the secondary neutral had not been grounded. Once the bond was made and the neutral to case voltage went to 0V, the nuisance tripping went away. [4]*

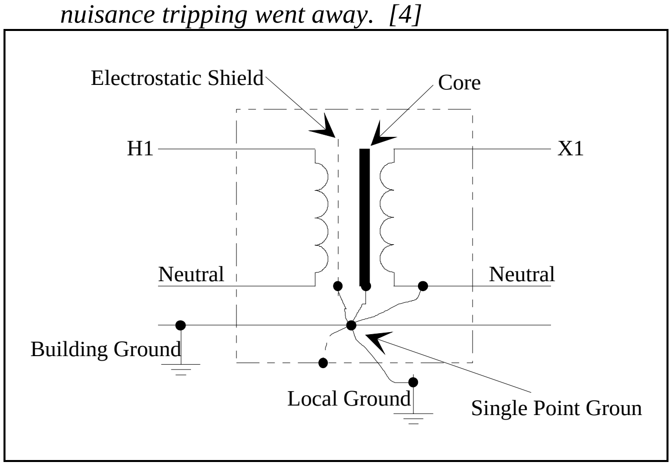

Figure 3 - Isolation Transformer [4]

This brings up the importance of measuring neutral to ground voltages. Equipment with microprocessors often use the equipment ground for the DC reference ground. If the neutral to ground voltage is too large, as in the case above, this may cause interference with the equipment. These voltages may be due to missing bonds or ground loop currents.

A problem to be aware of in three-phase installations is voltage imbalance. This can cause long term damage to three-phase motors and may cause three-phase adjustable speed drives to produce positive sequence third harmonic current. This has been observed in areas that utilize three-phase four wire delta transformers. With all the single phase load connected to one transformer, that winding is in risk of saturating. If this occurs three phase loads will see unbalanced voltages and currents.

Isolated Grounds

This is an area where common sense should prevail. There are many ideas on what constitute a "clean" ground connection. In many installations of sensitive equipment, this is the area in which people look first to accuse as the source of equipment problems. Keep the three reasons for grounding in proper order:

1. Personnel Safety
2. Over current Protection
3. Noise Control

Personnel Safety:

The primary reason for grounding systems is to minimize touch potentials between equipment. By eliminating an equipment grounding conductor or by not connecting the equipment ground to the power system ground, personnel may be the path of least resistance.

Over Current Protection:

The second reason for grounding is to provide a low impedance path for fault current to return to the source. As discussed previously, the impedance between two conductors is proportional to the distance between them. So be conscious of the path the equipment grounding conductor has been run.

Noise Control:

In most installations the first two conditions are adequately addressed unless sensitive electronic equipment is present. It is under these circumstances that specific equipment should be investigated with great detail. Figure 4 shows the proper installation of an isolated ground, "green wire" circuit. Notice that the "green wire" does not get bonded to any other grounds except at the termination to the building grounding system at the main service. If an isolation transformer were in the circuit, a bond between the "green wire", neutral, and building ground would need to be made at that point. This is done to assure correct operation of the over current protective devices.

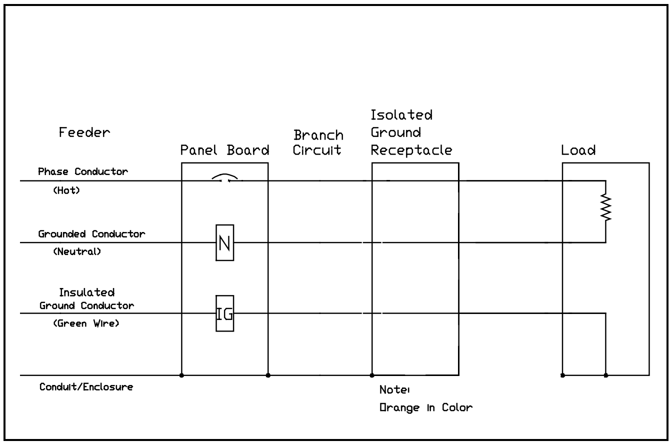

Figure 4 - Isolated Grounds

To avoid ground loops all together, it may be discovered that the system ground connection to a piece of equipment has been replaced by an isolated grounding electrode. As a reply to those who condone this practice, the following quote is provided:

> *"The idea that the earth is an infinite electrical sump with zero resistance is simply not so. The popular notion that the earth is a place to banish all noise and that it is somehow dissipated and lost is simply not so. All current must flow in loops, and any current that enters the earth must also leave the earth."[1]*

The fact remains that if a fault occurs, the current will try to return to the source. Instead of having a defined path, every bracket and person that completes the path will conduct current. From a noise point of view, the condition may be worse. For instance, if peripheral equipment is connected through a communications network, the ground path may be completed by the communication shielding. Instead of being diverted by an equipment ground, leakage current is now a potential source of common-mode noise. The best approach in limiting this condition is to connect all equipment to a common grounding grid. This is the principle practiced in computer room grounding.

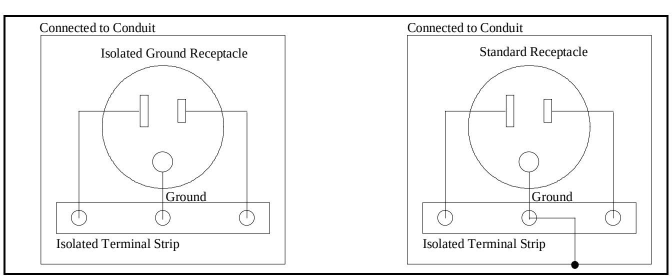

Figure 5 - Receptacles

Figure 5 illustrates the detail that site surveys should entail. Recently a multi-level office building was investigated. During the preliminary investigation, it would appear that all precautions had been taken to isolate computer loads from all other loads. Special panels with isolated grounds were installed dedicated for sensitive loads only. Even though the design was state of the art for its time, it was negated by the installation and the implementation. Each office was equipped with two receptacles, general use and "clean power" use. All of the circuits had been installed with the standard type receptacle that bonds the grounding conductor to the conduit. Furthermore, less than half the offices checked were utilizing the "clean power" circuits for computers.

Harmonic Producing Equipment

Harmonic measurements are one of the more straight forward parts of the survey. The analysis that is done with the measurements may not be obvious, and can involve a lot of engineering judgment. From the preliminary information, the major harmonic producing equipment should be identified. It is recommended that all secondary bus of large transformers, 500 kVA and larger, be measured. All large harmonic producers should also be measured. When taking measurements remember these key points:

- Measure current in amps so there is no confusion to how much current is being injected.
- Phase angles are as important as the magnitudes.
- Take simultaneous measurements of voltage and current on all phases.

Of the three, having the phase angles are of the greatest importance. These can indicate whether triplen harmonics are in the positive or negative sequence network. If computer simulations are to be performed, this will indicate the amount of cancellation to expect. System impedance's may also be calculated at each frequency measured indicating the linearity of the system. The impedance information may be used to determine if unexpected capacitors are present, or how effective harmonic filters may be.

Transient Concerns

For the most part, if all the wiring and grounding problems are resolved, so are the transient concerns. Still there are phenomena, such as utility capacitor switching events, that may cause problems. The best place to start is the notes from the employee interviews. If it is indicated that the process shuts down every morning at 8 o'clock, then it is likely to be related to capacitor switching. If problems occur when lightning storms pass through, then low side surges should be investigated. The key is to listen to the witnesses and hope that an event occurs, triggering the analyzer at the locations selected for monitoring.

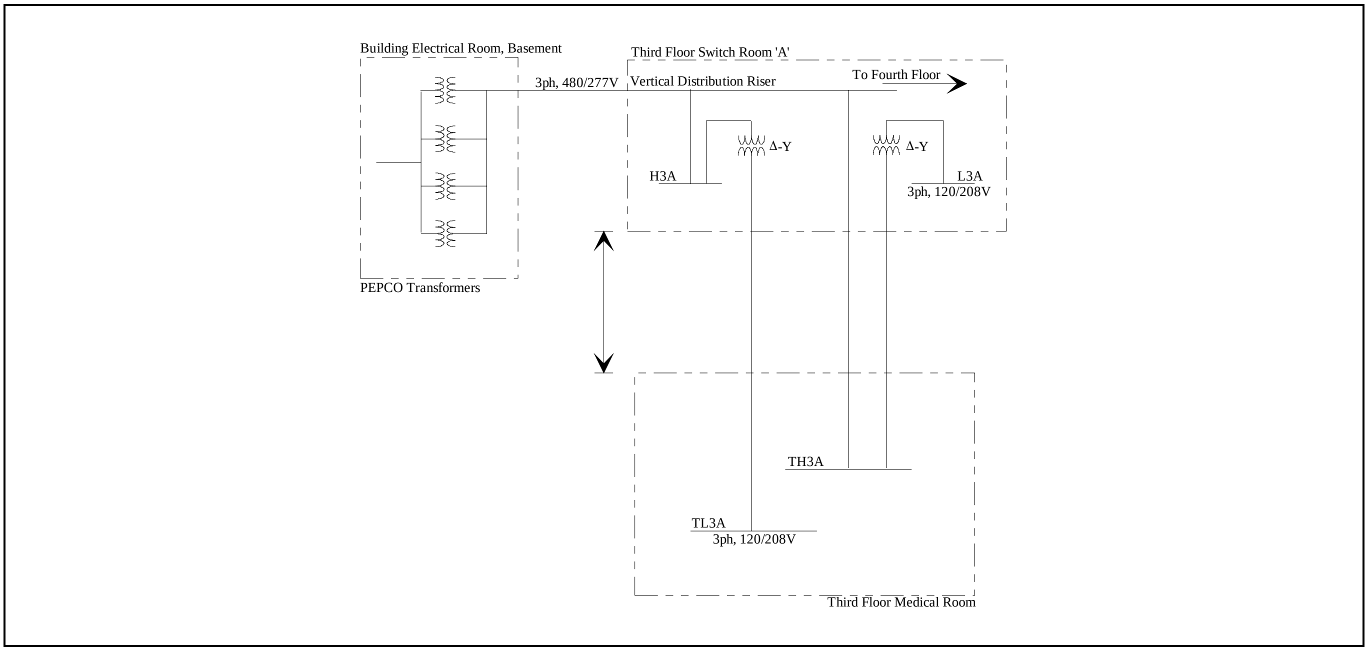

Figure 6 - System One-Line Diagram

The Report and Recommendations

When writing the report, keep in mind that the information that is presented is as much for your benefit as it is for those you are writing it for. The body should be written with the entire audience in mind. Appendices should contain the pertinent calculations and measurements taken. This is especially true for the measurements. Reports are typically easy to find, where as measurements tend to get filed or stored. Methodology and assumptions should be clearly defined so that a year from now you can recall your findings. Figure 6 shows a simplified one-line diagram. Creating this document is a good idea even if detailed drawings are available. Drawing your own one-line allows you to show the information that was found to be critical during the survey. This same approach should be followed when complicated control schemes must be deciphered.

It is certain that notes will be taken throughout the survey, either mental or written. As part of the preparation for the survey, a structured form should be developed for taking notes. Figure 7 shows a form for taking down panel board information. Similar to the survey schedule discussed earlier, developing the form will help define the measurements that should be taken while on site. Once the form is created and the survey is complete, it provides a good way to summarize the notes for the customer and for future reference.

The report should include information about similar areas that aren't experiencing problems. Sometimes the solution lies in what has been done right instead of looking for what has been done wrong.

Recommendations should be decisive. This doesn't mean that choices or options aren't allowed, but explain the pros and cons in detail. Keep in mind that this area of the report shouldn't require a consultant to decipher the conclusions.

Third Floor Power Measurement Summary

Device	Ident.	Neutral Bond	Isolated Ground	Phase A V	Phase A I	Phase B V	Phase B I	Phase C V	Phase C I	Vng	In	Comments
Panel 208/120	PTL3A BMI/Fluke	No	Semi, bar not isolated	117.20 3.00	19.60 87.80	117.80 2.80	16.30 119.00	117.60 2.90	20.80 115.90	0.40 n/a	32.40 708.00	Green wire in cond. to xfmr, # #1/0 AWG Feeders, 50' from xfmr
Transformer Primary	TTL3A BMI/Fluke	Yes #1/0 AWG	n/a #2 AWG	469.10 1.80	3.10 54.00	470.80 1.80	2.80 69.20	470.50 1.80	4.00 52.50	n/a	n/a	480/208-120, D/Y, 45 kVA, %Z=3.7 #6 AWG pri, #1/0 AWG sec
Transformer Delta Current	Fluke			469.10 1.80	1.27 92.30							
Panel 208/120	PL3A BMI/Fluke	No	No	117.10 2.00	29.90 19.10	116.40 1.90	37.40 11.20	117.00 1.90	33.90 13.00	0.00 n/a	13.10 145.70	General Purpose, in elect. room A #4/0 AWG Feeders
Transformer Primary	TL3A BMI/Fluke	Yes #4/0 AWG	n/a	465.60 1.80	35.30 12.00	471.20 2.00	30.30 10.00	471.70 1.70	21.20 11.80	n/a	n/a	480/208-120, D/Y, 75 kVA, %Z=4.9 #2 AWG pri, #4/0 AWG sec
Panel 480/277	PTH3A BMI											Not Measured
Panel 480/277	PH3A BMI	No	No	271.60 1.90	39.00 5.50	272.20 1.80	18.70 7.90	272.70 1.80	51.40 4.30	0.00 n/a	29.70 15.60	General Purpose, in elect. room A #350MCM AWG Feeders
Panel 208/120	PTL3B BMI	No	Yes	115.70 2.70	23.10 71.30	116.80 2.80	17.20 108.10	116.50 2.50	18.30 98.60	0.00 n/a	30.50 354.90	Green wire in cond. (wired correctly) #1/0 AWG Feeders, 50' from xfmr
Panel 208/120	PL3B BMI	No	No	116.70 1.80	57.80 15.30	116.30 1.90	47.50 17.60	116.80 2.00	42.00 17.00	0.00 n/a	27.30 86.60	General Purpose, in elect. room A #4/0 AWG Feeders
Panel 480/277	PTH3B BMI	No	No	268.00 1.60	38.50 6.80	268.00 1.90	39.80 7.30	269.00 1.50	39.40 7.40	0.30 n/a	1.10 201.40	#3/0 AWG Feeders
Panel 480/277	PH3B BMI	No	No	270.50 1.80	83.40 5.70	271.10 1.90	65.80 7.10	271.60 1.60	58.90 6.50	0.30 n/a	26.20 18.80	General Purpose, in elect. room B #350MCM AWG Feeders
Panel 208/120	PL3C BMI	No	No	115.80 1.40	55.30 19.90	115.10 1.40	48.50 12.20	115.90 1.70	37.40 32.20	0.20 n/a	24.10 86.60	
Transformer Primary	TL3C	#500MCM	#1/0									480/208-120, D/Y, 112.5 kVA, %Z= #2/0 AWG pri, #500MCM AWG sec

Survey Date: 29-Apr-93 **Performed by:** Brian Prokuda
Location: **Sheet No.:** 1 0f 1

Figure 7 - Survey Notes and Measurements

Conclusions

Performing site surveys requires a lot of planning and preparation. Preliminary work can help narrow the problems and predict the necessary equipment and time required. A site survey can entail a broad range of subject areas, but the key to solving the problem is to keep your eyes and ears open.

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