Improving Process Reliability due to Electrical Interruptions Part I

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Abstract

This paper will discuss methods for improving the electrical reliability of process equipment. Readers will gain an introduction to the methodology and process of improving equipment reliability. Mini case studies will be discussed and part two of this paper titled "Improving Process Reliability due to Electrical Interruptions Part II" shows a case study of a General Motors complex that has made reliability a priority.

Introduction

The application of methods discussed in IEEE 1346 "Electric Power System Compatibility with Electronic Process Equipment" will be shown. This includes the combination of equipment sag testing and site monitoring data to determine the probability of down time. Here the importance of understanding a solutions improvement on site voltage variations as well as equipment vulnerability will be stressed. The susceptibility of common power electronic equipment will be outlined. The primary focus will be on momentary sags (voltage events down to 0.10puV for ½ cycle to 3 seconds) and ways to improve process reliability for these events. Simple steps that facilities personnel can do to improve reliability will be discussed. It is recognized that transient events are also the cause of many reliability issues, but is not the focus of this paper.

With facilities operating near peak production and using Just In Time (JIT) delivery, reliability becomes critical. For instance, one manufacturer used to have three weeks to produce a product run from order to delivery. This time has been reduced to one week while their production has increased 10-15% per year over the last 15 years. Their operation shuts down with a sag to 70% of voltage for 3 cycles or more. The cost of such a shut-down is enormous because there is virtually no excess production capacity to make up lost production time. In fact, it is sometimes necessary to ship jobs to a competitor to meet production deadlines.

Over the last 10 years the US Industrial demand for electricity has increased by 19% requiring 1270 billion kWh in 1997[1] During this same period U.S. manufacturers on average have operated as high as 84% of capacity and utilities have went from delivering 81% to 91% of their capacity.[1] This means that U.S. manufacturers are producing more, requiring more electric power and are therefore less tolerant to down time. As an example of the strain being put on our electrical infrastructure, consider the following. Detroit Edison controls 10,430MW of generation in southeast Michigan and predicts over 11,000MW of peak demand this summer.[2] To meet this demand with sufficient reserve the utility is wheeling power from Canada and as far south as North Carolina and bringing a decommissioned coal plant online.[2] In addition it is estimated that the distribution system is only designed to handle 10,000MW of power. With the system stressed, maintaining voltage stability and avoiding brownouts will be a challenge.

Sag Testing to Develop Equipment Susceptibility Curves

Most reliability cases involve the system voltage being reduced to a point where a single component is unable to function and shuts down. To correct such a problem requires the knowledge of a component or system tolerance to low voltage. This can be done by rote or by predictive testing. In other words an observer can use a meter in the field and say that a device turns off when their meter reads a particular voltage or a sag generator can be used to produce voltage sags of various magnitudes and duration in a controlled environment.

Here the process of predictive testing will be described using an AC contactor as an example. In many cases it is not necessary to sag test the entire piece of equipment. Often problems stem from a single component shutting down (the weak link in the chain). Therefore testing the control circuit or components of a control circuit will go a long way in determining the equipment susceptibility. There are processes that have large power components that will effect quality. As an example, processes that have critical temperatures that can be effected by low voltage to the heating unit. For these processes it may be necessary to sag test the entire unit, power supply and controls to determine the impact on production quality as well as voltage susceptibility. This determination is best made by production quality assurance personnel.

Figure 1 shows the effect of various voltages versus duration for a NEMA size 4 electromagnetic starter. As can be seen in the chart, one of three results occurred: 1) The starter remained closed, 2) The starter opened, or 3) The starter was unstable. It is seen that a sag down to 90Vrms for up to one second (60 cycles) will have no effect on the starter. A voltage sag down to 85Vrms to 68Vrms (depending on the duration) or below results in the starter turning off. In between these values the starter is unstable and may open or remain closed. These curves are made by using a sag generator to produce voltage sags of various magnitude and duration. For each of these tests, one of the three conditions mentioned above resulted. When near a change in state, the voltage for each sag was adjusted to the tenth of a volt to determine were the change in state occurred. The lines in Figure 1 were than plotted to define the contactor state for any given sag.

It is important to realize that these curves were developed with only one iteration of each sag condition. To provide reliable curves it is necessary to reproduce the test numerous times with a number of device samples. Also, the sagged voltage was in phase with the original line voltage. Other tests have shown that phase shift in the sagged voltage can dramatically impact a devices ability to ride through a sag. This point is made so that it is understood that several curves may exist for a single device.

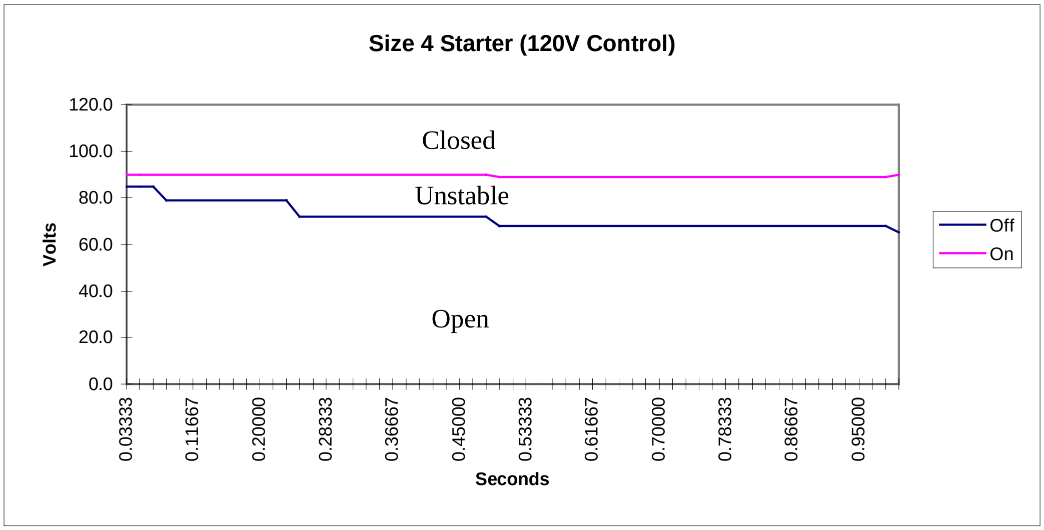

Figure 1 - Voltage Reliability Curve for a NEMA Size 4 Starter

Site Historical Data

To perform a cost benefit analysis it is necessary to understand how many events per year will affect a particular process. For this to be done requires monitoring to track the magnitude and duration of events. This monitoring may be done for the entire facility or just critical buses. It is recommended that the main utility connection as well as each of the distribution transformer secondaries be monitored. This type of monitoring scheme will help determine whether a problem is internal or external to the facility.

Figure 2 shows all recorded events at the utility connection for a facility since 1990. The events are categorized by percent nominal voltage and duration of sag. The outages recorded were from 10 seconds to 65 minutes in duration. Sags were from a few cycles to 3.4 seconds in duration. It is noted here that in Figure 2 the phase with the deepest sag was used for the voltage magnitude. With the exception of the outages the faults were non-symmetrical. The figure does not show that the number of events per year has been on the rise over the last two years.

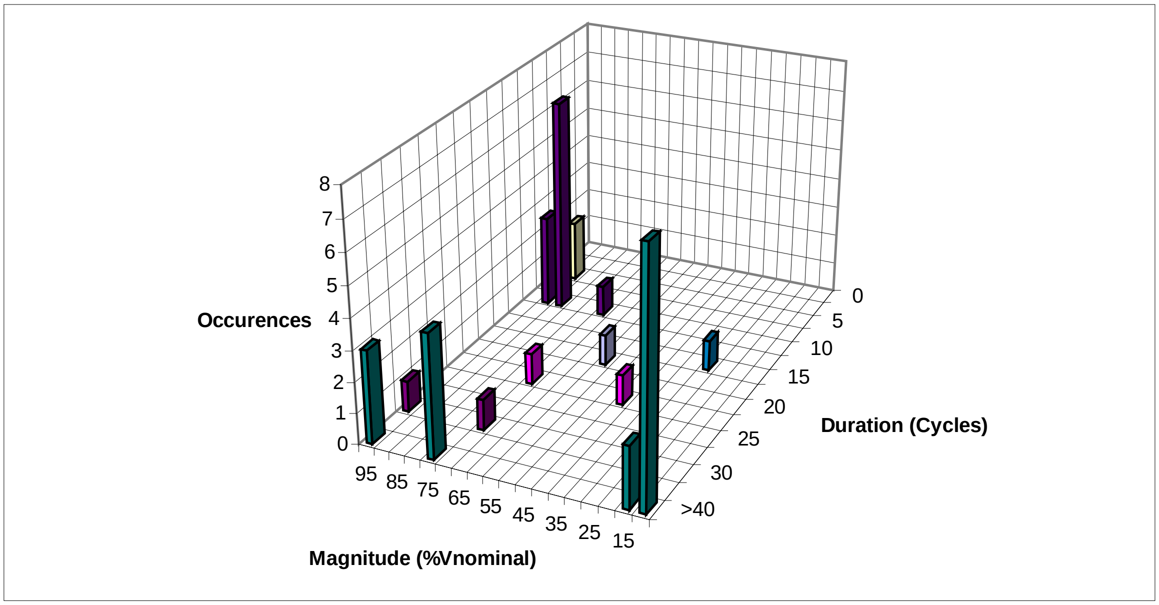

Figure 2 - Magnitude vs. Duration of all Voltage Events from 1990 through 1997

Combining Equipment Susceptibility Curves with Site Historical Data

Figure 3 shows the same information as shown in Figure 2 normalized to one year. The shading shows the anticipated number of events on a per year basis that will be at or below the particular level of voltage and duration. For example, within the voltage reliability graph (Figure 3) there is an equipment susceptibility curve that shows that if the voltage is below 69% of nominal for more than 13 cycles the equipment will shut down. With the data from Figure 2, critical equipment would be expected to go down 2 to 4 times per year. The 2 to 4 event area is so large in Figure 3, it is likely that most sensitive equipment at the facility would fall into this range. So even without specific susceptibility curves, it can be said that all or part of the facility could go down 2 to 4 times a year.

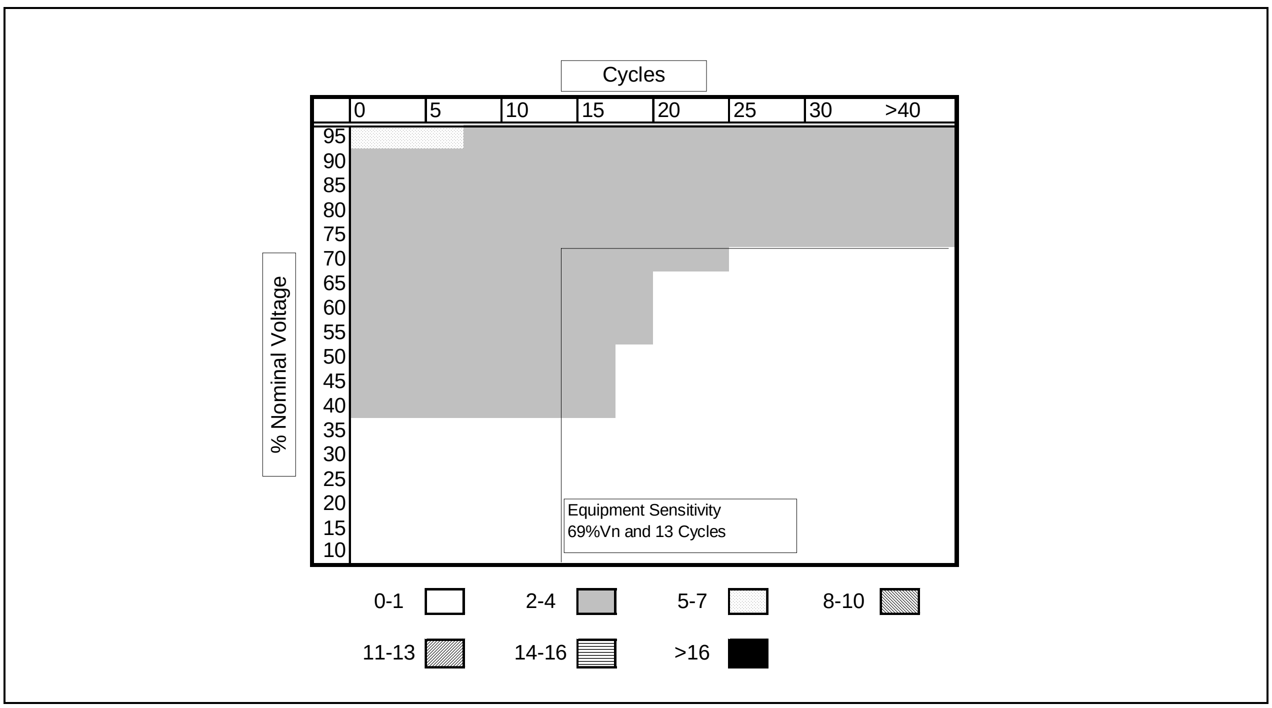

Figure 3 - Facility Voltage Reliability Graph Normalized to a per Year Basis

The goal when implementing a solution is to maximize the white area shown in Figure 3 or to improve equipment reliability to a point where the equipment sensitivity curve falls into the white area. Figure 4 shows all the events from 1990 to 1997 (Figure 2) that would have been protected by a Westinghouse Dynamic Voltage Restorer (DVR). The connected DVR is a 2.0MVA unit with 660kJ of stored energy. The results in Figure 4 assume that the load is at unity power factor and that the fault is three phase with no phase shift from the original voltage. The maximum injection voltage will be 100% times the ratio of DVR MVA to load MVA. For instance, a 2MVA DVR applied to a 4MVA load has a maximum injection of 50% rated voltage.

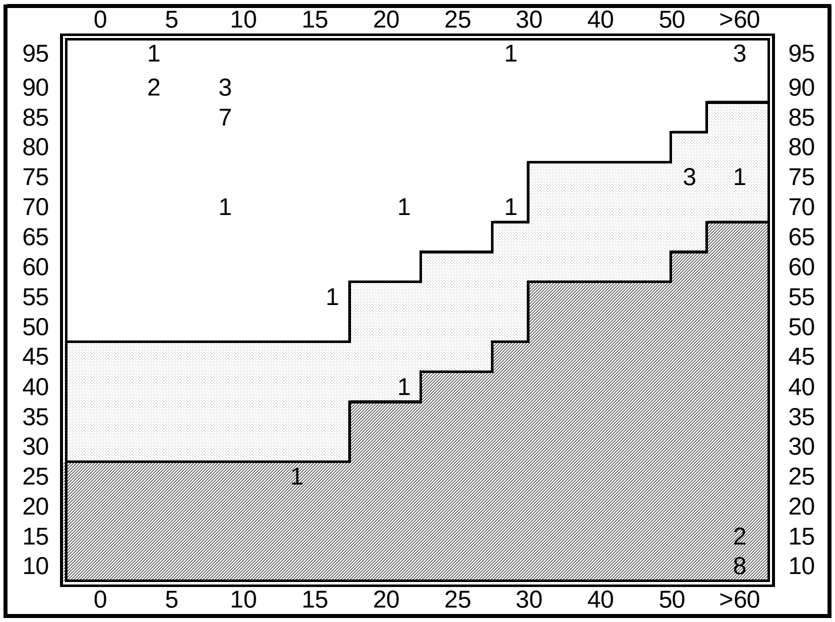

Figure 4 - Facility Events Covered by a 2MVA DVR with 660kJ of Stored Energy and 4.0MVA of Load

In Figure 4, events in the white area are those that the DVR will restore 100%. Events in the dark gray area are those that the facility will likely not be able to ride through with the specified DVR. Events in the light gray area are those that will not be restored 100%, but are likely to allow the facility to ride through. Without specific equipment sensitivity curves for critical equipment it is not possible to determine how deep and long of a sag that the facility will be able to ride through. From past work in this area, it is surmised that sags down to 80% of nominal voltage will not cause a problem. This is the criteria used to determine the light gray area. This area is created because the DVR will inject as much voltage for as long as possible, even if 100% voltage restoration isn't possible.

Figure 5 shows the modified reliability graph for the facility with a 2 MVA DVR. For the purpose of this graph, the events shown in the light gray area of Figure 4 have been moved to the likely magnitude and duration with the specified DVR. Figure 4 shows that the application of a DVR for this facility greatly reduces the magnitude and duration of sag events. Even though the white area in the figure has been increased, the equipment susceptibility curve shown is still in the 2 to 4 times per year range. So even though the solution has significantly improved the over all power, it is not the proper solution to protect this particular piece of equipment. This is why it is important to understand both the ride through capability of facility equipment as well as the number, depth and duration of sags per year. With only part of the information, it is possible to be mislead into thinking that a particular solution will reduce process down time.

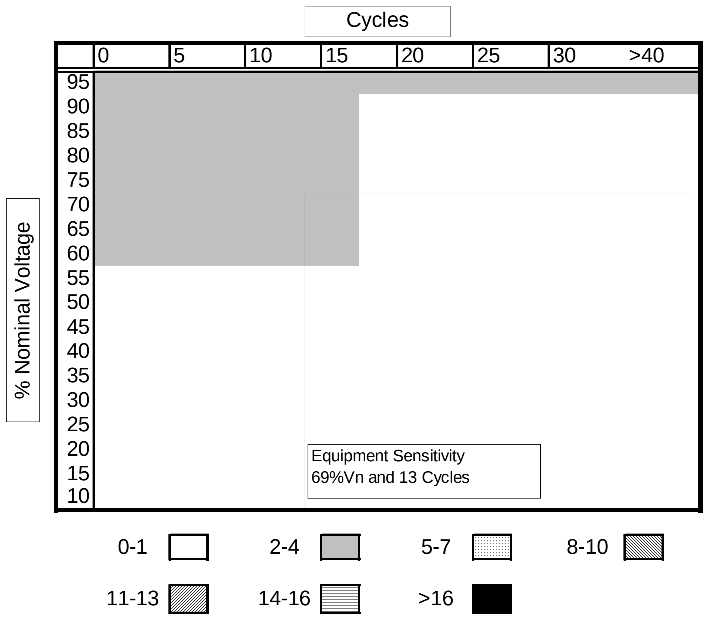

Figure 5 - Facility Voltage Reliability Graph Normalized to a per Year Basis with a 2MVA 660kJ DVR

Overview of Available Solutions

Browse through any issue of Power Quality Assurance magazine and endless solutions for improved reliability are available. It is important to realize that no one solution is the correct one for all problems. Facility people need to determine how critical a process is and what cost can be justified to improve its reliability. Many of the solutions available today are designed to protect all or large portions of the load. The selection and application of these solutions could justify a paper on each technology. If one of these technologies is being considered it is strongly recommended that an independent adviser who understands each technology be obtained to help apply the appropriate solution.

There are simple solutions that can be implemented by plant personnel as a first step to improved reliability. At the top of this list is assuring that equipment has been set up for the facilities nominal voltage. Next is to make sure that distribution transformers are tapped to supply as close to nominal voltage as possible. In many cases it has been found that problems arise from simple things like transformer taps not being set properly. This is particularly true of equipment that comes from overseas where there are often as many as five different utilization voltages for control and power. Adjusting taps so that each voltage is as close to nominal as possible can improve the overall equipment ride through significantly. For instance, a critical component designed to operate at 120Vrms is fed via a 480V to 120V transformer. The distribution bus feeding the transformer is operating at 460Vrms. Now lets say that the component will go off line at 80Vrms. A sag down to 70% voltage will drop the device off line as opposed to a sag down to 67% if the transformer feeding the distribution bus were adjusted to provide nominal voltage. Running busses at higher than nominal voltage is a problem as well. Sensitive electronic devices have tight protection against over voltage. For the same reasons discussed for sags above, if bus voltages are high, the margin for non interrupted service is compromised.

Another less common problem is the inappropriate firmware loaded into electronic devices. Many electronic devices have protection schemes as part of their control algorithm. If plant voltage is within the published specifications for a device that shuts down, have the manufacturer confirm that the proper firmware or power supply card has been installed. Cases have been seen where devices with a wide voltage range (+ / - 10%) had the wrong firmware loaded and were susceptible to voltage variations as small as + / - 1%.

It is important that critical support systems be fully redundant. If two sources of power are available, a critical system should not require both sources to be operational. This concept seems simple but is often violated. Furthermore, critical systems should have independently redundant systems fed from the second source of power.

Load Characteristics

Motor drive information is a good example of what manufactures will provide if it is requested. Most modern drives have published ride through characteristics. As an example, the Allen Bradley 1336 drives will operate continuously down to 85% of nominal voltage. If the bus voltage falls below 58% of nominal at any time, the drive shuts down due to an undervoltage fault. If the line voltage is between 58% and 85% of nominal, the drive has 30 cycles (0.5 seconds) to go above 85% of nominal or the drive will shut down due to a line loss fault. The over voltage trip for these drives is 119% based on a nominal voltage of 480Vrms.

Another common component in modern controls is the PLC power supply. The susceptibility curve generated from sag testing a lightly loaded Allen Bradley SLC 500 power supply is shown in Figure 6. From the figure it is seen that the power supply will shut down if the bus voltage drops below 48% of nominal for more than 30 cycles.

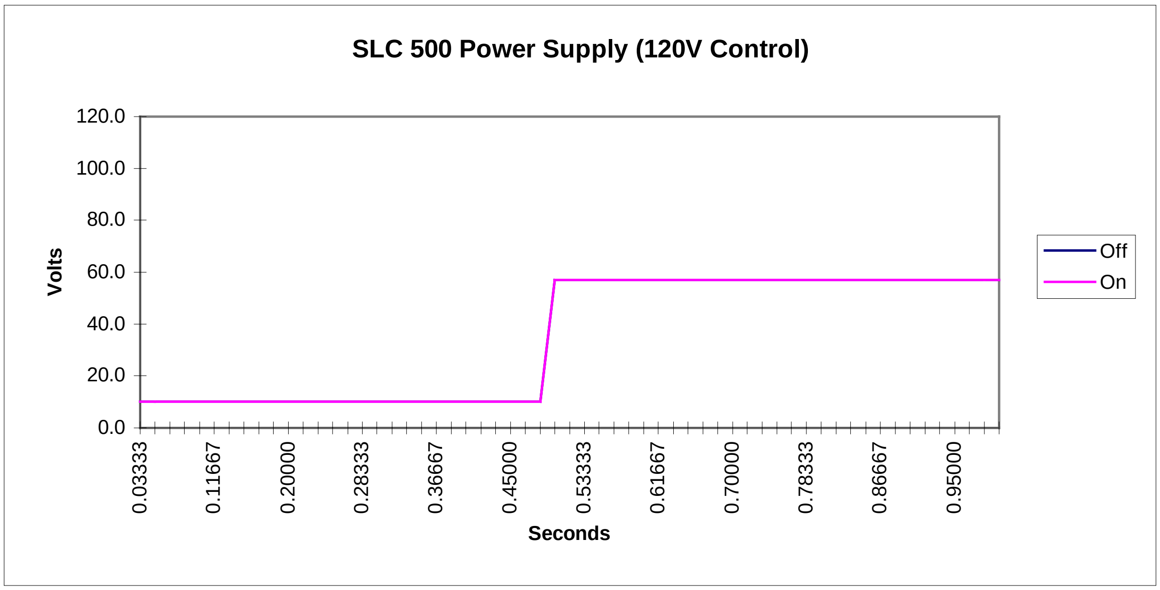

Figure 6 - No Effect above 10V for 2 to 30 Cycles and above 57V for 30 to 60 Cycles

Above, the susceptibility of components that are typically considered critical in any process have been shown. From the section **Combining Equipment Susceptibility Curves with Site Historical Data**, it was shown that having this type of information is necessary to determine the likely-hood of a process going down. While this type of information is not usually available, it is critical that facility personnel request it from vendors and Original Equipment Manufacturers (OEM's). If this isn't done, suppliers will have no incentive to do the testing and provide the information. In the mean time there are independent resources available to perform this type of testing.

Mini Case Studies

Voltage Variation due to Internal Loads:
In many facilities there are loads that require a lot of reactive power for a short duration. These are usually due to large motors starting or spot welder operation. For this case, compressor motors cycle on and off requiring the reactive power shown in Figure 7. Short reactive power requirements by all plant loads caused voltage fluctuations as large as 2.0% on the utility system, which are seen by all buses in the facility. Voltage fluctuations on the bus feeding the compressors were as large as 3.0% of nominal.

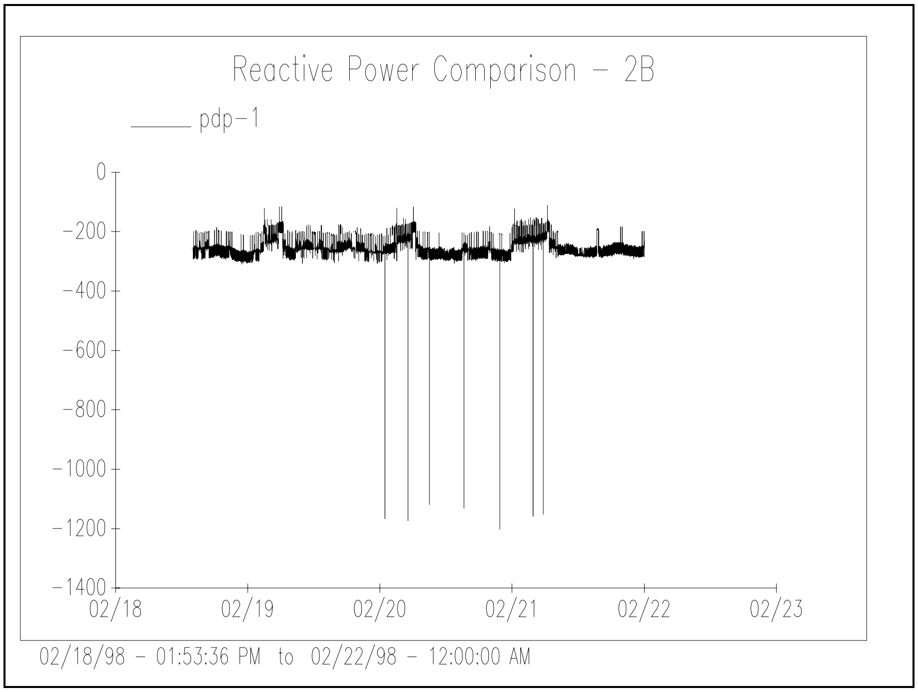

Figure 7 - PDP 1 Reactive Power

The primary complaint by plant personnel was light flicker and as a result many control problems were blamed on poor power. Figure 8 shows the susceptibility curve for the 277V, 400W Metal Halide light fixtures used at the facility. Testing showed that for sags 3 to 120 cycles in duration a 1.6% change in voltage was perceptible, a 2.6% change in voltage was very noticeable and the fixture turned off at 124.7Vrms.

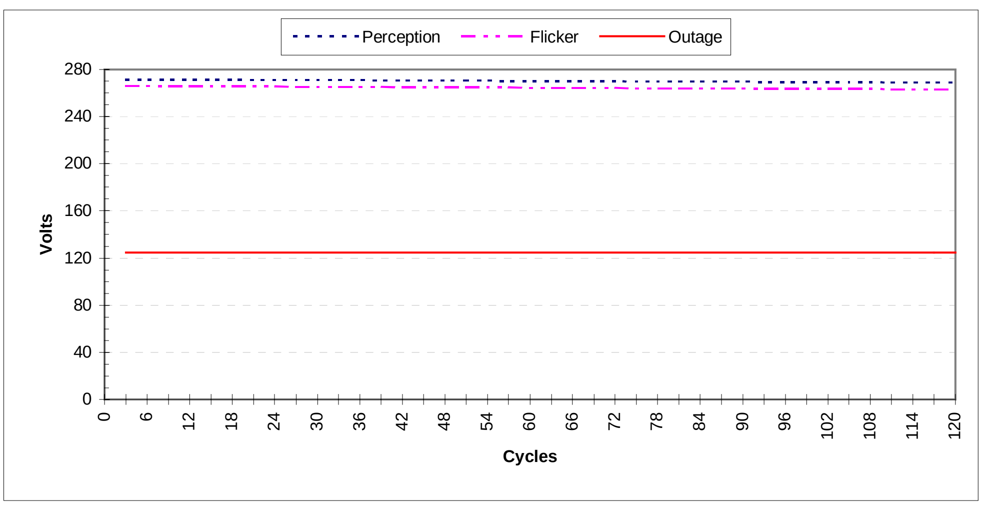

Figure 8 - Reliability Curve for a 400W Metal Halide 277Vrms Light Fixture

After further investigation the control problems being blamed on poor power were due to other problems not related to power. The facility was already planning on installing soft start controls for the compressors that should alleviate the light flicker. Unfortunately, there are very few options to remedy this problem. For instance, if this would have been a spot welder it is obvious that the soft start solution wouldn't apply. The alternative is a VAr Compensator which is very costly with complex control and over kill for such an application. There are manufacturers that offer automatic power factor correction systems with solid state switches and real time control which switch in the required reactive power within 20 milliseconds. These are a reasonable solution and cost about 1.5 to 2.0 times that of a traditional automatic power factor correction system which switches steps of capacitors in each 15 to 30 seconds. The least cost alternative is an old idea revisited, the use of series capacitors. These should be applied cautiously to avoid setting up resonance in the power system, but are effective at providing real time reactive power control.

Compressor System:
Figure 9 shows a simplified one line diagram for a facilities primary compressors supplying plant air. Plant air is critical to this plants process. From the diagram, the first concern is that the compressor and support components rely on four separate transformers for operation. If a fault occurs on the secondary of any one of the transformers, it is likely that plant air will go down. While there are multiple chillers and instrument air compressors, the backups are fed from the same bus and transformer as the primary units. These systems should be split up to have the primary unit on one bus and the secondary unit fed from a second bus and transformer. This way a problem would have to occur on two transformers simultaneously to bring down those support systems. With this scheme it would also be possible to have sub-cycle transfer switches which could transfer load to a non-faulted bus seamlessly. Finally, compressor controls should be derived from the same transformer feeding the compressor.

Chilled water units are fed from drives which will resume operation if the nominal line voltage is achieved within 120 cycles (2 seconds) from the start of a sag or outage. The instrument air systems are operated by across the line starters (Figure 1), a sag down to 75% of nominal voltage will likely shut down these processes. The compressor control will remain on line for sags down to 63% of nominal voltage (see Figure 10). The Multilin protection units will assume a de-energized state when the voltage drops below 85V (71% of nominal) for 3 cycles or more. An updated model of the Multilin protection was released in 1996 which assumes a de-energized state when the voltage goes below 80V (67% of nominal) for 15 cycles or more.

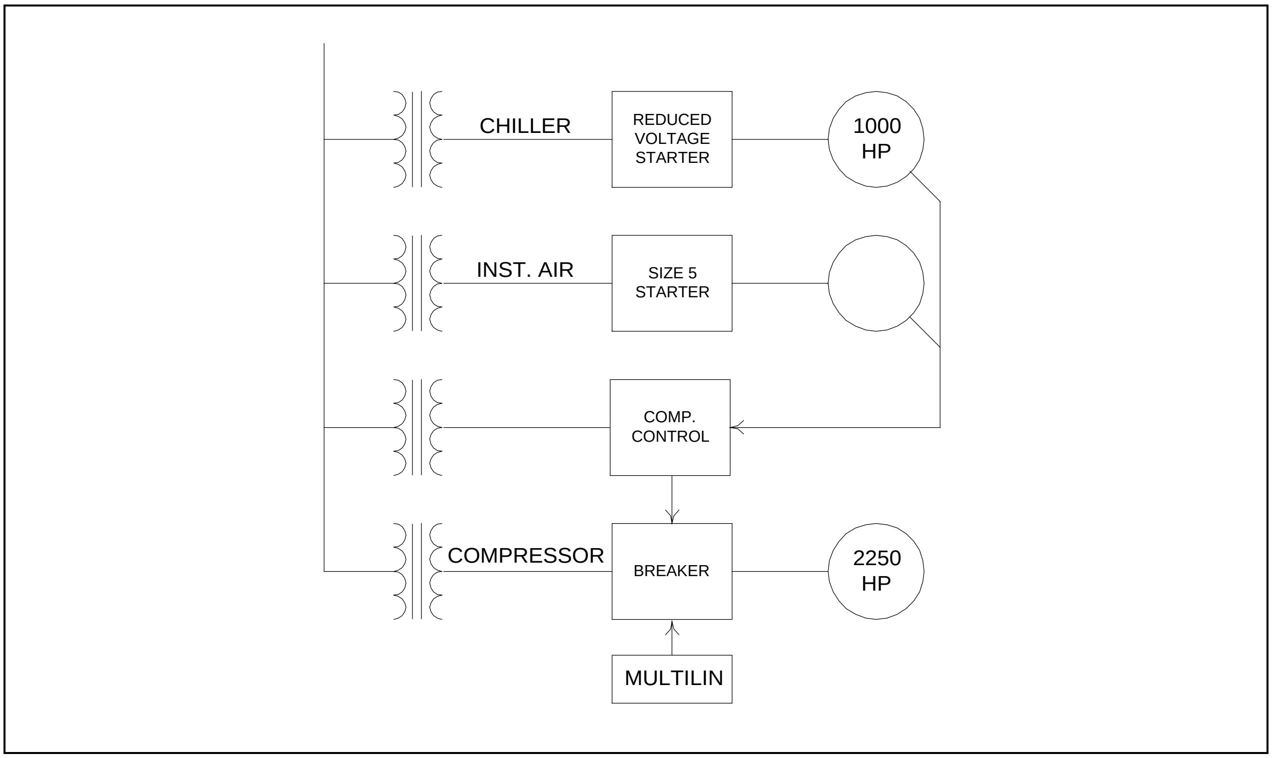

Figure 9 - Large Compressor Simplified One Line Diagram

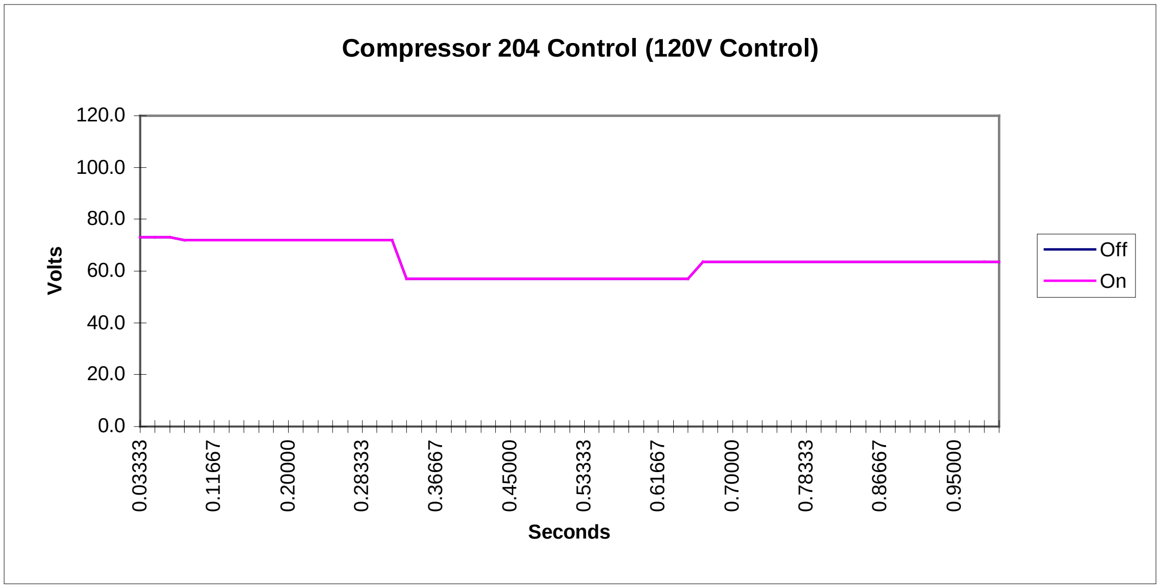

Figure 10 - No Effect above 73V 2 to 60 Cycles

For this facilities compressed air, the instrument air system is the critical load due to sags and the chiller drives are critical for over voltages. These systems had gone down a few times per year and from the study it was found that the likely cause were utility capacitor switching events. The chilled water drives have 3.0% line reactors, but the bus feeding the drives was operating above 490Vrms. The compromise of operating above nominal voltage coupled with the size of utility capacitor being switched resulted in the drives going down due to over-voltage. Adjusting the taps on the distribution transformer and the utility changing the size of capacitor switched at one time resolved this problem.

911 Computer Resetting:
A local 911 system was resetting itself at random. The operator reported that the problem only occurred in the winter months. The system was supposedly fed from a dedicated circuit and a UPS had been installed to remedy the problem. When someone indicates that the problem only occurs in the winter months and a sag issue is likely, the first thing to do is look under desks for personal space heaters. These can easily create 5 to 10% voltage fluctuations on branch circuits. Also, loads such as copiers and laser printers can cause similar fluctuations.

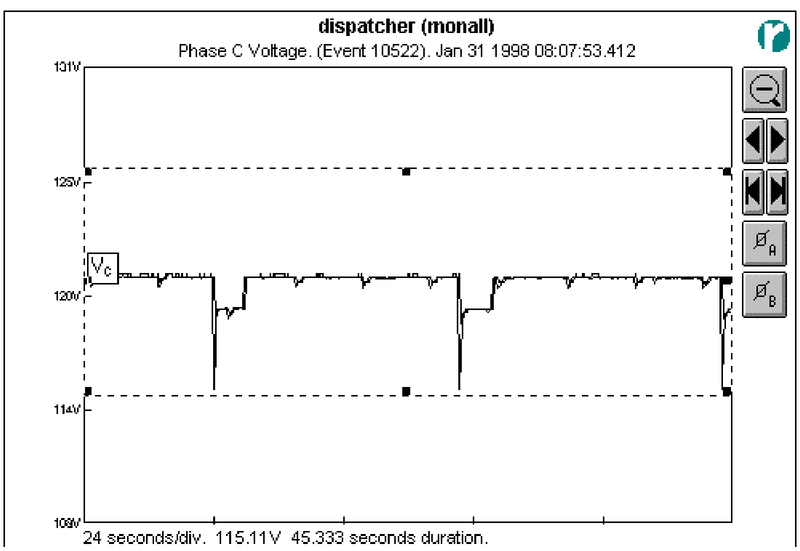

Figure 11 - Voltage Sags on Line Side of Dispatcher UPS

Figures 11 and 12 show the line and load side of the dispatcher UPS (model APC 2200) respectively. For both figures, the window is + / - 10% of 120Vrms and the dashed box is + / - 5% of 120V centered on the nominal recorded voltage. From the figures it is seen that the input and output of the UPS are nearly identical.

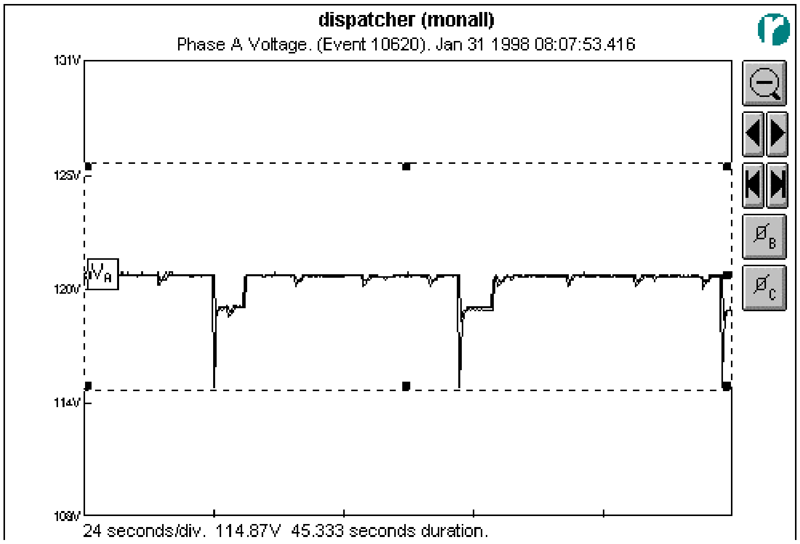

Figure 12 - Voltage Sags on Load Side of Dispatcher UPS (Corresponding to Figure 11)

This is because the UPS that was installed uses a tap changer to compensate for small changes in voltage. Unless the voltage goes below 85% of nominal, the UPS inverter will not be activated. If a double conversion type UPS would have been used, a constant output would have been maintained. This is an example of a proper application that didn't work because there wasn't the necessary understanding of the solution hardware. It turned out that the 911 computer circuit was not dedicated as originally thought. Also, it was found that a personal space heater as well as a copier were connected to this circuit. The problem was solved by removing the objectionable load from the 911 computer circuit and it was recommended that the UPS be replaced with a double conversion type.

Conclusions

- Production output of facilities are growing rapidly at a time when electric utility capacity is remaining flat. This puts a strain on utility systems making it difficult to provide reliable power.
- It is possible to characterize the susceptibility of critical loads and compare them with a facilities voltage history to determine a ROI to improve reliability.
- In doing reliability testing, often it is only necessary to test the control circuit or critical components of the control circuit. For these cases only the ability to remain on line is critical.
- There are processes that it may be necessary to perform sag tests on the entire unit to determine the impact on product quality as well as the ability to remain on line.
- Look at both equipment susceptibility curves as well as site historical data. A solution that significantly reduces the magnitude and duration of site historical data may not improve the number of times per year that a critical operation goes down. Without the equipment sensitivity curves, a false sense of security may be realized.
- Process reliability can be greatly improved by simple actions. Such actions include maintaining nominal voltage settings on distribution buses and equipment control circuits. Also, the segregation of critical support equipment so that they are not dependent on a single power source.
- When applying a solution, make sure the hardware being installed is going to perform as expected.

Biographies

Brian Prokuda, P.E. presently owns and operates Keweenaw Power Systems, Inc. Brian works with industrial and commercial clients to troubleshoot, analyze and recommend solutions for power and control related electrical problems. He holds a Professional Engineering and Electrical Journeyman's license in the State of Michigan and a BSEE and MSEPE from Michigan Technological University and Rensselaer Polytechnic Institute respectively. Currently Brian is a member of the IEEE Capacitor Subcommittee, the IEEE-519 committee and the IEEE-1346 committee. Prior to becoming independent, Brian design harmonic filters for Var Controls, Inc., headed up the data collection for the EPRI Distribution Power Quality project at Electrotek Concepts, Inc. and designed power, process control and drive systems for the Dow Chemical Company.

Andrew (Andy) Hernandez works with the General Motors Corporation, North American Operations (NAO), Worldwide Facilities Group (WFG), as the Sr. Divisional Electrical Power Engineer for the Delphi Saginaw Steering Systems. Mr. Hernandez has been with GM for 15 1/2 years starting in 1983, as a co-op student, for the Chevrolet Motor Division, in Detroit, Michigan. He was hired full time in 1985, by Saginaw Division, in Detroit, where he worked as a Plant Electrical Engineer in the areas of electrical controls, welding, induction hardening and power distribution. In 1990, he was transferred to the Saginaw Division World Headquarters in Saginaw, Michigan, where he worked as a Sr. Manufacturing Engineer for the Advanced Manufacturing Engineering department. He specialized in CAD technology creating CNC and CMM part programs from CAD models and was named vice-president of the North American DMIS Users Group (NADUG), in 1992. In 1994, he became the Sr. Divisional Electrical Power Engineer, in Saginaw. His responsibilities include power distribution for all Delphi Saginaw Steering plants in the U.S. (9 Plants), as well as, consultant for all Delphi Saginaw Steering overseas electrical power distribution. In addition, he also participates in WFG regional power distribution teams as a consultant. Mr. Hernandez holds a BSEE (1984) from Wayne St. University, in Detroit, Michigan.

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