CHAPTER 2

FACILITY POWER SYSTEM

2-1. Dependable power system requirements

Commercial power companies attempt to provide continuous, trouble-free, dependable service. The computer and other sophisticated electronic devices have become of great concern throughout industry as users become more dependent on continuous up-time and trouble-free operation of their systems. Better knowledge of ac power and the problems that introduce faulty conditions would prevent unnecessary downtime and costly repairs. Initial site preparation, proper installation procedures, and the use of proper power line conditioning devices can prevent many of these related problems.

a. Environmental conditions play a major part in insuring that computer systems operate at maximum efficiency. Proper temperature control becomes very important. Variations in temperature lead to component thermal shock, resulting in excessive downtime. High particulate counts in the atmosphere contaminate and cause problems. Corrosives have short- and long-term adverse effects. Vibration in heavy industrial areas must be observed and considered. Radio frequency interference (RFI) must be detected and prevented and so must electrostatic discharge (ESD).

b. Conductive contamination of computer room equipment by zinc whiskers can cause voltage or signal perturbations leading to machine errors or equipment shutdown. Zinc whiskers can grow on metal stringers or on the bottom or sides of floor tiles that have a zinc electroplated-passivation coating on the tile's sheet metal pan. As floor tiles are moved or disturbed, the zinc whiskers break off , become airborne, and make their way inside computer systems' equipment. The zinc whiskers lodge themselves in electronic components of logic cards and power supplies causing either a voltage or signal perturbation. At this point the machine posts an error or shuts down. Inspection, cleaning, and floor tile replacement can prevent or correct this problem. However, computer room floor tile manufacturers have identified this problem as no zinc electroplated floor tiles have been manufactured for several years.

c. The five most prevalent causes of computer and electronic problems are: (1) poor or improper grounding of equipment, (2) loose wiring connections, (3) improper computer room temperature and humidity control, (4) degraded power, and (5) systems mismatching.

d. Power line noise, poor regulation, and impulse transients can cause a host of problems when coupled into sensitive electrical and electronic circuits. Steps can be taken to reduce these problems by proper conditioning, grounding, and shielding. Yet, the weakest link in such circuitry may well be the power supply, since these impulse transients and the line noise may be coupled through it and superimposed on the signals. Low-level analog circuits are not unique in this respect. Digital instrumentation, computers, data processing equipment, recorders, etc., are all vulnerable.

e. The commercial utility specifications define limits for amplitude variations, frequency variations, and harmonic distortion for the power they furnish, but make no official mention of the fluctuations lasting from 1 microsecond to 30 milliseconds that occur during load switching, transformer tap switching, or phase compensation. Some utilities have, however, admitted that voltage variations to 300 percent, lasting up to 1 minute, may occur. Their position is understandable, considering that many of the fluctuations, impulse transients, and interruptions are not caused by their own equipment.

f. When the electric lights flicker, it means that a power line voltage fluctuation has occurred. It also means that the fluctuation lasted about half a second since the human eye cannot detect light intensity changes that occur at much faster rates. However, many of the fluctuations that appear on power lines last for only a few milliseconds or microseconds. Critical electronic circuits respond to these high-speed fluctuations, causing erratic and erroneous operation. In addition, subjecting circuit components to the cumulative stresses exerted by these impulse transients can cause intermittent changes or component breakdowns that may occur even at a time when line transients are not present. Therefore, it is vital to determine whether the power source is clean.

g. The power line is exposed to all the noise voltages generated by the appliances, tools, and machines that receive power from it, and these noise voltages are superimposed on the line voltage and coupled through the power step-down transformer. When these noise voltages pass through the transformer, they appear in the power supply. The noise voltages may cause the power supply to break into oscillation, or may simply pass through it to appear in the electronic logic, control, or amplifier circuits. In either case, the noise voltages may cause a computer to make errors, may induce non-programmed jumps, or may actually cause equipment damage.

h. Power line conductors also act as antennas and pick up radiated voltage from automobile ignition systems, high-power transmitters, fluorescent lamps, diathermy machines, and lightning. These voltages appear equally on each conductor of a pair, and consequently cannot be measured between them. The voltages do, however, appear between either lead and ground. While this voltage cannot be detected between the input leads, it is coupled through the distribution capacitances between the individual turns of the primary and secondary transformer winding and appears as normal mode noise across the secondary winding. Suppressing these line surges, dips, transients, and power fluctuations at their radiated voltage sources would be an impossible task. The only realistic approach to eliminating their effects is to isolate each critical equipment installation from these disturbances.

i. There are only six basic categories of power line problems - total loss of line power for extended periods, insufficient or excessive power line voltage, harmonic distortion, high frequency noise, impulse transients, and combinations of these.

(1) With a total loss of power, the equipment receives no power and does not operate.

(2) During insufficient or excessive voltage, many types of equipment malfunctions and even equipment damage can occur, but the condition can be detected by monitoring the power and voltage with an ac voltmeter.

(3) Harmonic distortion is detected using either an oscilloscope or a harmonic distortion analyzer.

(4) The remaining types of problems, noise and impulse transients, cannot be detected by either the human eye or an ordinary voltmeter, because neither the eye nor the meter can respond to the rates of changes that occur when these phenomena are present. Studies have concluded that these types of transient overvoltages cause almost 90 percent of soft and hard failure to computer systems through the power line. The ideal device for detecting either noise or impulse transients is a power line monitor, provided it has the proper characteristics and is correctly connected to the power circuit. However, even many expensive monitors do not give total true peak amplitudes, rendering it impossible to correlate the amplitude of an impulse and its relationship to the sinewave. The best power line monitors will record transients with amplitudes varying from a few hundred voltage to several hundreds or thousands of volts which last for as little as 30 nanoseconds. Some record amplitude, frequency, and time. Some monitor only single-phase power lines and others accept and monitor three-phase inputs. Proper connections of the monitoring equipment are a must. An improperly connected monitor may totally ignore line voltage

abnormalities, and the power line may be erroneously eliminated as the culprit when critical measuring or data processing equipment malfunctions. Measurement limits must also be set properly or much of the valuable data may be misinterpreted and ignored.

2-2. Commercial (utility) power

Electrical power generating plants are generally located in remote areas near some natural source of power such as water, oil, or coal. The electrical power must be delivered to where it is consumed via a transmission line. To minimize losses, power is transmitted at high voltage and low current. The generator outputs three-phase, ac power normally at 18,000 to 22,000 volts. The voltage is then increased through step-up transformers to 69,000 to 500,000 volts. These high voltage transmission lines are then tapped off at substations, which step the voltage down and deliver three-phase ac power to the local lines at some intermediate voltage such as 13,800 volts. The final reduction to a nominal 480 volts or 208/120 volts usually occurs at a transformer located near or in the user's facility. This may also be derived from the incoming 480 volt power line with an additional step-down transformer.

a. Power is generated and transmitted in three-phase form for several reasons. Three-phase current produces a rotating field, which is useful in motor applications. Poly-phase motors are simpler to construct, are more efficient, and operate more smoothly, especially at larger horsepower ratings; i.e., 100 horsepower and above. Three-phase power also has less ripple when rectified, thus requiring less filtering. The three-phase, three-wire transmission system delivers 1.73 (square root of 3) times as much power as a two-wire, single-phase system. This results in a savings of 25 percent in the amount of copper required to transmit a given amount of power a fixed distance with a given line loss and fixed voltages between conductors.

b. North American utility companies attempt to maintain electrical power within the following tolerances.

(1) The nominal frequency of 60 hertz is maintained within ±0.5 hertz. The frequency is generally within ±0.2 hertz in the United States and Canada because of the grid integrity between the two countries and between areas within each country.

(2) Utilities attempt to provide voltage with no harmonic distortion; i.e., no frequency component other than the 60 hertz fundamental frequency. There will, however, inevitably be evidence of the 3^{rd}, 5^{th}, and 7^{th} harmonics.

(3) Utilities also strive to limit noise spikes - generated either within or outside the service drop (from transformer to main service panel). Spikes (impulse transients) from lightning and switching operations will be present, however.

(4) "Normal" voltage root mean square (RMS) amplitudes are as follows.

(a) The 120 volts normal is permitted to drop to 111 volts at the utility feed (distribution transformer).

(b) From the utility an additional 3 percent voltage drop is allowed to the service entrance (meter).

(c) A 2 percent drop is considered acceptable from the service entrance to the equipment.

(d) The lowest allowable RMS value at the equipment is, therefore, 105 volts without brownouts.

2-3. Power line phenomena

There are six basic power line disturbances or anomalies.

a. A loss of voltage or a complete power outage can range from downed power lines to failed transformers, to tripped circuit breakers, etc. These power outages may last for a short one-half cycle of the 60 hertz sinewave (8.3 milliseconds) or for several hours. Most are no longer than a few seconds.

b. High or low voltages/amplitude changes can be detected with a voltmeter or a voltage recorder. Causes may be power lines, distribution panels, and/or the wiring being too heavily loaded. In addition, being too close to the source of the power or too far from the source of power can cause large voltage fluctuations, as well as starting or stopping heavy motor loads, non-uniform loading of poly-phase transformers, or poor regulation. If an undervoltage condition continues for more than 0.5 cycle (8.3 milliseconds), but less than 1 minute, this is referred to as a sag . If an overvoltage condition continues for more than 0.5 cycles (8.3 milliseconds), but less than 1 minute, this is referred to as a swell. Longer than 1 minute they are referred to as an undervoltage or overvoltage.

c. Harmonic distortion occurs when the normal sinewave is mis-shaped caused by harmonics (multiples of the primary frequency). When 60 hertz power is generated, multiple harmonic frequencies are generated but normally only the odd harmonics have sufficient amplitude to be of concern. Generally, these harmonics can only be detected by specially designed equipment. Flat-topping of the sinewave, as seen on an oscilloscope, is the first indication of harmonic distortion. Under severe conditions, the sinewave can look extremely distorted. Causes may include overloading or improper loading of transformers, faulty regulation transformers, fluorescent or other electric-discharge lighting, and/or data processing equipment.

d. Noise is normally detected as bad or faulty data and then investigated with an oscilloscope. Oscilloscopes are used to detect and analyze high frequency events or even to analyze the 60 hertz power sinewave. Noise is a low voltage, low current, high frequency signal riding on the 60 hertz sinewave and is characterized by having a repeatable frequency pattern, one that can be determined and analyzed. Generally it is electromagnetic interference (EMI) and is caused by having the power or data lines or the equipment too close to a source of EMI; a large motor or transformer for instance. Improper grounds or grounding can also be a cause. Noise can also be RFI if a radio tower or transmitter is located nearby.

e. Transients or impulses are high voltage, high-current, fast bursts of energy riding on the 60 hertz sinewave. They also exhibit a non-repeatable frequency pattern even when resulting from the same repeated event. They exhibit extremely fast rise times (1 microsecond to peak) and last for less than 8.3 milliseconds, usually decaying to 50 percent of peak value in 1 millisecond or less. Because they have no repeatable frequency pattern and are random in occurrence, they are extremely difficult to detect. Power line analyzers must be used to detect the presence of transients although the first indication of their existence is usually data errors, computer crashes, and damaged circuitry. Microprocessor based equipment is very susceptible to damage from these anomalies. Transients occur whenever the current through any inductive load (motors, transformers, coils of any kind) is changed at a rapid rate. This rapid change in current is the result of switching actions, sudden power outages, and applications of power. Transients are also induced on power and data lines by nearby lightning strikes or having data lines too close to power lines that are being switched.

f. The most common anomaly is any combination of the above. While any of these problems can and do occur by themselves, the more general rule is for them to occur in combinations. Transients always accompany voltage outages. High or low voltages may result in noise when power supplies are put under the strain of having to work at input voltage levels outside their design limits.

g. Different anomalies have different affects on various types of equipment. Take, for example, the length of a power interruption. A wall clock or scanner may be unaffected for up to four cycles without power. Other equipment like card readers, symbol generators, and many computers cannot stand to be without power for even one-half cycle (8.3 milliseconds). The equipment that is the most susceptible to short interruptions will also be the most adversely affected by the short duration impulses and vice versa.

h. Manufacturers attempt to build some protection into their equipment but competition limits what they can do economically. The Information Technology Industry Council (ITI) sets guidelines for such protection by suggesting an ac input power profile envelope shown in appendix B. They suggest that information technology equipment should be designed to meet these guidelines. However, even if the equipment were designed to this power profile guide, the envelope does not cover the power profile of the utilities supplying the power.

i. Power companies attempt to provide the cleanest and most stable power (input voltage)to their customers. There is very little attempt to constrain anomalies shorter than one half cycle (8.3 milliseconds); i.e., impulses, EMI, RFI. The input power line may carry short duration variations (less than 8.3 milliseconds duration) whose voltage amplitudes can be hundreds of times greater than nominal. These "Type I disturbances" are often damaging to electronic equipment. Between 8.3 milliseconds and 0.5 second the power line may still vary as much as +30 percent to –40 percent of nominal. These "Type II disturbances" (sags and swells) may also adversely affect the equipment as will the 'Type III disturbances," voltage dropouts, and overvoltages."

(1) To counteract these conditions and protect computerized equipment from these anomalies, the ITI recommends that all computerized equipment be designed to operate within the set guidelines. Equipment designed and manufactured to meet this recommendation should then withstand any variations within the guidelines. Therefore, an impulse with voltage amplitude less than 200 percent of nominal rated RMS and shorter than 100 microseconds duration should not adversely affect the equipment. Neither should those less than 100 percent and shorter than 1 millisecond or less than 30 percent and shorter than 8.33 milliseconds.

(2) Engineers from IBM conducted a study from which they were able to determine the incidence rate of harmful power line disturbances. They studied a large number of installations over an extended period of time and in 1974 published their findings in a document [1] "Monitoring of Computer Installation for Power Line Disturbances," G. W. Allen and D. Segal, Institute of Electrical and Electronic (IEEE) Winter Power Meeting Conference Paper C74-199-6. The results showed that 88.5 percent of power line disturbances were Type I disturbances, 11 percent were Type II disturbances, and 0.5 percent were Type III disturbances. Type I, II, and III disturbances were defined as having durations of less than 0.5 cycles, 0.5 to 120 cycles, and greater than 120 cycles, respectively.

(a) While Type I disturbances are the most damaging to equipment and data, even Types II and III can be of great importance for customers who cannot tolerate the inconvenience and high cost of downtime or erroneous data, loss of data, etc. There will be many cases where a customer may need and be willing to go to great expense to eliminate even the least frequent of these occurrences.

(b) Electronic chips have become denser – more than one million components on a small chip – and are thus even more susceptible to Type I disturbances. Utilities are attempting to hold closer tolerances on the voltage, and yet, sags and swells (Type II) and outages (Type III) are on the increase.

(3) Several recent power quality surveys have been conducted and published in an effort to define the electrical environment. These studies are [2] "Diagnosing Power Quality-Related Computer Problems," T. S. Key, IEEE Transactions on Industry Applications (1979); [3] "The Quality of U.S. Commercial AC Power," M. Goldstein and P.D. Speranza, INTELLEC (IEEE International Telecommunications Energy Conference, 1982); [4] "Canadian National Power Quality Survey Results," M. B. Hughes and J. S. Chan, Proceedings of EPRI's PQA '95; [5] "Point of Utilization Power Quality Study Results," D. S. Dorr, IEEE Transactions on Industry Applications (1995); [6] "Preliminary Results of Monitoring from the EPRI Distribution Power Quality Project," D. D. Sabin and T.E. Grehe, Proceedings of EPRI's PQA '95; [7] "Power Quality Site Surveys: Facts, Fiction, and Fallacies," F. D. Martzloff and T.S. Gruzs, IEEE Transactions on Industry Applications (1988); and [8] "Matching Appliances to their Electrical Environments," T. S. Key, D.S. Door, M.B. Hughes and J.J. Stanislawski,, Proceedings of EPRI's PQA '95. Studies [1], [2] and [3] are compared in study [7] and in the appendix of IEEE Std. P1100-1992. Studies [4], [5] and [6] are compared in study [8].

(4) Recent studies have redefined Type I, II, and III disturbances as transient, momentary, and steady-state disturbances respectively. Transient disturbances include unipolar transients, oscillatory transients (such as capacitor switching), localized faults, and other events typically lasting less than 10 milliseconds. Momentary disturbances are voltage sags, swells, and interruptions lasting more than 10 milliseconds but less than 3 seconds. Steady-state disturbances are undervoltages, overvoltages, and interruptions that last 3 seconds or longer.

2-4. Power quality requirements

Prior to design and installation of a sophisticated automated data processing (ADP), the end user should request from the electric utility a report on the quality of distribution supplied power at the location. Quality of supplied power is intended to include not only the annual expected outage rate at the specified feeder location, which is now available from feeder outage records, but also a voltage sag history using the following methods.

a. Install one power analyzer per selected substation to record on paper or magnetic tape the magnitude of voltage sags and their duration in cycles together with date and time of occurrence. Installations would be made at one major distribution substation per 25-mile radius with the monitored voltage being the distribution supply voltage as stepped down by metering or station service transformers. Only voltage sags of 10 percent or greater would be monitored.

b. The voltage sag histories would be collected monthly and the cause of the recorded sags identified from fault records to establish location and type of system fault causing the voltage sag.

c. Short circuit computer runs would be performed duplicating the fault conditions to establish the magnitude and duration of the monitored sags, which occurred at the non-monitored substation busses. The duration assigned would be the same as that recorded at the monitored station.

d. Annual voltage sag histories would then be developed for all distribution substations.

e. The above steps establish voltage sag histories for all major substation busses on the electric supply system. One remaining step remains and that is to establish the expected voltage sag history at the customer's computer location on the feeder. If the computer is to be supplied from a feeder originating from the same distribution substation bus for which the substation voltage sag history was developed, no further corrections are necessary. If on the other hand, the feeder in question originates from another distribution substation bus which is not directly connected to the bus for which the substation voltage sag history was developed, it will be necessary to adjust the counts of voltage sags due to feeder faults in proportion to the total number of feeder faults occurring on the two busses. If the number of faults occurring on feeders supplied from each bus of a two separate bus substation is about the same, the correction will not be necessary.

2-5. Power quality parameters

Since over 88 percent of the harmful power line disturbances recorded in the IBM study were Type I disturbances (transients), additional investigation of the specific disruptions is warranted. The majority of these disturbances (49 percent of the overall total) were "oscillatory, decaying transients." These would be the result of lightning or some other sharp electrical "hit" that would excite the natural frequency of the subject electrical system (much like a tuning fork is excited). The electrical system will then ring at its natural frequency, f_n (different electrical systems have different natural frequencies just as different mechanical systems have different natural frequencies), defined as:

$$f_n = 1/2\pi(LC)^{1/2}$$

The amplitude of the natural frequency (voltage in this case) will then decay at an exponential rate dependent upon the stiffness of the electrical system, amount of wiring, wire sizes, layout, etc. Due to the fact that induced lightning can be one of the initiators of this oscillatory action, the initial amplitude (voltage) of the resultant sinewave can be very high (thousands of volts) and may contain a lot of energy (thousands of joules).

a. The remaining Type I disturbances were "voltage spikes (impulse transients)" characterized by very fast rise times and slow decay times. These single uni-directional events contain a wide range of frequencies as indicated by the 1 microsecond rise time to full amplitude indicating the presence of several extremely high frequency components in excess of 1 megahertz (MHz) and the relatively slow decay time to 50 percent of full amplitude of 1 millisecond (1000 microseconds). This slow decay time indicates low frequency components of 1 kilohertz (kHz) or less.

b. For years, transient suppression devices have been tested for "impulse transient" suppression capability using transient wave forms given in American National Standards Institute (ANSI)/IEEE Guide C62.41-1991, IEEE Recommended Practice for Surge Voltages in Low Voltage AC Power Circuits. These wave forms were 1.2 microseconds x 50 microseconds for the voltage and 8 microseconds x 20 microseconds for the current. A study of wave forms actually recorded in the field was published as an IEEE paper (85 WM 243-1). This study, conducted in nine cities across the United States, over a 2-year period shows a much different real wave shape. Both voltage and current were recorded and correlated. To be accepted as valid data, the voltage and current events had to both occur within a 50 microsecond window.

(1) A total of 277,612 correlated events were recorded measuring the peak value and the time to reach peak along with the 50 percent decay point value and the time to reach that value. The computer rendition of the resultant wave form is a 1 microsecond x 1000 microseconds voltage wave form and a 60 microseconds by 1000 microseconds current wave form. A total of 89.4 percent of the calculated wave forms fall within +10 percent of these wave forms.

(2) From the data it was concluded that the equipment in the field and associated transient suppressors are subjected to far greater amounts of transient energy than in the lab. The frequency

content of these wave forms is also much wider than the laboratory wave forms, ranging from below 1 kHz to over 1 MHz. Many suppressors that give good to excellent results in the lab cannot handle the field experienced transients with their high energy and broad frequency range.

c. Data lines and instrumentation lines, while not directly affected by power line problems, can be adversely affected if located in close proximity to power lines or if located where they can be affected by induced lightning transients. Power lines or power wiring and control wiring can induce noise into data and instrumentation wiring when it is run parallel to them. Transients on the power lines paralleling data lines can also be induced onto these low voltage lines and damage data or instrumentation equipment. As little as 10 volts applied to a transistor-transistor logic (TTL) circuit for only 30 nanoseconds will cause the destruction of the TTL junction. Data line instrumentation should never be run in close parallel proximity to power and control voltage lines.

d. The affect of lightning transients may be reduced by using shielded cable for data transmission, and instrumentation care must be taken to ground the shield on these cables only at one end of the cable run to prevent induced circulating currents.

e. Data and instrumentation cable, run underground, should be buried at least 4 feet down to protect from lightning. Lightning striking the ground can raise the ground potential and induce transients into underground wiring not encased in steel pipe. Most buried cable is now encased in either polyvinyl chloride (PVC) or fiberglass if not directly buried and, therefore, is subject to lightning inducted transients if buried too close to the surface. Data and instrumentation cable inside buildings should never be run closer than 5 feet to an outside wall in a high lightning area for the same reason, induced transients from nearby or direct lightning strikes.

2-6. Detection of power line anomalies

Instrumentation has been developed to record and better understand the power line disturbance phenomena. Iron vane meters were developed to read voltage, current, frequency, and then power to enable operators to maintain constant voltage and frequencies and read current values. Then came recorders to supply a constant record of these events. As long as the major interest was only in the areas of no voltage, high and low voltage, sags, and surges, these instruments were sufficient.

a. Electronics brought in a new dimension; higher data frequencies meant that things happened faster and new instrumentation was developed to read and record these events, recording oscillographs and oscilloscopes. The higher frequency, faster electronics were also more susceptible to the higher frequency anomalies on the power supply line. Power line noise (EMI) and impulses were mistaken as data by the electronics and processed as such. Solid-state electronics and the microprocessor chip brought us high density – thousands and millions of solid-state components on a small 1/4" by 3/8" chip. The low voltage requirement of these circuits and the high density made them extremely susceptible to even minor overvoltages. A TTL junction will be destroyed at only 10 volts.

b. Due to the randomness of the power line anomalies, it became necessary to develop high-speed event recorders to detect the presence of the high-speed anomalies: noise and impulses. Such an instrument will measure and record only the event itself. The occurrences of events can be recorded for later analysis without the requirement of the constant presence of the operator or the accumulation of meaningless recorded data. A general discussion is presented below of two different power line monitors, which can record and analyze power disturbances.

(1) The first monitor, called the "universal disturbance analyzer" is extremely versatile and because of this feature requires greater skill to set up and operate. If limits are not properly chosen and

programmed in, and depending upon the "print-out mode" chosen, the user can either end up with insufficient data upon which to base corrections decisions or with large amounts of superfluous data to wade through to determine what problem needs to be corrected. Such data to the untrained individual may lead them to believe that one problem exists when the problem is really something else. For instance: one might be misled to believe that sag-surge problems existed because of reams of sag-surge data when in reality the limits had been set so low that what was actually recorded was a lot of normal voltage fluctuations well within the permissible limits set by equipment manufacturers and governing bodies; i.e., fluctuations not harmful to equipment. However, when properly set up, this type of instrument can produce much valuable data for the experienced user.

(2) The second monitor, called the "power line consultant" does not have the versatility of the first. However, this lack of versatility results in ease of set up and eliminates questions regarding the validity of the final data. This instrument can produce all the data required to make an intelligent decision about a problem, and therefore the proper correction device, without the skill needed with the first instrument.