2 Power Frequency Disturbance

2.1 INTRODUCTION

The term *power frequency disturbance* describes events that are slower and longer lasting compared to electrical transients (see Chapter 3). Power frequency disturbances can last anywhere from one complete cycle to several seconds or even minutes. While the disturbance can be nothing more than an inconvenience manifesting itself as a flickering of lights or bumpy ride in an elevator, in other instances the effects can be harmful to electrical equipment. Typically, the deleterious effects of power frequency disturbances are predominantly felt in the long run, and such disturbances do not result in immediate failure of electrical devices.

The effects of power frequency disturbances vary from one piece of equipment to another and with the age of the equipment. Equipment that is old and has been subjected to harmful disturbances over a prolonged period is more susceptible to failure than new equipment. Fortunately, because power frequency disturbances are slower and longer lasting events, they are easily measured using instrumentation that is simple in construction.

2.2 COMMON POWER FREQUENCY DISTURBANCES

2.2.1 Voltage Sags

One of the most common power frequency disturbances is voltage sag. By definition, voltage sag is an event that can last from half of a cycle to several seconds. Voltage sags typically are due to starting on large loads, such as an electric motor or an arc furnace. Induction motors draw starting currents ranging between 600 and 800% of their nominal full load currents. The current starts at the high value and tapers off to the normal running current in about 2 to 8 sec, based on the motor design and load inertia. Depending on the instant at which the voltage is applied to the motor, the current can be highly asymmetrical.

Figure 2.1 contains the waveform of the starting current of a 50-hp induction motor with a rated full-load current of 60 A at 460 VAC. During the first half of the cycle, the asymmetrical current attains a peak value of 860 A. When the circuit feeding the motor has high impedance, appreciable voltage sag can be produced. Figure 2.2 shows a 100-kVA transformer feeding the 50-hp motor just described. If the transformer has a leakage reactance of 5.0%, the voltage sag due to starting this motor is calculated as follows:

Full load current of the 100-kVA transformer at 480 V = 120 A.
Voltage drop due to the starting inrush = $5.0 \times 860 \div (120 \times \sqrt{2}) = 25.3\%$.

If the reactance of the power lines and the utility transformer feeding this transformer were included in the calculations, the voltage sag would be worse than the value

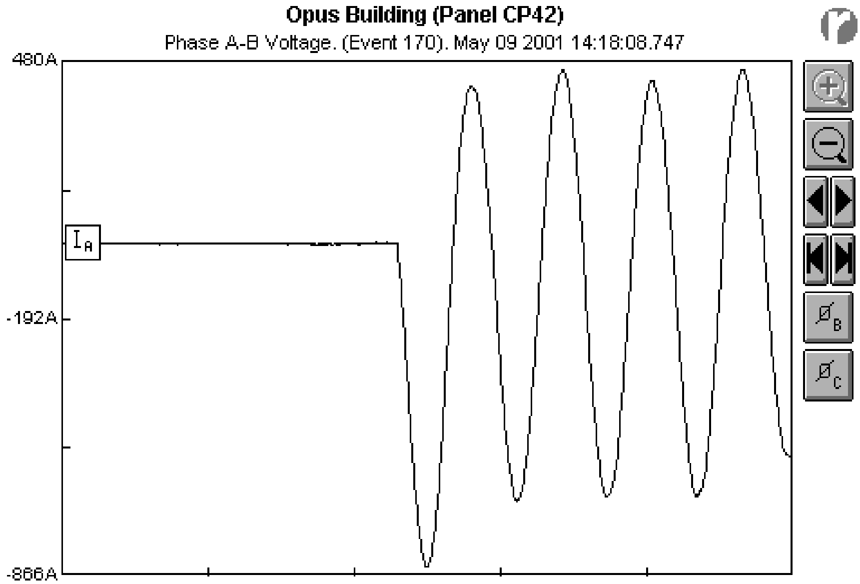


FIGURE 2.1 Motor-starting current waveform. A 5-hp motor was started across the line. The motor full-load current was 60 A. The first half-cycle peak reached a value of 860 A.

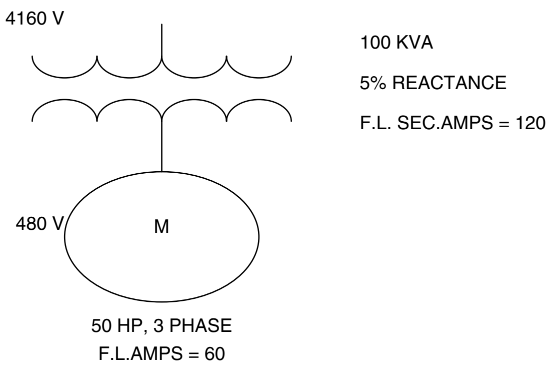


FIGURE 2.2 Schematic for example problem.

indicated. It is not difficult to see that any device that is sensitive to a voltage sag of 25% would be affected by the motor starting event.

Arc furnaces are another example of loads that can produce large voltage sags in electrical power systems. Arc furnaces operate by imposing a short circuit in a batch of metal and then drawing an arc, which produces temperatures in excess of 10,000°C, which melt the metal batch. Arc furnaces employ large inductors to stabilize the current due to the arc. Tens of thousands of amperes are drawn during the initial few seconds of the process. Figure 2.3 depicts typical current drawn by an arc furnace. Once the arc becomes stable, the current draw becomes more uniform. Due to the nature of the current drawn by the arc furnace, which is extremely nonlinear, large harmonic currents are also produced. Severe voltage sags are common in power lines that supply large arc furnaces, which are typically rated in the 30- to 50-MVA range and higher.

Arc furnaces are operated in conjunction with large capacitor banks and harmonic filters to improve the power factor and also to filter the harmonic frequency currents so they do not unduly affect other power users sharing the same power lines. It is not uncommon to see arc furnaces supplied from dedicated utility power lines to minimize their impact on other power users. The presence of large capacitance in an electrical system can result in voltage rise due to the leading reactive power demands of the capacitors, unless they are adequately canceled by the lagging reactive power required by the loads. This is why capacitor banks, whether for power factor correction or harmonic current filtration, are switched on when the furnace is brought on line and switched off when the arc furnace is off line.

Utility faults are also responsible for voltage sags. Approximately 70% of the utility-related faults occur in overhead power lines. Some common causes of utility faults are lightning strikes, contact with trees or birds and animals, and failure of insulators. The utility attempts to clear the fault by opening and closing the faulted circuit using reclosers, which can require from 40 to 60 cycles. The power line experiences voltage sags or total loss of power for the short duration it takes to clear the fault. Obviously, if the fault persists, the power outage continues until the problem

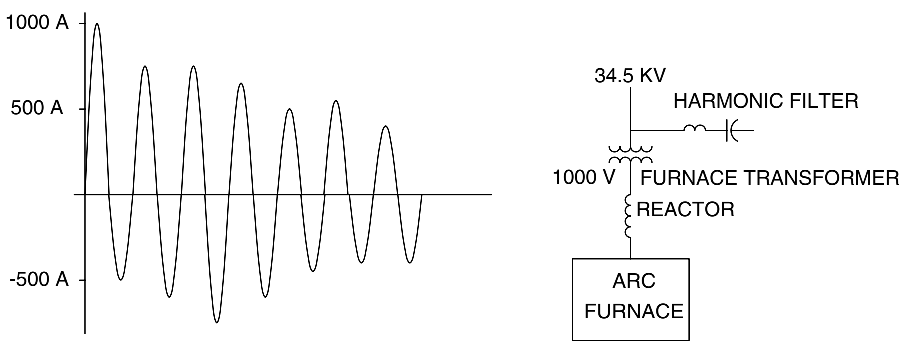


FIGURE 2.3 Typical current draw by arc furnace at the primary transformer. Large current fluctuations normally occur for several seconds before steady state is obtained.

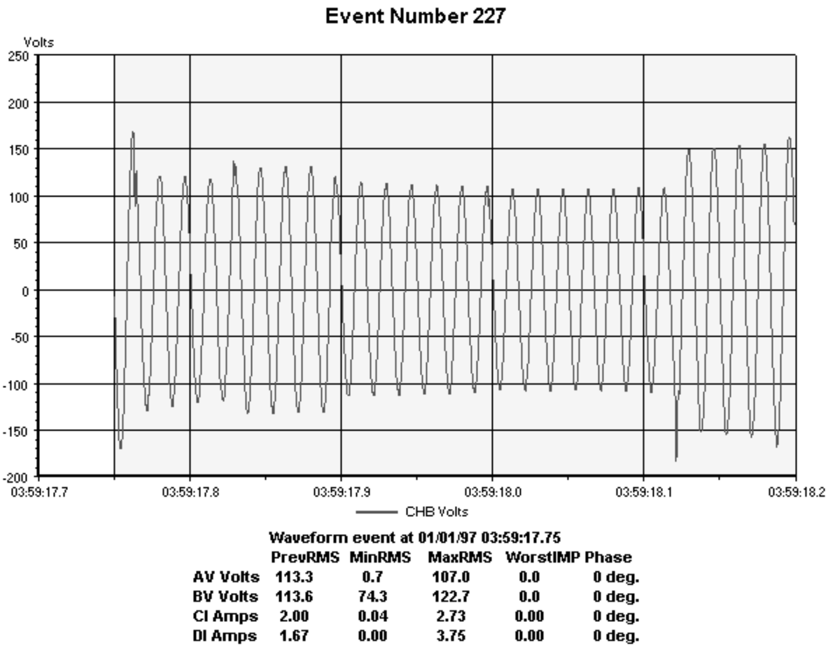
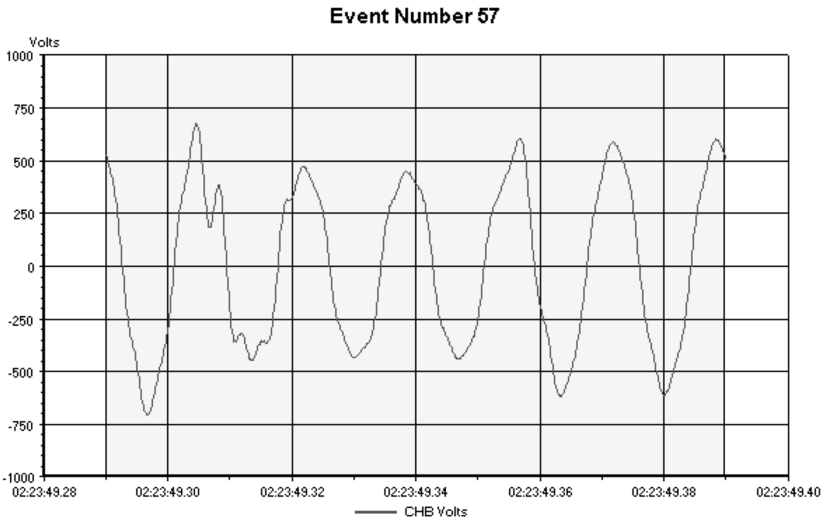


FIGURE 2.4 Voltage sag at a refinery due to a utility fault. The sag caused the programmable logic controller to drop out, which resulted in interruption of power. The sag lasted for approximately 21 cycles.

is corrected. Figure 2.4 shows voltage sag due to a utility fault near a refinery. This fault was attributed to stormy weather conditions just prior to the event. The sag lasted for approximately 21 cycles before the conditions returned to normal. The duration of the sag was sufficient to affect the operation of very critical process controllers in the refinery, which interrupted refinery production.

Figure 2.5 indicates voltage sag caused by utility switching operations near an aluminum smelter. Even though the sag lasted for only five cycles in this particular case, its magnitude was sufficient to cause several motor controllers to drop offline. Typically, electromagnetic controllers could ride through such events due to energy stored in their magnetic fields; however, the motor controllers in this facility contained electronic voltage-sensing circuits more sensitive to the voltage sags. In such cases, either the sensitive circuit should be adjusted to decrease its sensitivity or voltage-support devices such as capacitors or batteries should be provided.

Voltage sags and swells are also generated when loads are transferred from one power source to another. One example is transfer of load from the utility source to the standby generator source during loss of utility power. Most facilities contain emergency generators to maintain power to critical loads in case of an emergency. Sudden application and rejection of loads to a generator could create significant voltage sags or swells. Figures 2.6 and 2.7 show generator bus voltage during two sets of operating conditions. If critical loads are not able to withstand the imposed



Waveform event at 07/03/98 02:23:49.29

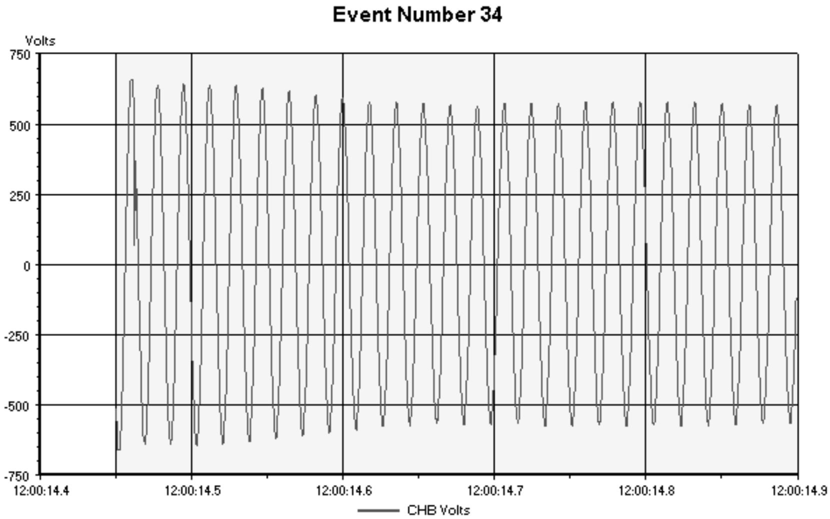
	PrevRMS	MinRMS	MaxRMS	WorstIMP	Phase
AV Volts	483.7	434.7	476.1	0.0	0 deg.
BV Volts	457.0	331.6	451.0	0.0	0 deg.
CI Amps	0.070	0.063	0.107	0.000	0 deg.
DI Amps	0.176	0.125	0.190	0.000	0 deg.

FIGURE 2.5 Voltage sag caused by utility switching at an aluminum smelter. The sag lasted for five cycles and caused motor controllers to drop out.

voltage conditions, problems are imminent. Such determinations should be made at the time when the generators are commissioned into service. The response of the generator or the sensitivity of the loads, or a combination of each, should be adjusted to obtain optimum performance. During power transfer from the utility to the generator, frequency deviations occur along with voltage changes. The generator frequency can fluctuate as much as ±5 Hz for a brief duration during this time. It is once again important to ensure that sensitive loads can perform satisfactorily within this frequency tolerance for the duration of the disturbance.

Flicker (or light flicker, as it is sometimes called) is a low-frequency phenomenon in which the magnitude of the voltage or frequency changes at such a rate as to be perceptible to the human eye. Flicker is also a subjective term. Depending on the sensitivity of the observer, light flicker may or may not be perceived. For instance, it has been found that 50% of people tested perceive light flicker as an annoyance under the following conditions:

Voltage Change	Changes/Second
1 volt	4
2 volts	2
4 volts	1



BV,CV Impulse event at 11/15/96 12:00:14.45

	PrevRMS	MinRMS	MaxRMS	WorstIMP	Phase	HFHits
AV Volts	119.3	119.1	119.3	0.0	0 deg	0
BV Volts	476.5	389.4	466.0	-405.0	132 deg	1
CV Volts	475.8	389.5	464.8	-322.0	17 deg	1
DI Amps	1.390	1.633	2.217	0.000	0 deg	0

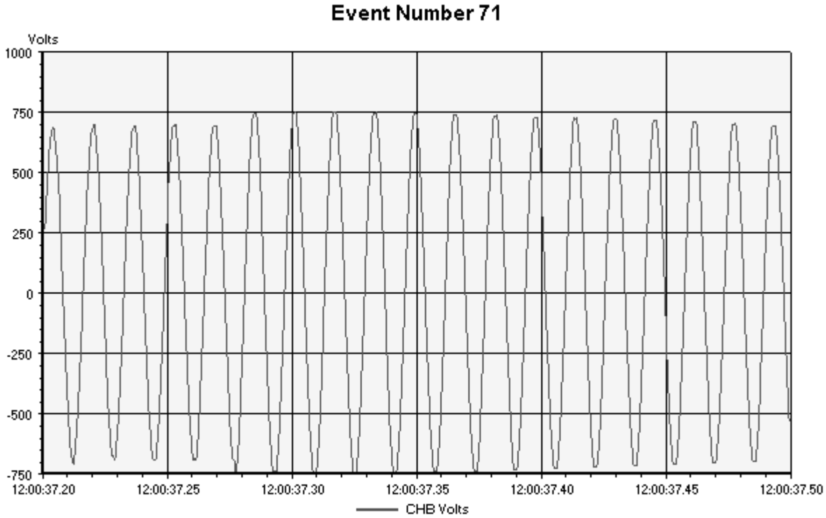
FIGURE 2.6 Voltage sag due to generator step load application. The nominal 480-V generator bus experienced a sag to 389 V that lasted for approximately 1 sec.

For small voltage changes that occur infrequently, flicker is not a serious concern but certainly can be a source of major annoyance. Typically, flicker is caused when a load that requires large currents during startup is initially energized. If the starts are frequent or if the current requirement of the load fluctuates rapidly during each cycle of operation, then flicker effects can be quite pronounced. Examples of loads that could cause light flicker are elevators, arc furnaces, and arc welders.

Figure 2.8 shows the voltage at a lighting panel supplying a multiunit residence. The graph shows the voltage change when one of the elevators for the building is operated, during which the voltage at the panel changes at the rate of 3 to 4 V. The light flicker in the building was quite evident. The problem in this particular building was due to one switchboard feeding both the lighting panel and the elevators. Under these conditions, unless the source supplying the load is large, interaction between the elevator and the lighting is likely to occur.

Flicker is expressed as:

$$f_v = 100 \times (V_{max} - V_{min})/V_{nom}$$



Waveform event at 11/15/96 12:00:37.20

	PrevRMS	MinRMS	MaxRMS	WorstIMP	Phase
AV Volts	119.2	119.2	119.3	0.0	0 deg.
BV Volts	480.4	477.7	541.6	0.0	0 deg.
CV Volts	481.8	478.4	540.0	0.0	0 deg.
DI Amps	2.292	0.000	2.038	0.000	0 deg.

FIGURE 2.7 Voltage swell due to step load rejection. The nominal 480-V generator bus experienced a rise to 541 V that lasted for approximately 18 cycles.

where V_{max} and V_{min} represent the change in voltage over the nominal voltage V_{nom}. For example, if the voltage in a circuit rated at 120 V nominal changed from 122 to 115 V, the flicker is given by:

$$f_v = 100 \times (122 - 115)/120 = 5.83\%$$

In the early stages of development of AC power, light flicker was a serious problem. Power generation and distribution systems were not stiff enough to absorb large fluctuating currents. Manufacturing facilities used a large number of pumps and compressors of reciprocating design. Due to their pulsating power requirements, light flicker was a frequent problem. The use of centrifugal- or impeller-type pumps and compressors reduced the flicker problem considerably. The flicker problems were not, for the most part, eliminated until large generating stations came into service.

Light flicker due to arc furnaces requires extra mention. Arc furnaces, commonly found in many industrial towns, typically use scrap metal as the starting point. An arc is struck in the metal by applying voltage to the batch from a specially constructed furnace transformer. The heat due to the arc melts the scrap metal, which is drawn out from the furnace to produce raw material for a variety of industrial facilities. Arc furnaces impose large electrical power requirements on the electrical system.

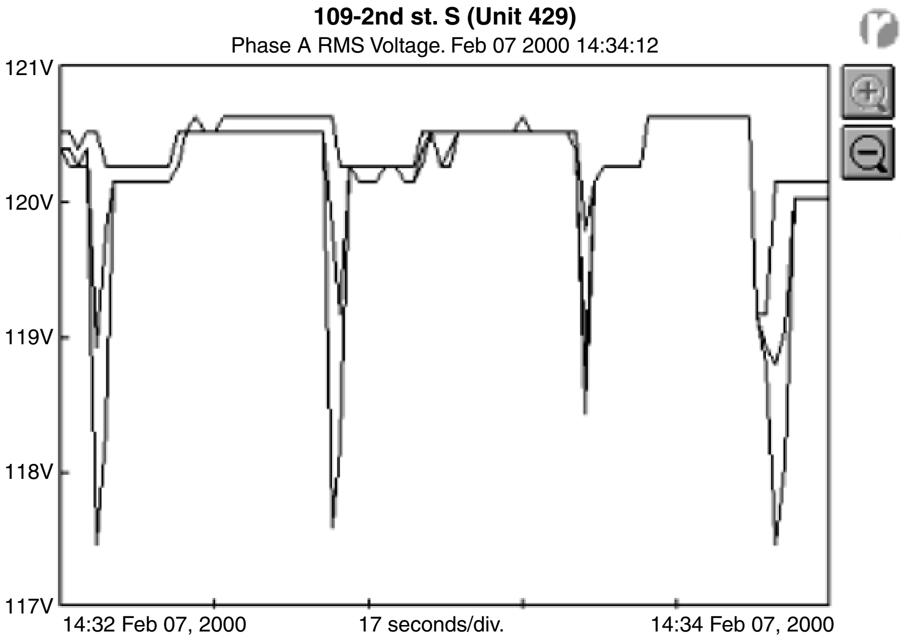


FIGURE 2.8 Voltage changes during elevator operation in a residential multiunit complex. The rate of voltage change causes perceptible light flicker.

The current drawn from the source tends to be highly cyclic as arcs are repeatedly struck and stabilized in different parts of the batch. The voltage at the supply lines to an arc furnace might appear as shown in Figure 2.9. The envelope of the change in voltage represents the flicker content of the voltage. The rate at which the voltage changes is the flicker frequency:

$$\Delta V = V_{max} - V_{min}$$

$$V_{nom} = \text{average voltage} = (V_{max} + V_{min})/2$$

$$f = 2 \times (V_{max} - V_{min}) \times 100/(V_{max} + V_{min})$$

Normally, we would use root mean square (RMS) values for the calculations, but, assuming that the voltages are sinusoidal, we could use the maximum values and still derive the same results. It has been found that a flicker frequency of 8 to 10 Hz with a voltage variation of 0.3 to 0.4% is usually the threshold of perception that leads to annoyance.

Arc furnaces are normally operated with capacitor banks or capacitor bank/filter circuits, which can amplify some of the characteristic frequency harmonic currents generated by the furnace, leading to severe light flicker. For arc furnace

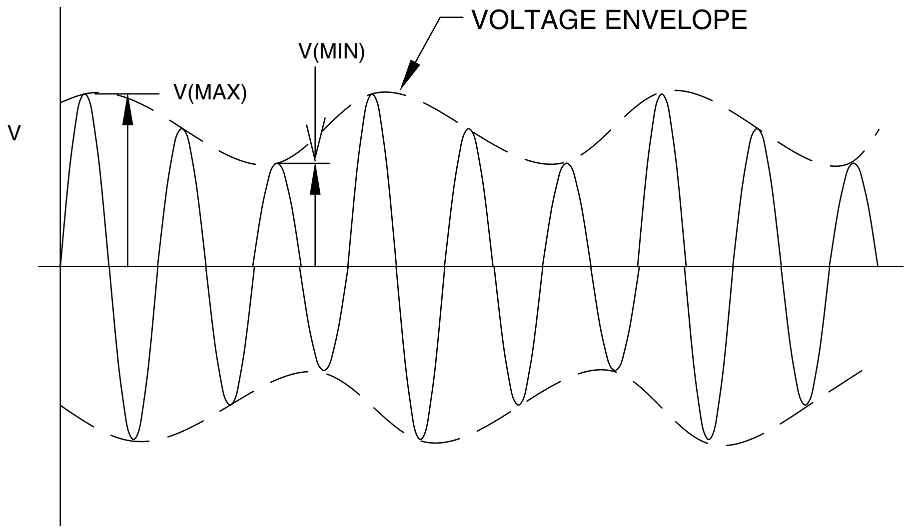
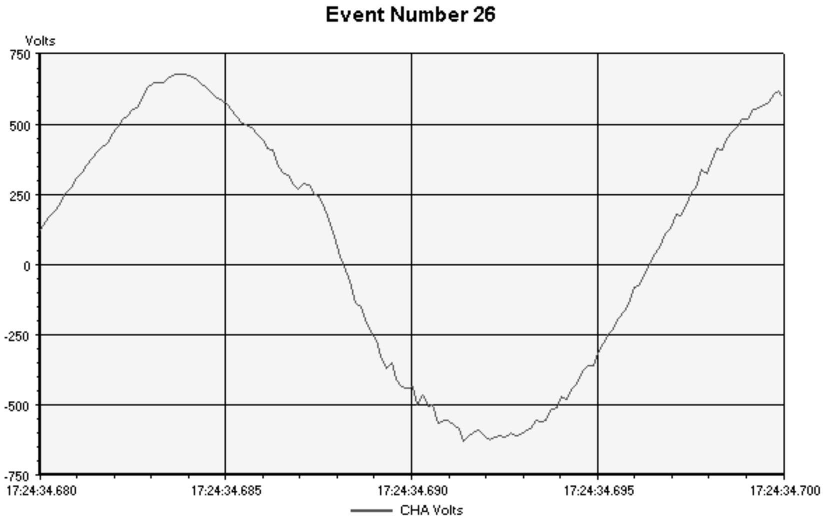


FIGURE 2.9 Typical arc furnace supply voltage indicating voltage fluctuation at the flicker frequency.

applications, careful planning is essential in the configuration and placement of the furnace and the filters to minimize flicker. Very often, arc furnaces are supplied by dedicated utility power lines that are not shared by other users. This follows from the principle that as the voltage source becomes larger (lower source impedance), the tendency to produce voltage flicker due to the operation of arc furnaces is lessened.

Low-frequency noise superimposed on the fundamental power frequency is a power quality concern. Discussion of this phenomenon is included in this chapter mainly because these are slower events that do not readily fit into any other category. Low-frequency noise is a signal with a frequency that is a multiple of the fundamental power frequency. Figure 2.10 illustrates a voltage waveform found in an aluminum smelting plant. In this plant, when the aluminum pot lines are operating, power factor improvement capacitors are also brought online to improve the power factor. When the capacitor banks are online, no significant noise is noticed in the power lines. When the capacitor banks are turned off, noise can be found on the voltage waveform (as shown) because the capacitor banks absorb the higher order harmonic frequency currents produced by the rectifiers feeding the pot lines. In this facility, the rest of the power system is not affected by the noise because of the low magnitudes. It is conceivable that at higher levels the noise could couple to nearby signal or communication circuits and cause problems.

Adjustable speed drives (ASDs) produce noise signals that are very often troublesome. The noise frequency generated by the ASDs is typically higher than the harmonic frequencies of the fundamental voltage. Because of this, the noise could find its way into sensitive data and signal circuits unless such circuits are sufficiently isolated from the ASD power lines.



Waveform event at 07/16/98 17:24:34.68

	PrevRMS	MinRMS	MaxRMS	WorstIMP	Phase
AV Volts	464.6	438.4	455.0	0.0	0 deg.
BV Volts	470.1	443.4	460.2	0.0	0 deg.
CV Volts	4.52	4.73	5.02	0.00	0 deg.
DV Volts	4.56	4.64	5.53	0.00	0 deg.

FIGURE 2.10 Low-frequency noise superimposed on the 480-V bus after switching off the capacitor bank.

2.3 CURES FOR LOW-FREQUENCY DISTURBANCES

Power-frequency or low-frequency disturbances are slow phenomena caused by switching events related to the power frequency. Such disturbances are dispersed with time once the incident causing the disturbance is removed. This allows the power system to return to normal operation. Low-frequency disturbances also reveal themselves more readily. For example, dimming of lights accompanies voltage sag on the system; when the voltage rises, lights shine brighter. While low-frequency disturbances are easily detected or measured, they are not easily corrected. Transients, on the other hand, are not easily detected or measured but are cured with much more ease than a low-frequency event. Measures available to deal with low-frequency disturbances are discussed in this section.

2.3.1 Isolation Transformers

Isolation transformers, as their name indicates, have primary and secondary windings, which are separated by an insulating or isolating medium. Isolation transformers do not help in curing voltage sags or swells; they merely transform the voltage from a primary level to a secondary level to enable power transfer from one winding to the other. However, if the problem is due to common mode noise, isolation transformers help to minimize noise coupling, and shielded isolation transformers

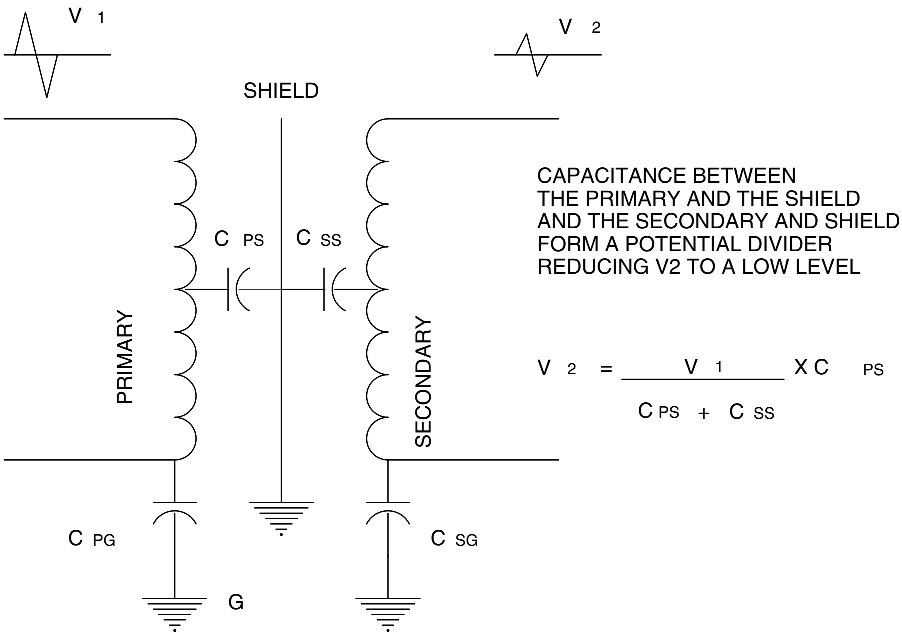


FIGURE 2.11 Common mode noise attenuation by shielded isolation transformer.

can help to a greater degree. Common mode noise is equally present in the line and the neutral circuits with respect to ground. Common mode noise may be converted to transverse mode noise (noise between the line and the neutral) in electrical circuits, which is troublesome for sensitive data and signal circuits. Shielded isolation transformers can limit the amount of common mode noise converted to transverse mode noise. The effectiveness with which a transformer limits common mode noise is called *attenuation* (A) and is expressed in decibels (dB):

$$A = 20 \log (V_1/V_2)$$

where V_1 is the common mode noise voltage at the transformer primary and V_2 is the differential mode noise at the transformer secondary. Figure 2.11 shows how common mode noise attenuation is obtained by the use of a shielded isolation transformer. The presence of a shield between the primary and secondary windings reduces the interwinding capacitance and thereby reduces noise coupling between the two windings.

Example: Find the attenuation of a transformer that can limit 1 V common mode noise to 10 mV of transverse mode noise at the secondary:

$$A = 20 \log (1/0.01) = 40 \text{ dB}$$

Isolation transformers using a single shield provide attenuation in a range of 40 to 60 dB. Higher attenuation may be obtained by specially designed isolation transformers using multiple shields configured to form a continuous enclosure around the secondary winding. Attenuation of the order of 100 dB may be realized with such techniques.

2.3.2 Voltage Regulators

Voltage regulators are devices that can maintain a constant voltage (within tolerance) for voltage changes of predetermined limits above and below the nominal value. A switching voltage regulator maintains constant output voltage by switching the taps of an autotransformer in response to changes in the system voltage, as shown in Figure 2.12. The electronic switch responds to a signal from the voltage-sensing circuitry and switches to the tap connection necessary to maintain the output voltage constant. The switching is typically accomplished within half of a cycle, which is within the ride-through capability of most sensitive devices.

Ferro-resonant voltage regulators are static devices that have no moving components. They operate on the principle that, in a transformer, when the secondary magnetic circuit is operating in the saturation region the secondary winding is decoupled from the primary and therefore is not sensitive to voltage changes in the primary. The secondary winding has a capacitor connected across its terminals that

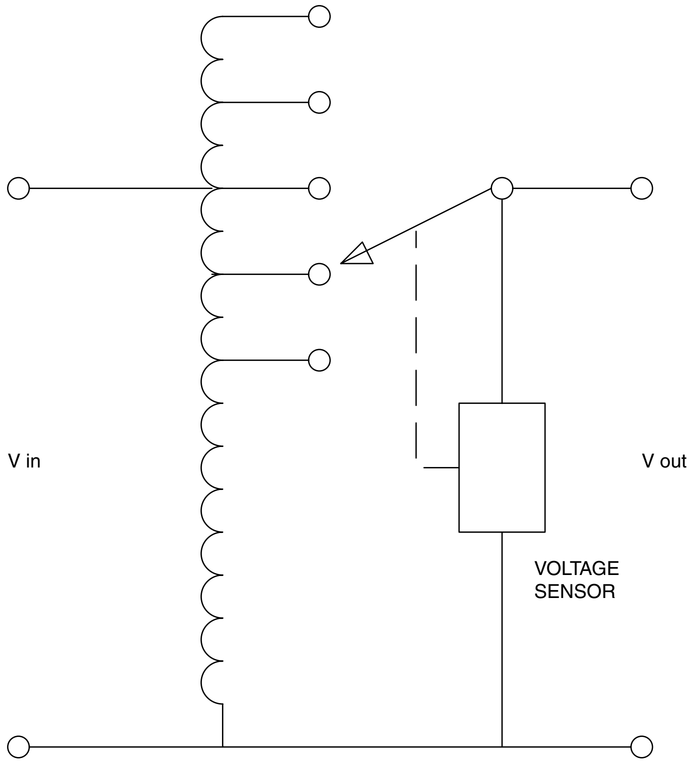


FIGURE 2.12 Tap-changer voltage regulator.

forms a parallel resonant circuit with the inductance of the secondary winding. Large magnetic fields are created in the magnetic core surrounding the secondary windings, thereby decoupling the secondary winding from the primary. Typically ferro-resonant transformer regulators can maintain secondary voltage to within ±0.5% for changes in the primary voltages of ±20%. Figure 2.13 contains the schematic of a ferro-resonance transformer type of voltage regulator.

Ferro-resonance transformers are sensitive to loads above their rated current. In extreme cases of overload, secondary windings can become detuned, at which point the output of the transformer becomes very low. Voltage sags far below the rated level can also have a detuning effect on the transformer. Within the rated voltage and load limits, however, the ferro-resonance transformer regulators are very effective in maintaining fairly constant voltage levels.

2.3.3 Static Uninterruptible Power Source Systems

Static uninterruptible power sources (UPSs) have no rotating parts, such as motors or generators. These are devices that maintain power to the loads during loss of

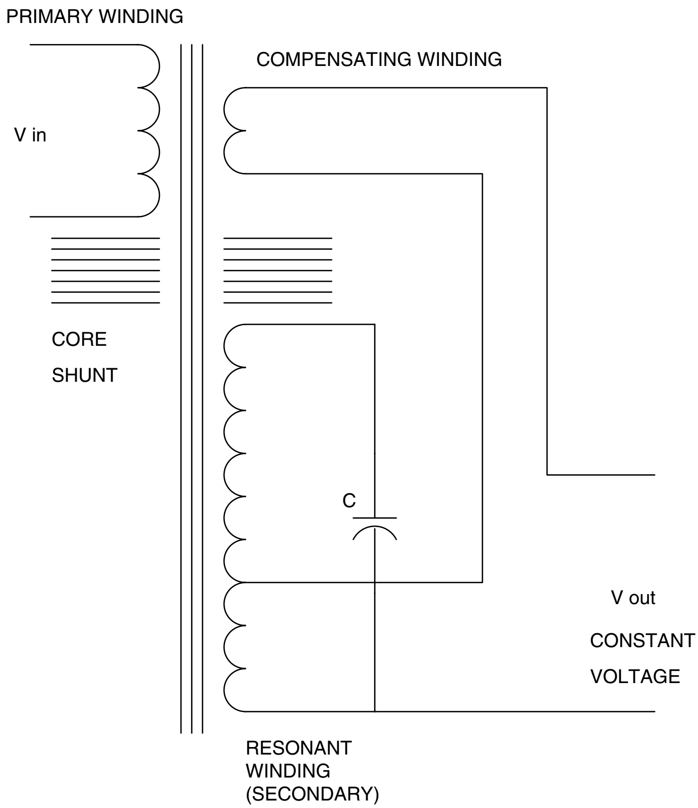


FIGURE 2.13 Ferro-resonant transformer.

normal power for a duration that is a function of the individual UPS system. All UPS units have an input rectifier to convert the AC voltage into DC voltage, a battery system to provide power to loads during loss of normal power, and an inverter which converts the DC voltage of the battery to an AC voltage suitable for the load being supplied. Depending on the UPS unit, these three main components are configured differently. Static UPS systems may be broadly classified into offline and online units. In the offline units, the loads are normally supplied from the primary electrical source directly. The primary electrical source may be utility power or an in-house generator. If the primary power source fails or falls outside preset parameters, the power to the loads is switched to the batteries and the inverter. The switching is accomplished within half of a cycle in most UPS units, thereby allowing critical loads to continue to receive power. During power transfer from the normal power to the batteries, the loads might be subjected to transients. Once the loads are transferred to the batteries, the length of time for which the loads would continue to receive power depends on the capacity of the batteries and the amount of load. UPS units usually can supply power for 15 to 30 min, at which time the batteries become depleted to a level insufficient to supply the loads, and the UPS unit shuts down. Some offline UPS system manufacturers provide optional battery packs to enhance the time of operation of the units after loss of normal power.

In online UPS units, normal power is rectified into DC power and in turn inverted to AC power to supply the loads. The loads are continuously supplied from the DC bus even during times when the normal power is available. A battery system is also connected to the DC bus of the UPS unit and kept charged from the normal source. When normal power fails, the DC bus is supplied from the battery system. No actual power transfer occurs during this time, as the batteries are already connected to the DC bus. Online units can be equipped with options such as manual and static bypass switches to circumvent the UPS and supply power to the loads directly from the normal source or an alternate source such as a standby generator. An offline unit is shown in Figure 2.14, and an online unit in Figure 2.15. Two important advantages of online UPS units are because: (1) power is normally supplied from the DC bus, the UPS unit in effect isolates the loads from the source which keeps power system disturbances and transients from interacting with the loads, and (2) since power to the loads is not switched during loss of normal power, no switching transients are produced. As might be expected, online UPS systems cost considerably more than offline units.

The output voltage of static UPS units tends to contain waveform distortions higher than those for normal power derived from the utility or a generator. This is due to the presence of the inverter in the output section of the UPS system. For some lower priced UPS units, the distortion can be substantial, with the waveform resembling a square wave. Figure 2.16 shows the output waveform of a UPS unit commonly used in offices to supply computer workstations. More expensive units use higher order inverter sections to improve the waveform of the output voltage, as shown in Figure 2.17. It is important to take into consideration the level of susceptibility of the loads to waveform distortion. Problems attributed to excessive voltage distortion have been noticed in some applications involving medical electronics and voice communication.

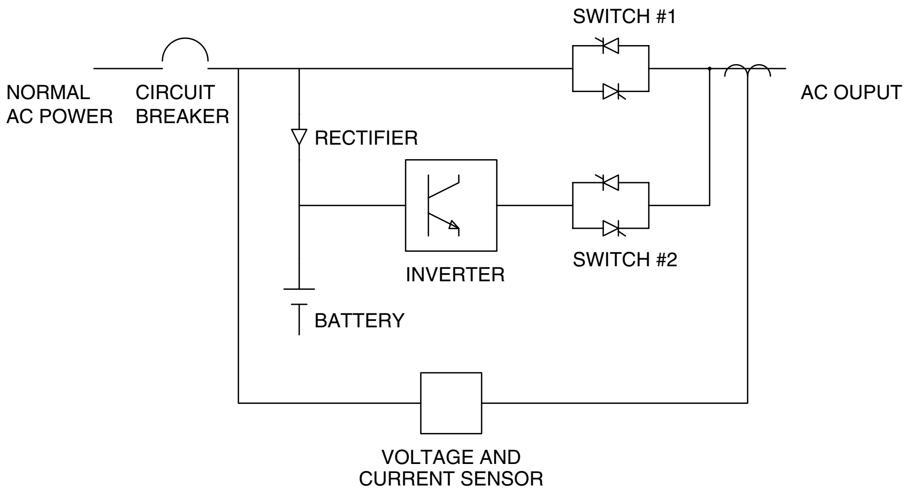


FIGURE 2.14 Offline uninterruptible power source (UPS) system.

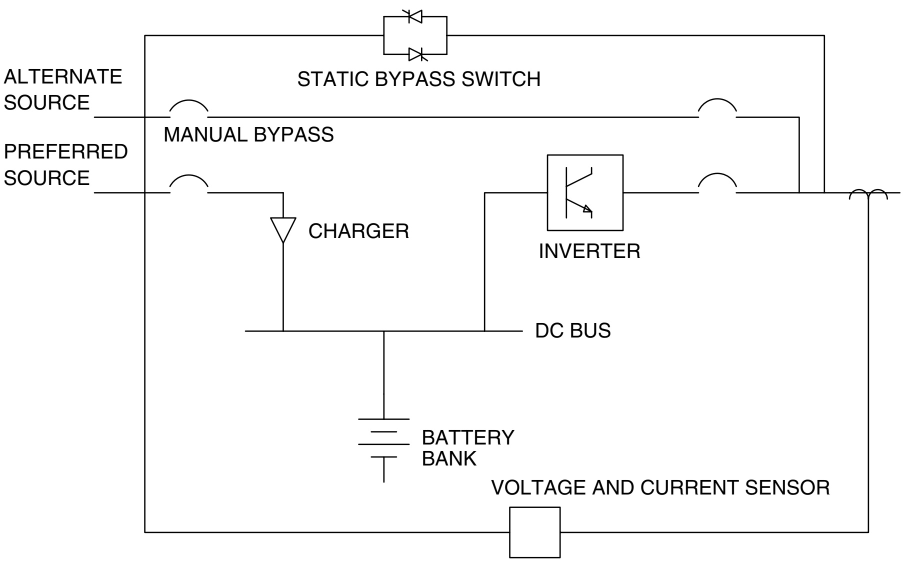
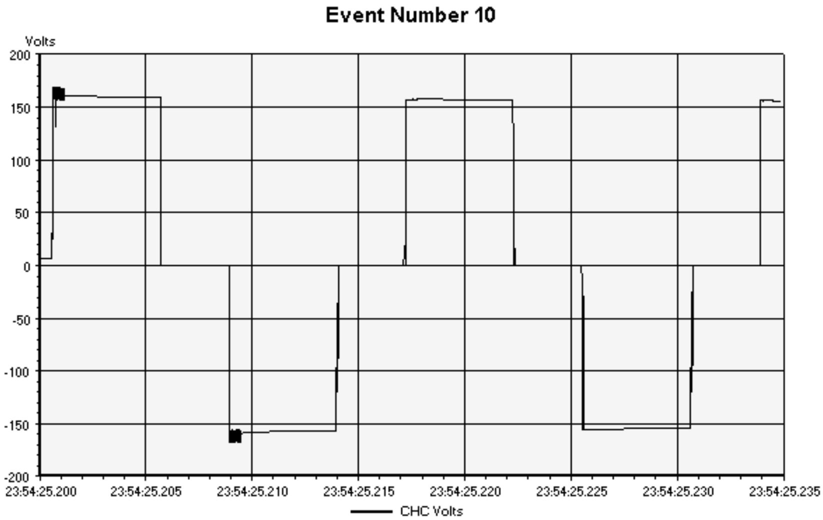


FIGURE 2.15 Online uninterruptible power source (UPS) system.

2.3.4 Rotary Uninterruptible Power Source Units

Rotary UPS (RUPS) units utilize rotating members to provide uninterrupted power to loads, as shown in Figure 2.18. In this configuration, an AC induction motor drives an AC generator, which supplies power to critical loads. The motor operates from normal utility power. A diesel engine or other type of prime mover is coupled to the same shaft as the motor and the generator. During normal operation, the diesel engine is decoupled from the common shaft by an electric clutch. If the utility power



CV,DV Impulse event at 10/22/99 23:54:25.20

	PrevRMS	MinRMS	MaxRMS	WorstIMP	Phase	HFHits
AV Volts	120.3	120.1	120.2	0.0	0 deg	0
BV Volts	0.37	0.28	0.29	0.00	0 deg	0
CV Volts	119.4	126.6	129.2	-168.0	143 deg	24
DV Volts	0.44	0.45	0.86	34.30	141 deg	18

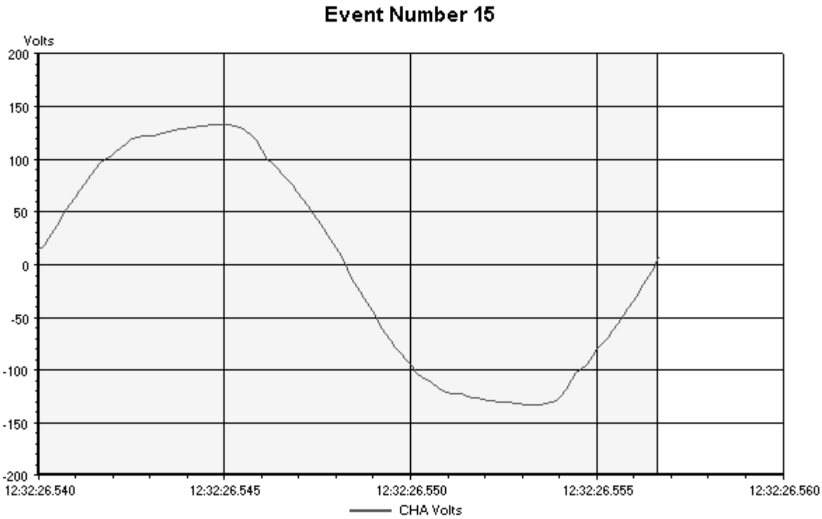
FIGURE 2.16 Output voltage waveform from an offline uninterruptible power source (UPS) system. The ringing during switching is evident during the first cycle.

fails, the prime mover shaft is coupled to the generator shaft and the generator gets its mechanical power from the prime mover. The motor shaft is attached to a flywheel, and the total inertia of the system is sufficient to maintain power to the loads until the prime mover comes up to full speed. Once the normal power returns, the induction motor becomes the primary source of mechanical power and the prime mover is decoupled from the shaft.

In a different type of RUPS system, during loss of normal power the AC motor is supplied from a battery bank by means of an inverter (Figure 2.19). The batteries are kept charged by the normal power source. The motor is powered from the batteries until the batteries become depleted. In some applications, standby generators are used to supply the battery bank in case of loss of normal power. Other combinations are used to provide uninterrupted power to critical loads, but we will not attempt to review all the available technologies. It is sufficient to point out that low-frequency disturbances are effectively mitigated using one of the means mentioned in this section.

2.4 VOLTAGE TOLERANCE CRITERIA

Manufacturers of computers and data-processing equipment do not generally publish data informing the user of the voltage tolerance limits for their equipment. An agency



Waveform event at 07/30/99 12:32:26.54

	PrevRMS	MinRMS	MaxRMS	WorstIMP	Phase
AV Volts	118.3	99.0	99.0	0.0	0 deg.
BV Volts	5.68	8.76	8.76	0.00	0 deg.
CV Volts	118.7	119.1	119.1	0.0	0 deg.
DV Volts	0.56	0.57	0.57	0.00	0 deg.

FIGURE 2.17 Voltage waveform from an online uninterruptible power source (UPS) system. The waveform, even though less than ideal, contains considerably lower distortion than the waveform of the offline unit shown in Figure 2.16.

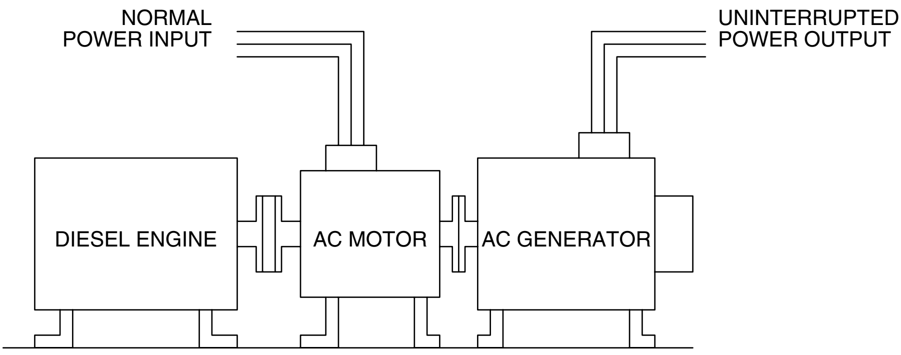


FIGURE 2.18 Rotary uninterruptible power source (RUPS) system using a diesel engine, AC motor, and AC generator to supply uninterrupted power to critical loads.

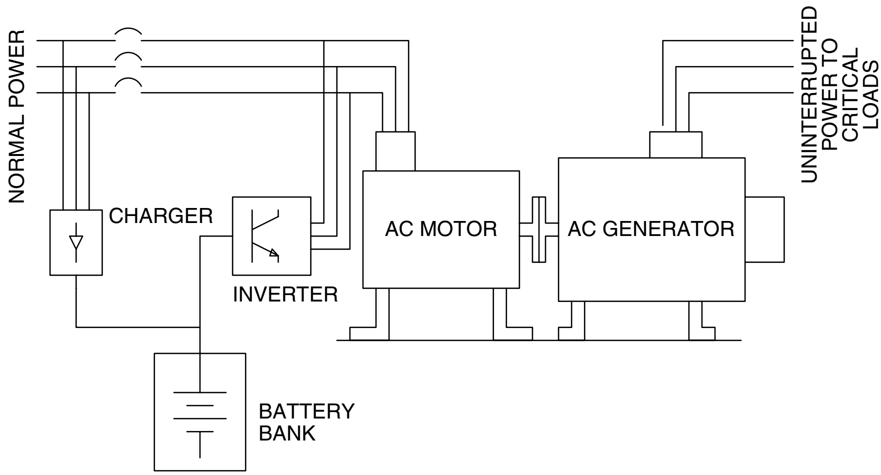


FIGURE 2.19 Rotary uninterruptible power source (RUPS) system using a battery bank, AC motor, and AC generator to provide uninterrupted power to critical loads.

known as the Information Technology Industry Council (ITIC) has published a graph that provides guidelines as to the voltage tolerance limits within which information technology equipment should function satisfactorily (Figure 2.20). The ordinate (y-axis) represents the voltage as a percentage of the nominal voltage. The abscissa (x-axis) is the time duration in seconds (or cycles). The graph contains three regions. The area within the graph is the voltage tolerance envelope, in which equipment should operate satisfactorily. The area above the graph is the prohibited region, in which equipment damage might result. The area below the graph is the region where the equipment might not function satisfactorily but no damage to the equipment should result. Several types of events fall within the regions bounded by the ITIC graph, as described below:

- *Steady-State Tolerance.* The steady-state range describes an RMS voltage that is either slowly varying or is constant. The subject range is ±10% from the nominal voltage. Any voltage in this range may be present for an indefinite period and is a function of the normal loading and losses in the distribution system.
- *Line Voltage Swell.* This region describes a voltage swell having an RMS amplitude up to 120% of the nominal voltage, with a duration of up to 0.5 sec. This transient may occur when large loads are removed from the system or when voltage is applied from sources other than the utility.
- *Low-Frequency Decaying Ring Wave.* This region describes a decaying ring wave transient that typically results from the connection of power factor correction capacitors to an AC power distribution system. The frequency of this transient may vary from 200 Hz to 5 kHz, depending on the resonant frequency of the AC distribution system. The magnitude of the transient is expressed as a percentage of the peak 60 Hz nominal (not the RMS). The transient is assumed to be completely decayed by the end of the half-cycle in which it occurs. The transient is assumed to occur

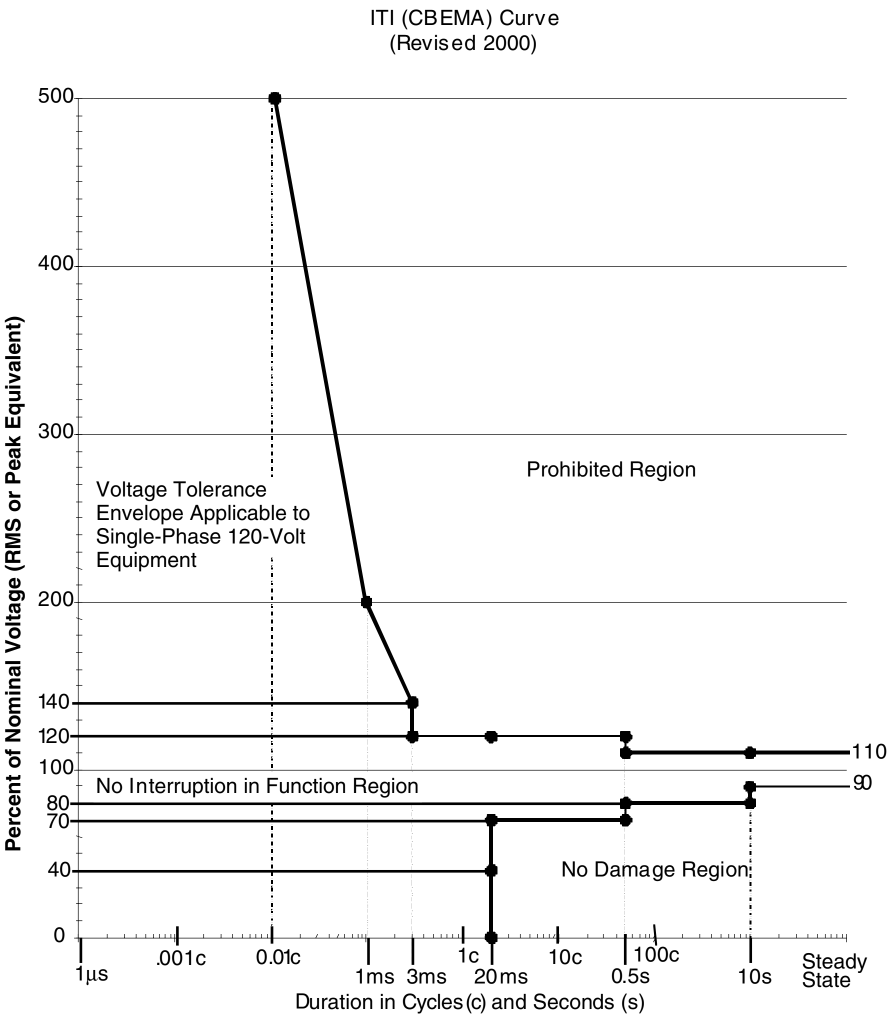


FIGURE 2.20 Information Technology Industry Council (ITIC) graph providing guidelines as to the voltage tolerance limits within which information technology equipment should function satisfactorily. (Courtesy of the Information Technology Industry Council, Washington, D.C.)

near the peak of the nominal voltage waveform. The amplitude of the transient varies from 140% for 200-Hz ring waves to 200% for 5-kHz ring waves, with a linear increase in amplitude with frequency.

- *High-Frequency Impulse Ring Wave.* This region describes the transients that typically occur as the result of lightning strikes. Waveshapes applicable to this transient and general test conditions are described in the ANSI/IEEE C62.41 standard. This region of the curve deals with both amplitude and duration (energy) rather than RMS amplitude. The intent is to provide 80 J minimum transient immunity.

- *Voltage Sags.* Two different RMS voltage sags are described. Generally the transients result from application of heavy loads as well as fault conditions at various points in the AC power distribution system. Sags to 80% of nominal are assumed to have a typical duration of up to 10 sec and sags to 70% of nominal are assumed to have a duration of up to 0.5 sec.
- *Drop Out.* Voltage drop out includes both severe RMS voltage sags and complete interruption of the applied voltage followed by immediate reapplication of the nominal voltage. The interruption may last up to 20 msec. The transient typically results from the occurrence and subsequent clearing of the faults in the distribution system.
- *No Damage Region.* Events in this region include sags and drop outs that are more severe than those specified in the preceding paragraphs and continuously applied voltages that are less than the lower limit of the steady-state tolerance range. A normal functional state of the information technology equipment is not expected during these conditions, but no damage to equipment should result.
- *Prohibited Region.* This region includes any surge or swell which exceed the upper limit of the envelope. If information technology equipment is subjected to such conditions damage might result.

The ITIC graph apples to 120-V circuits obtained from 120-V, 120/240-V, and 120/208-V distribution systems. Other nominal voltages and frequencies are not specifically considered, but their applicability may be determined in each case. The curve is useful in determining if problems could be expected under particular power system voltage conditions (see Chapter 9).

2.5 CONCLUSIONS

Power frequency disturbances are perhaps not as damaging to electrical equipment as short time transients, but they can cause a variety of problems in the operation of an electrical power system. These disturbances may be utility (source) generated or generated within a facility due to the loads. Disturbances propagated from the source are not easily cured and fixed because, at the source level, we may be dealing with very high power and energy levels and the cures and fixes tend to be complex and expensive. However, disturbances internal to the facility are more easily cured or controlled. The effects of a disturbance within the facility may be minimized by separating the offending loads from the sensitive, susceptible loads. The offending loads should be located as close to the source of electrical power as possible to minimize their impact on the rest of the power system. Whether the power frequency disturbances are internal or external to a facility, the power conditioners discussed here are effective in dealing with these events.