2.1. Power Frequency Disturbances

- The term describes events that are **slower** and **longer lasting** compared to electrical transients.
- **Power frequency disturbances** can last anywhere from one complete cycle to several seconds or even minutes.
- **The effects** of power frequency disturbances vary from one piece of equipment to another and with the age of the 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

Common Power Frequency Disturbances:

- Following three consider as common power frequency disturbances;
  1) Voltage sag (US English) or Voltage dip (British English)
  2) Voltage swell and
  3) Voltage variation

Voltage sag

- A voltage sag is a reduction in the RMS voltage in the range of 0.1 to 0.9 p.u. (retained) for duration greater than half a mains cycle and less than 1 minute. Often referred to as a 'sag'.
- **Caused by** faults, increased load demand and transitional events such as large motor starting.
- Voltage sags typically are due to starting on large loads, such as an electric motor or an arc furnace.

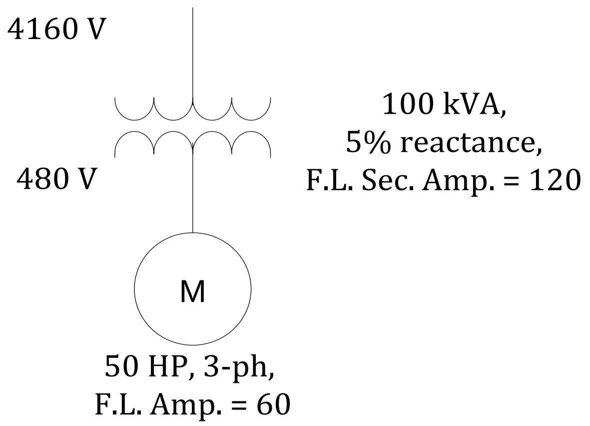

Figure 2. 1 schematic for example problem

- **Figure-2.1** shows a 100 kVA transformer feeding the 50-hp motor. If the transformer has a leakage reactance of 5%, the voltage sag due to starting this motor is calculated further

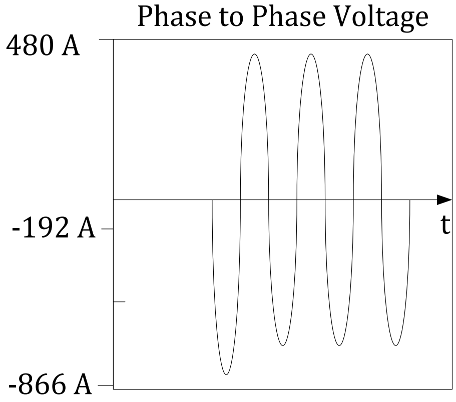

Figure 2. 2 Motor starting current waveform. A 5-hp motor was started across the line. The motor full load current was 60 A. The first half cycle peak reached a value of 860 A

- **Figure-2.2** contains the waveform of the starting current of 50-hp induction motor with rated full load current of 60 A at 460 V AC. 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.

From Figure-2.1 and Figure-2.2,

- Full load current of the 100 kVA transformer at 480 V = **120 A**
- Voltage drop due to starting inrush = 55×860 ÷ (120×√2)=**25.3**%

Voltage Swell

- A voltage swell is an increase in the RMS voltage above the nominal voltage or a sliding reference voltage. The increase lasts from half a cycle to several seconds.
- Switching off large loads, capacitor banks energizing, and transfer of loads from one power source to another cause voltage swells.
- For pure resistive load, power factor angle becomes 0°.

Voltage Interruption

- A voltage interruption is a large decrease in RMS voltage to less than a small percentile of the nominal voltage, or a complete loss of voltage.
- Voltage interruptions may come from accidents like faults and component malfunctions, or from scheduled downtime.

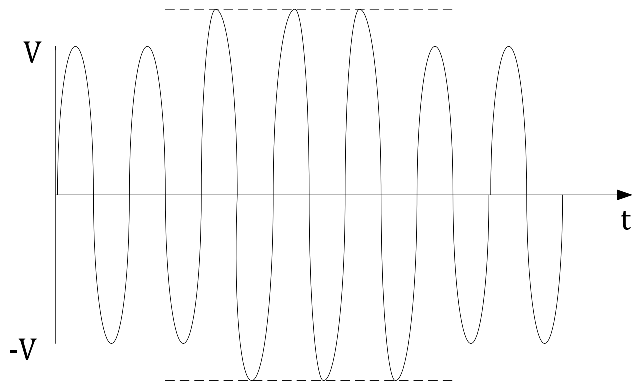

Figure 2.3 Voltage Swell typical waveform

- Short voltage interruptions are typically the result of a malfunction of a switching device or a deliberate or inadvertent operation of a fuse, circuit breaker, or recloser in response to faults and disturbances.
- Long interruptions are usually the result of scheduled downtime, where part of an electrical power system is disconnected in order to perform maintenance or repairs.

Effects of Voltage Change

- A change in voltage causes a decrease or an increase in the amount of energy supplied to components in an electrical power system, which leads to an amount of energy that is different from the amount required for normal operations.
- A decrease in energy during a voltage dip can cause equipment to reset or shut down and cause mechanical devices, such as motors, to stall or overheat.
- An increase in voltage during a voltage swell can cause immediate or long-term breakdown of components because of overheating.
- Because the voltage level during a voltage interruption rapidly decays to zero, or to almost zero, no energy is transferred to components in an electrical power system when there are voltage interruptions.
- A voltage interruption therefore can cause the complete shutdown of equipment and also can lead to damage.
- A voltage interruption over a large geographical area that lasts for a long term is known as a blackout.

2.3. Cures for Low-frequency disturbances

- The low-frequency or Power-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.
- The low-frequency disturbances are easily detected or measured but they are not easily corrected.
- The measures available to deal with low-frequency disturbances are as per following.

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 other. However, if the problem is due to common mode noise, isolation transformers help to minimize noise coupling, and shielded isolation transformers can help to a greater degree.
- **Shielded isolation transformers** can limit the amount of common mode noise converted to transverse mode noise.

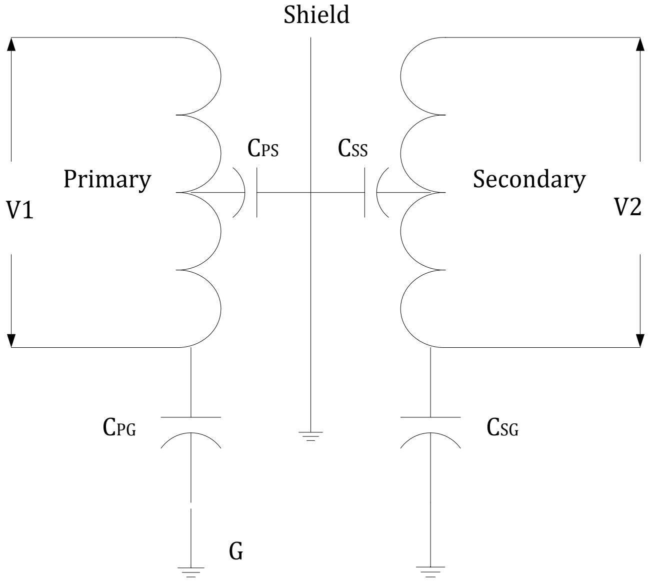

Figure 2.4 Common mode noise attenuation by shielded isolation transformer

From figure 2.4, Capacitance between the primary and the shield, and the secondary and the shield, form a potential divider reducing V_2 to a low level.

$$V_2 = \frac{V_1}{C_{PS} + C_{SS}} \times C_{PS}$$

- The effectiveness with which a transformer limits common mode noise is called **attenuation (A)** and is expressed in decibel (dB):

$$A = 20 \log\left(\frac{V_1}{V_2}\right)$$

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 2.4 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 inter-winding capacitance and thereby reduces noise coupling between the two windings.

<u>VOLTAGE REGULATORS</u>

- Voltage regulators are devices that can maintain a constant voltage for changes in voltage 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 2.5.
- 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.

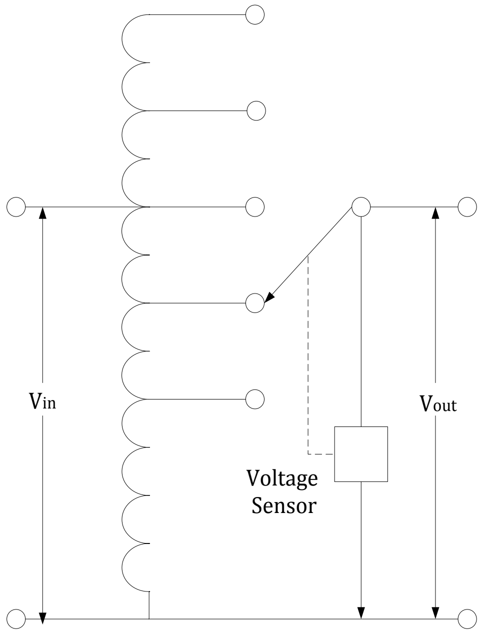

Figure 2. 5 Tap-changing voltage regulator

STATIC UNINTERRUPTIBLE POWER SOURCE SYSTEM (STATIC UPS)

- Static UPSs have no rotating parts, such as motors or generators. These are devices that maintain power to the loads during loss of normal power for a duration that is a function of the individual UPS system.

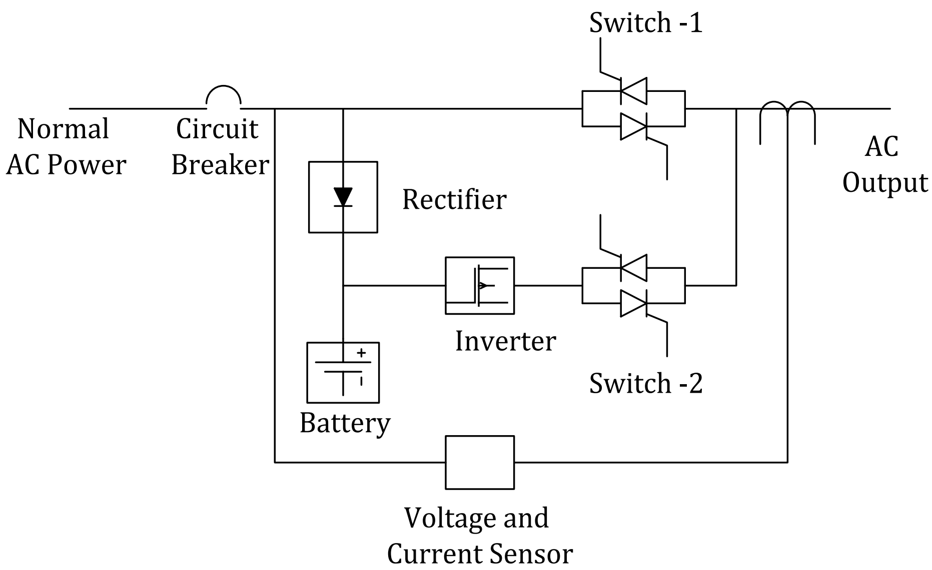

Figure 2. 6 Offline UPS system

- 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 system may be classified into offline and online units.

- As shown in figure 2.6, 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.

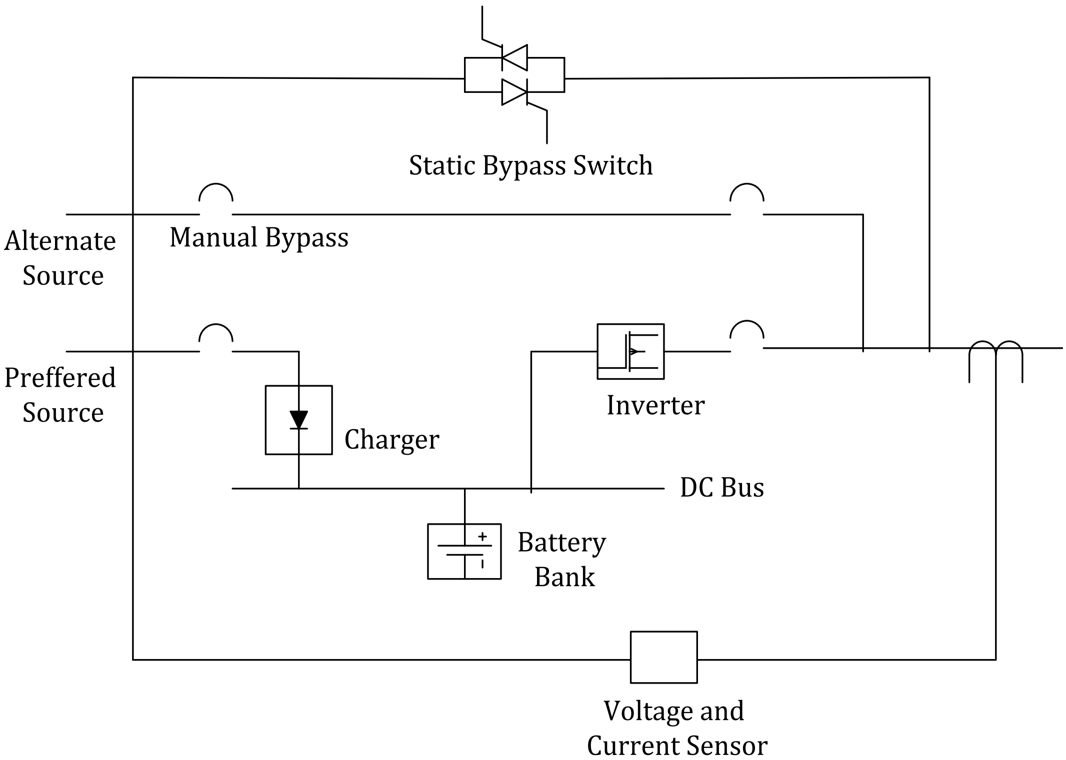

Figure 2. 7 Online UPS system

- As shown in figure 2.7, in online UPS system, 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.

- 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.

ROTARY UNINTERRUPTIBLE POWER SOURCE SYSTEM (ROTARY UPS)

- Rotary UPS (RUPS) units utilize rotating members to provide uninterrupted power to loads, as shown in figure 2.8.

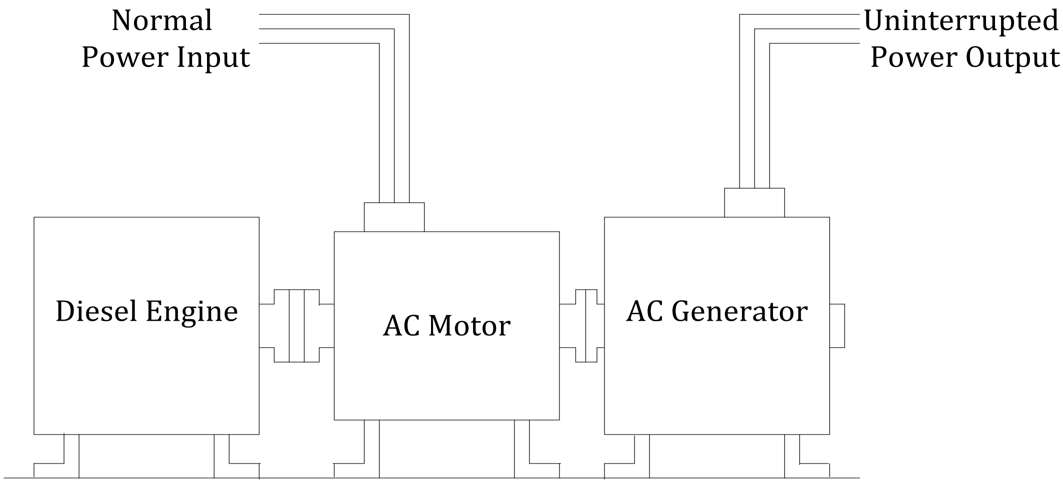

Figure 2. 8 Rotary UPS system using a diesel engine, AC motor, and AC generator

- 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 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 2.9).
- 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.

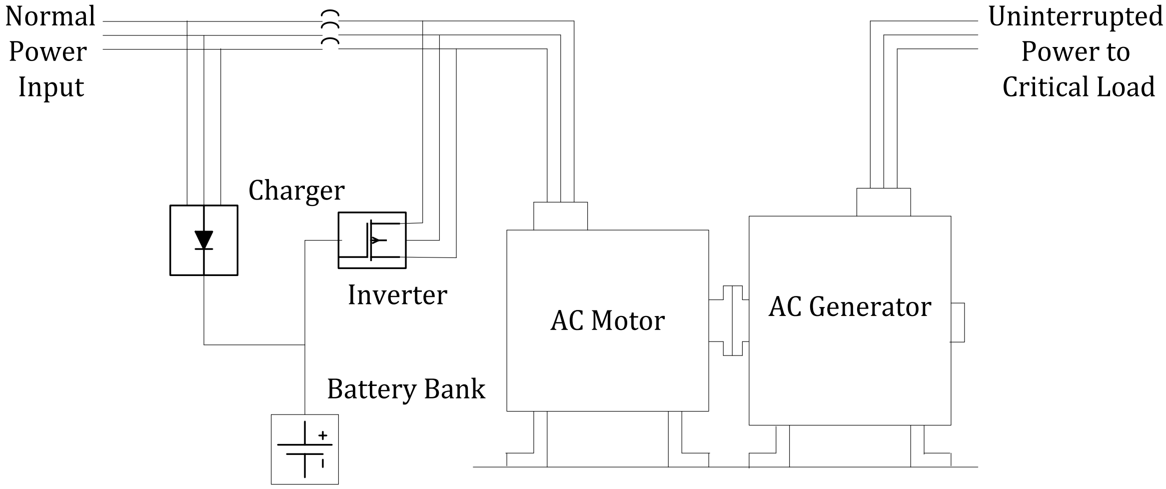

Figure 2. 9 Rotary uninterruptible power source (RUPS) system using a battery bank

2.4. Voltage Tolerance Criteria

- An agency known as the Information Technology Industry Council (ITIC) has published a graph that provides guidelines to the voltage tolerance limits within which information technology equipment should function satisfactorily (Figure 2.10).

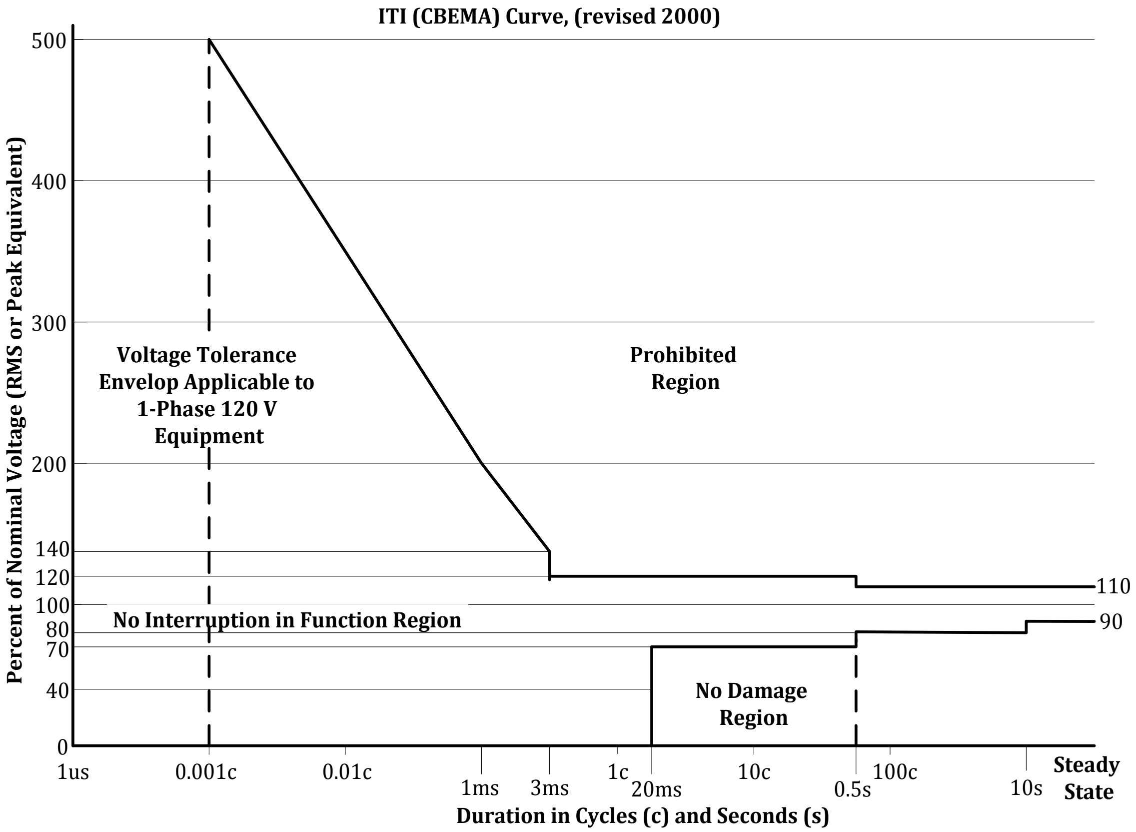

Figure 2. 10 Information Technology Industry Council (ITIC) graph providing guidelines as to the voltage tolerance limits within which information technology equipment should function satisfactorily. (Courtesy of the Information Technology Industry Council, Washington, D.C.)

- 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 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. The wave-shapes 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 applies 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.
