1C.6.1—Voltage Disturbances

1. Scope

The purpose of this document is to state *typical* levels of voltage disturbances, which may be encountered by customers on PacifiCorp's electrical system. These disturbances are to be considered as normal occurrences that cannot be reasonably avoided. Also, the causes of the more common electrical disturbances and their characteristics are discussed.

This document does not cover reliability guidelines dealing with outages. Instead, it serves to describe the nature of power system electrical disturbances other than outages, which may affect the customer.

2. References and Resource Documents

This handbook reflects the requirements of the industry documents listed below that were in effect at the time of publication. When a referenced document is superseded by an approved revision, the revision shall apply.

ANSI/IEEE 446, *IEEE Orange Book, IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications*

ANSI/IEEE C62.41, *IEEE Recommended Practice on Surge Voltage and Low-Voltage AC Power Circuits*

IEEE 1159.1, *IEEE Recommended Practice on Monitoring Power Quality*

3. General

Although PacifiCorp makes every effort to design a robust power transmission and distribution system, which seeks to minimize disturbances, utilities cannot design and construct a system that is disturbance-free. From a total system standpoint, it is usually much more cost effective to selectively install power conditioning equipment at the location where premium grade power is needed than to install voltage disturbance mitigation equipment in the utility distribution system.

Most voltage disturbances occurring in the utility system will have little or no effect on most customer equipment. It, therefore, makes little sense to protect this equipment from these disturbances; however, some equipment is much more susceptible to electrical disturbances. If the performance of customer equipment seems to be adversely affected by voltage disturbances, the customer should work with the equipment supplier or manufacturer to condition the power such that the equipment in question can ride through disturbances. If this approach does not work for some reason, PacifiCorp can assist the customer in finding solutions for equipment susceptibility to disturbances.

PacifiCorp encourages its customers to specify equipment, prior to purchase, which will ride through events above the SEMI-F47 curve and which can operate well in the typical electrical environment as outlined in this document. More specifically, PacifiCorp encourages its customers to avoid equipment that derives timing information from the zero crossings of the voltage waveform. Many low-level voltage disturbances will create multiple zero crossings within one cycle, and cause this type of equipment to malfunction.

The entire western United States is interconnected into one giant power system and a large disturbance created anywhere on the system affects the entire system to some degree. The magnitude of the disturbance that a particular piece of equipment experiences is dependent on how electrically close it is to the disturbance, and if there are other supporting facilities between it and the disturbance to cushion or soften the impact. Also, the more susceptible the equipment is to a voltage disturbance, the closer such a disturbance appears to be.

4. Voltage Disturbance Definitions

Table 1 is a classification of disturbances and their duration that are commonly encountered within the electrical supply system. This table, derived from IEEE 1159, is for definition purposes only, and is not intended as a standard for determining the quality of power. Use of these standard terms to identify power system disturbances is recommended to improve communication between people working with electrical systems.

Table 1—Disturbances

Categories	Typical Spectral Content	Typical Duration	Typical Voltage Magnitude
Transients			
Impulsive			
Nanosecond (ns)	5 ns rise	< 50 ns	
Microsecond (µs)	1 µs rise	50 ns - 1 ms	
Millisecond (ms)	0.1 ms rise	> 1 ms	
Oscillatory			
Low Frequency	<5 kHz	0.3 - 5 ms	0 - 4 pu
Medium Frequency	5 - 500 kHz	20 µs	0 - 8 pu
High Frequency	0.5 - MHz (?)	5 µs	0 - 4 pu
Short Duration Variations			
Instantaneous			
Sag (Dip)		0.5 - 30 cycles	0.1 - 0.9 pu
Swell		0.5 - 30 cycles	1.1 - 1.8 pu
Momentary			
Interruption		30 cycle - 3 sec.	<0.1 pu
Sag (Dip)		30 cycles - 3 sec.	0.1 - 0.9 pu
Swell		30 cycles - 3 sec.	1.1 - 1.4 pu
Temporary			
Interruption		3 sec. - 1 min.	<0.1 pu
Sag (Dip)		3 sec. - 1 min.	0.1 - 0.9 pu
Swell		3 sec. - 1 min	1.1 - 1.2 pu
Long Duration Variations Interruption,			
Sustained Undervoltages		> 1 min.	0.0 pu
Overvoltages		> 1 min.	0.8 - 0.9 pu
		> 1 min.	1.1 - 1.2 pu
Voltage Unbalance		Steady State	0.5 - 7%

Categories	Typical Spectral Content	Typical Duration	Typical Voltage Magnitude
Waveform Distortion			
DC Offset		Steady State	0 - 0.1%
Harmoncs	0 - 9 kHz	Steady State	0 - 20%
Interharmonics	0 - 9 kHz	Steady State	0 - 2%
Notching		Steady State	
Noise	Broadband	Steady State	0 - 1%
Voltage Fluctuation (Flicker)	< 25 Hz	Intermittent	0.1 - 20%
Power Frequency Variations		< 10 sec	

NOTE: The definition for pu is “per unit” and one pu is equal to 100%.

5. Causes of Voltage Disturbances

The frequency of occurrence and the magnitude of a voltage disturbance are dependent on the cause of the disturbance. Some events are fairly predictable, such as capacitor bank or line switching. Other events, such as line faults, are more probable during certain adverse weather conditions. In the following sections, we will discuss the expected frequency of various types of disturbances, their characteristics, and a few sample voltage waveforms. Section 5.1 covers disturbances caused within the customer’s own facility, and 5.2 through 5.6 cover disturbances caused within the electrical utility system.

5.1. Customer Equipment

The adverse operation of customer-owned equipment can cause voltage disturbances, which may affect a customer’s own operations. Listed below is equipment that has a history of causing voltage disturbances. The items are generally listed in the order of most common to least common causes of problems. Some of these problems require little or no cost to repair, while others require special provisions.

1. **Loose electrical connections.** Connections in an electrical system become loose over time due to vibration and the heating-cooling cycle placed upon the conductors. The connections to aluminum conductors, which are commonly used on larger systems, loosen over time due to conductor deformation. The aluminum warms up under a heavy electrical load and expands. It then flows out from under a tight connector because of its softness. As the conductor cools, it becomes loose in the connector. Periodic tightening of connectors can often solve many problems.
2. **NEC violations.** Violations of the National Electrical Code include undersized wiring, improper grounding of the neutral wire, or the neutral connected to ground in multiple locations. This may cause low voltage, stray currents in the ground, or high neutral-to-earth voltages.
3. **Motor starts.** A starting motor appears as a large load with very poor power factor, which improves as the motor approaches full speed. Depending on the motor, this may take from two seconds to one minute. The effects from these starts may be reduced by starting the offending motors during noncritical periods, not turning them off as often and thus not having to start them as often, using reduced-voltage starters, or a low-distortion variable speed drive.

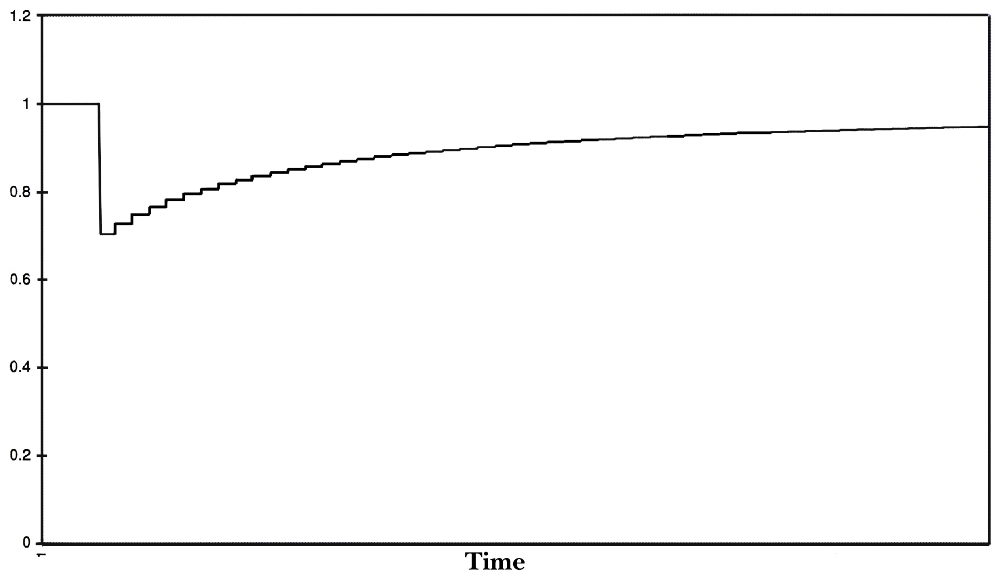

Figure 1—Typical Motor Start Voltage Profile

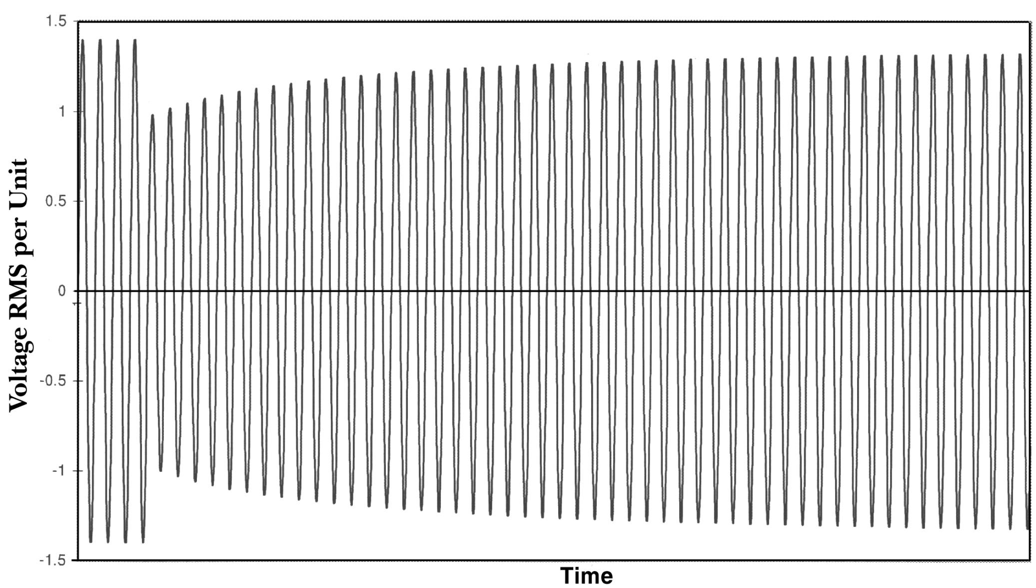

Figure 2—Typical Motor Start Voltage Waveform

4. **Variable speed drives.** These are also known as variable frequency drives (VFD) or adjustable speed drives (ASD). They may create excessive current harmonics, and thus distort the voltage waveform. Many drives contain a ramp function, which, if set improperly, can cause nuisance trips. For more information on drives please refer to 1C.4, Harmonic Distortion. Voltage distortion caused by the drive can interfere with the proper operation of the drive or other equipment within

a facility. Excessive current distortion from drives can lead to overheating of nearby capacitors or the utility transformer and premature failure.

5. **Electric arc welders.** These create very high levels of electrical noise. Some options for mitigation include serving the welder from a dedicated circuit from the main panel, minimizing supply impedance by using larger than typical conductors and/or service transformer serving the facility, or serving the susceptible equipment with an on-line UPS. If the electrical noise from the welding load is severe, filtering may be required to prevent disturbing neighboring utility customers.
6. **Power factor correction capacitors.** Switching these can create high-voltage transients, steady-state voltage shifts, and unwanted zero crossings of the voltage waveform. These can also cause high voltage under light load. In addition, capacitors can resonate with other equipment such as ASD or VFD. This can usually be avoided by using low-distortion (12 pulse) drives or through careful sizing of capacitors prior to installation.
7. **Copy machines & laser printers.** These are notorious for interfering with other office equipment by introducing harmonic distortion and highly fluctuating loads. Placing these on a dedicated circuit from the main panel is usually sufficient to solve the problem.
8. **Computer equipment.** These have solid-state switching power supplies, which can cause a significant amount of current distortion. A large office setting can have very high levels of third harmonic current distortion. The third harmonic and all other "triplen" harmonics add in the neutral. These can cause very high neutral currents to flow, even if the load is balanced among all three phases. It is possible for the neutral current to be much larger than the phase current in office buildings. One possible solution is to install a neutral blocking filter for third harmonics.
9. **X-ray, CT or MRI equipment.** These have a very high and distorted current draw when operating; however, the operating cycles are longer and the load is greater. These should be served from their own dedicated circuit. Sometimes the only way to properly serve these is to install a dedicated utility distribution transformer.

Customers are required to pay for any 'larger than typical' size utility equipment.

5.2. Capacitor Switching

Capacitors are installed on the utility's electrical system to provide reactive power for the customer's motor loads, and to provide voltage support on the system. Because the need for vars (volt-amperes reactive) varies over time, some of the capacitors must be switched in and out to follow the reactive load requirements. Some capacitors are switched multiple times a day, some are switched daily, some are switched seasonally, and some are always kept closed. The switching is required to maintain system voltage within reasonable limits, and also minimize the electrical system losses. Any needed vars, which are not produced by capacitors, must be produced by generation, which is usually more expensive.

The disturbance created by the switching of capacitors is a ringing of the voltage waveform lasting two cycles or less. The ringing often creates multiple zero crossings during one cycle. The voltage transient may exceed +150 percent of the magnitude of the steady-state voltage. This disturbance is normal and very common for utility operations.

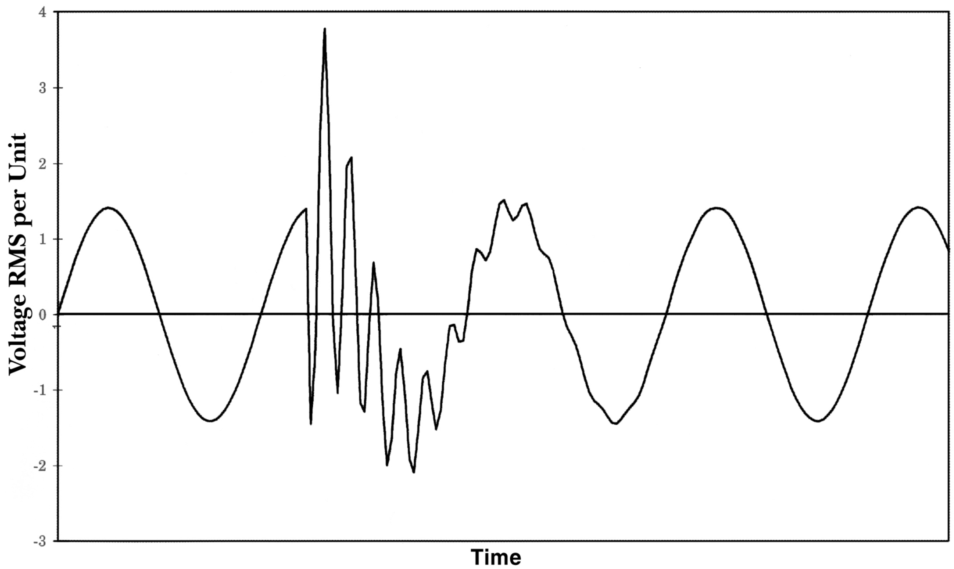

Figure 3—Typical Capacitor Bank Closing Voltage Waveform

The steady-state voltage will rise when the capacitor closes and may exceed the normal steady-state voltage limits for up to two minutes, until a voltage regulator compensates for the changed voltage. The voltage sag when the capacitor opens may also exceed the normal steady-state voltage limits until a voltage regulator compensates for the changed voltage. The magnitude of these changes can be expected to be within the *Voltage Level and Range* guidelines (see 1C.2.1).

5.3. Line Switching

The switching of both transmission and distribution lines is required to perform maintenance on the utility system, provide for the economic operation of the system, prevent the overloading of heavily loaded lines, and restore service in the event of a power outage. Line switching is done almost continually somewhere in the system. A voltage transient can be created by line switching, but is usually less severe than that created by capacitor switching and rarely creates noticeable problems for customer equipment.

5.4. System Faults

Electrical system faults are the most troublesome to the majority of customers. They occur whenever lightning hits the line, power lines slap together from excessive wind, or whenever a power line falls to the ground, such as when a power pole is hit by a vehicle. They occur whenever tree branches contact the power lines, such as during a wind storm; and they occur during a rain storm when a substantial amount of dust is stirred up, thus compromising the effectiveness of the line insulators. The clearing of these faults is necessary to prevent catastrophic damage to the electrical system, and to ensure public safety.

The word *fault* indicates either a short circuit condition, or an abnormal open wire condition. When the equipment required to serve the customer is involved in a fault, the voltage level often will be temporarily outside the levels stated in 1C.2.1, *Voltage Level and Range*.

The magnitude and duration of a fault inspired disturbance are determined by the customer's electrical distance to the fault, the system strength available between the customer and the fault, the nature of the fault, and how the fault was cleared.

5.4.1. Short Circuits

As shown in Figure 4 and Figure 5, during a short circuit the electrical system's voltage sags on the short circuited phases due to the resulting extremely high current flows. The sag magnitude can drop the voltage to zero volts under worst-case conditions. The unaffected phases may rise in voltage due to the increased ground and neutral current flow. This disturbance lasts from 30 milliseconds to a few seconds, after which protective equipment operates to clear the the short circuit. This equipment consists of circuit breakers, fuses, and related protective equipment.

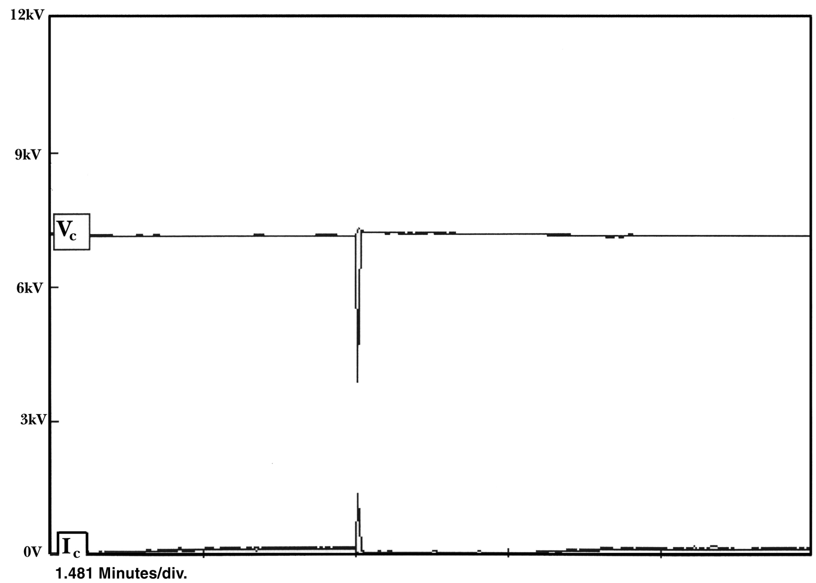

Figure 4—Typical Voltage and Current Behavior During a Fault

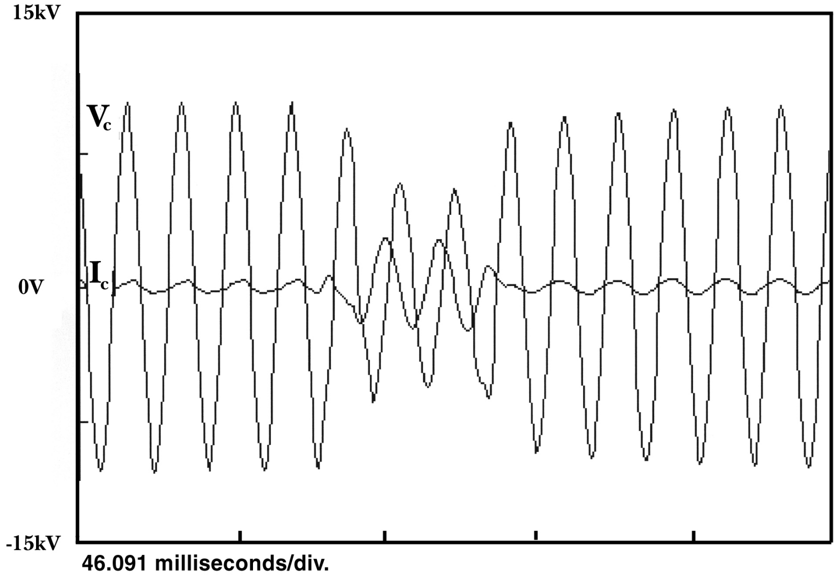

Figure 5—Typical Voltage and Current Waveforms During a Fault

If the customer is not being served directly by the faulted circuit, electrical service will resume at its normal levels. If the customer is being served by the faulted circuit, then a service interruption will occur . If a circuit breaker was used to clear the short circuit, service will usually be restored automatically after a very short time. If the short circuit cannot be cleared, after a predetermined number of attempts, usually two or three, the circuit breaker will lock open. At this point the fault is classified as permanent, and manual intervention is required to repair the facilities and clear the fault. This can take anywhere from one hour to several hours, depending on the damage to the system.

5.4.2. Open Circuits

Sometimes a three-phase electrical circuit will experience a fault on only one phase. This could be caused by a short circuit or by the failure of a line jumper. For a short circuit, protective equipment will act to disconnect the affected phase. This fault clearing or the opening of a line or jumper, causes a condition known as “single phasing’ whereby all remaining three-phase equipment in the affected circuit is supplied only by the remaining two phases. Single phasing can cause overheating and premature failure of equipment , especially three-phase motors and transformers. By state regulations, customers are responsible to protect their equipment from single phasing conditions.

5.5. System Frequency Disturbances

The electrical system must accurately and continuously match the generation of electrical power to the electrical system’s area load requirements. If the power generation exceeds the load, then the power system frequency will temporarily increase. If the load exceeds the power generated, then the frequency will temporarily decrease.

Occasionally an event occurs on the electrical power system that results in a wide-ranging disruption of electrical service. This results from automatic equipment operating to prevent catastrophic damage to the system. The equipment automatically sheds load if the system frequency drops below a predetermined threshold. It also automatically sheds generation if the system frequency is either much too high, or much too low.

Typical events that may cause such an event are the unexpected and sudden loss of a major generating station or major power lines under high load conditions, or the sudden loss of a major load center. These events are rare in nature, and affect a large geographic area.

5.6. Lightning Strikes

Lightning strikes are a well-known high-energy transient with a very short duration. Surge arresters and similar devices are designed to contain and control the damaging effects of the more distant and less severe disturbances. They might be unable to limit the effects of a close-in lightning strike due to their limited energy absorption capabilities. Most locations rarely suffer a direct lightning strike, but may see some limited damage from more distant strikes. Some locations are predictably more susceptible, such as mountaintop communications sites and communications towers on open plains.

For those locations that are concerned with lightning, special designs and construction practices must be followed. The best protection against damaging lightning strikes is combining large energy withstand arresters with a well-grounded system and lightning diversion mechanisms such as lightning rods, towers, or umbrellas. Even when employing all possible protective measures, a direct strike to the electrical system will almost always result in some damage.

It must be noted that surge arresters are not effective for voltages below 200 percent of the peak-to-peak nominal voltage. They are also not effective on zero-crossing transients. Their main benefit is the prevention of catastrophic damage to equipment.

The electrical utility installs some surge arresters on the system to protect selected utility equipment from severe overvoltage and damage. Utility equipment can withstand surges up to fifteen times rated voltage. As a consequence, customers should not plan on the utility-owned arresters protecting their equipment from lightning or other voltage transients.

It is recommended that customers install surge protective devices to protect their equipment.

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