# Quantum Chargers' Enhanced AC Line Transient Immunity

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## Introduction

This white paper outlines the most common AC power quality disturbances and how the Quantum chargers were designed to provide additional immunity to such disturbances.

## Nominal AC line Fluctuations

In a typical AC voltage distribution system, the steady state operating voltages will vary from nominal values due to voltage drops in the system as well as changes in the system's operating conditions. Utilities are required to maintain system service voltages within a suitable range. As such, utilities must regulate the service voltages to customers to ensure that voltage variation remains within acceptable limits. Voltage regulators – in substations or on feeders – are typically used to adjust the primary voltage to maintain service voltages within acceptable limits. These limits are set by various regulatory bodies and standards.

Most utilities in the US follow the ANSI voltage standards (ANSI C84.1). The **ANSI C84.1** is the American National Standard for Electric Power Systems and Equipment – Voltage Ratings (60 Hertz). The standard establishes the nominal voltage ratings and operating tolerances for 60-Hz electric power systems above 100 volts up to a maximum system voltage of 1200 kV (steady-state voltage levels only).

The standard specifies acceptable operational ranges at two locations on electric power systems:

- *Service Voltage*: The voltage at the interconnect point of the AC power system and the customer's facility, which is normally at the meter. Maintaining acceptable voltage at the service point is the utility's responsibility.
- *Utilization Voltage*: The voltage at the line terminals, where electrical equipment is connected. This voltage is the facility's responsibility.

The ANSI C84.1 divides voltages into two ranges. Range A is the optimal voltage range while Range B is acceptable, but not optimal (Table 1). Utilities must ensure that the service voltages remain within these limits and equipment manufacturers must design their equipment to operate satisfactorily within the given limits.

While in steady state, the service and distribution voltages remain within the preset limits, many power quality disturbances occur within a power system that cause momentarily and extended variations of service and utilization voltage limits that exceed the ANSI C84.1. Various power quality disturbances will be discussed next.

**Table 1: Voltage ranges according to ANSI C84.1 standard**

| For 120V – 600V Systems | | | | | | |
|---|---|---|---|---|---|---|
| Nominal Service Voltage (V) | Nominal Utilization Voltage (V) | Service Voltage (V) | | | | |
| | | Range A | | Range B | | |
| | | Max | Min | Max | Min | |
| **120** | **115** | 126 | 114 | 127 | 110 | |
| **240** | **230** | 252 | 228 | 254 | 220 | |
| **480** | **460** | 504 | 456 | 508 | 440 | |
| **600** | **575** | 630 | 570 | 635 | 550 | |

## AC Power Quality Disturbances

A wide number of power quality disturbances can affect the performance of electrical equipment at manufacturing and distribution facilities causing momentary or extended variations is the AC service or utilization voltages. Some of the most common power quality disturbances include:

1. Voltage Spikes / Surges
2. Interruptions
3. Voltage Sags
4. Undervoltages
5. Voltage Swells
6. Overvoltages

### *Voltage Spikes or Surges*

Voltage spikes or surges (also referred to as impulsive transients) are sudden high peak events that increase the nominal AC voltage for very short duration (Fig. 1).

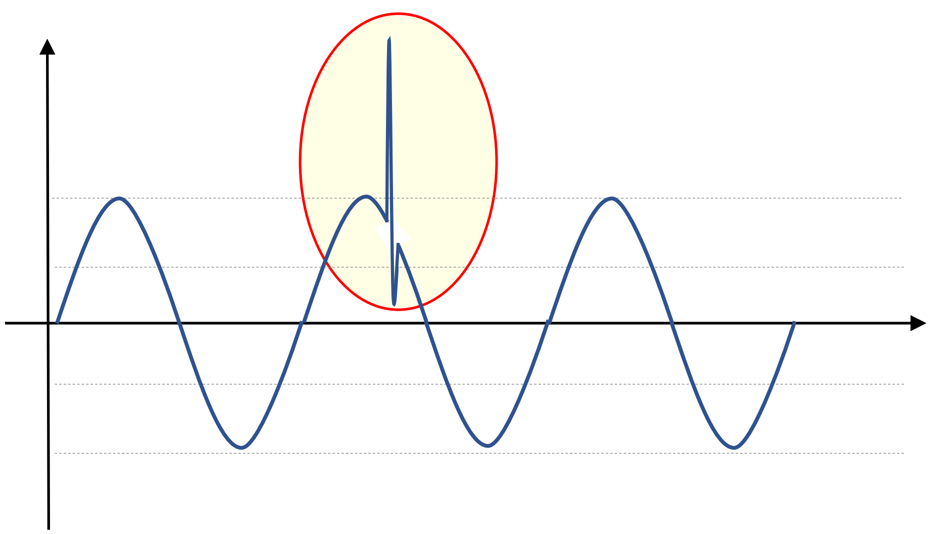

**Fig. 1: Typical AC voltage spike**

The most common cause of voltages pikes and surges is lightning strikes. Other causes include electrostatic discharge (ESD), switching of inductive loads, switching of power factor correction capacitor banks, poor grounding, and clearing of utility line faults. These factors can result in large amounts of energy transfer with very short rise and decay times

The table below shows the various transient sources, magnitudes, and durations.

**Table 2: Examples of transient sources and magnitudes**

| | Voltage | Current | Rise-time | Duration |
|---|---|---|---|---|
| **Lighting** | 25kV | 20kA | 10 μs | 1ms |
| **Switching** | 600V | 500A | 50μs | 500ms |
| **EMP** | 1kV | 10A | 20ns | 1ms |
| **ESD** | 15kV | 30A | <1ns | 100ns |

### *Interruptions*

Power interruptions occur when the AC line voltage decreases to less than 10% of the nominal line voltage (0.1 p.u.) for a period not longer than 60 seconds (Fig. 2). If the interruption lasts longer than one minute, it becomes a sustained interruption.

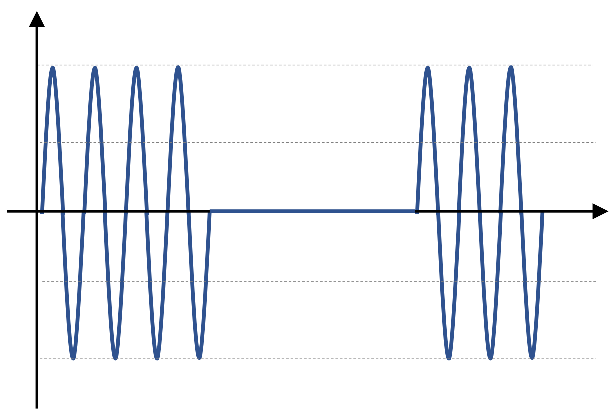

**Fig. 2: Power interruption (few cycles)**

Interruptions are usually the result of some sort of electrical power system failure or damage that may be caused by lightning, trees, animals, weather (high winds, heavy snow or ice on lines), insulation failure, improper/faulty grounding, equipment failure, or automatic re-closure of protection devices to isolate faulty sections of the system.

Interruptions can be classified, depending on their durations, as shown in Table 3 below.

**Table 3: Classification of Interruptions according to IEEE 1159**

| Type of Interruption | Duration |
|---|---|
| **Instantaneous** | 0.5 – 30 cycles |
| **Momentary** | 30 cycles – 3 secs |
| **Temporary** | 3 secs – 2 mins |
| **Sustained** | > 2 minutes |

### *Voltage Sags*

A voltage sag is a momentary reduction in the AC rms voltage to between 10% to 90% (0.1 to 0.9 p.u.) of the nominal rms voltage for period of half a cycle up to one minute. It is caused by AC line faults, starting of electric motors, switching on heavy loads, or excessive loading. Fig. 3 shows a voltage sag to 50% of nominal rms voltage.

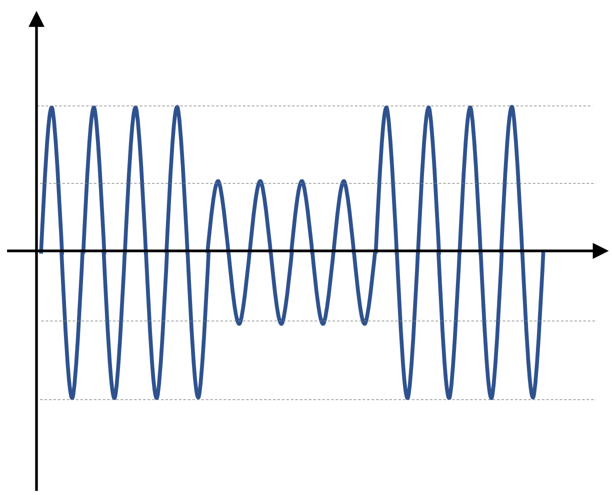

**Fig. 4: AC voltage sag**

### *Undervoltages*

An undervoltage is a decrease in the AC rms voltage to less than 90% (<0.9 p.u.) of the nominal rms voltage for a duration longer than one minute (Fig. 5). Undervoltages are the most common power quality disturbance that occurs in industrial facilities. Their effect can be quite severe as they may cause damage of sensitive equipment, such as Programmable Logic Controllers (PLCs), Adjustable Speed Drive (ASDs), and Chiller controllers.

The most common causes of undervoltages include closing and opening of circuit breakers, AC line faults, switching on large inductive loads, such as motor starting and transformer energizing, and equipment failure due to insulation breakdown, heating or short circuit.

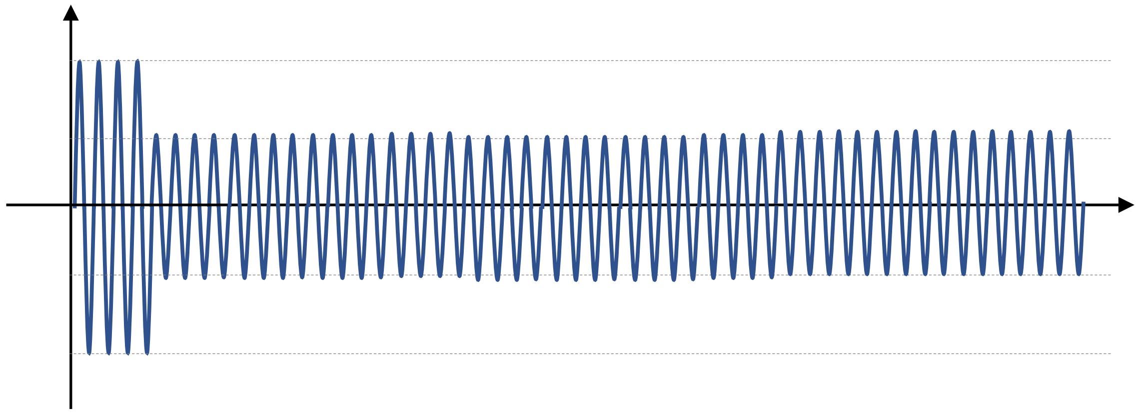

Fig. 5: AC undervoltage

Undervoltages can be classified depending on their durations as shown in Table 4 below.

**Table 4: Classification of Undervoltage according to IEEE 1159**

| Type of Undervoltage | Duration | Magnitude |
|---|---|---|
| **Instantaneous** | 0.5 – 30 cycles | 0.1 – 0.9 p.u. |
| **Momentary** | 30 cycles – 3 secs | 0.1 – 0.9 p.u. |
| **Temporary** | 3 secs – 1 min | 0.1 – 0.9 p.u. |

***Voltage Swells***

A voltage swell is a momentary increase in the AC rms voltage to between 110% to 180% (1.1 to 1.8 p.u.) of the nominal rms voltage for period of half a cycle up to one minute (Fig. 6). It is caused by switching off heavy loads, loss of generation, badly regulated transformers, and AC line faults.

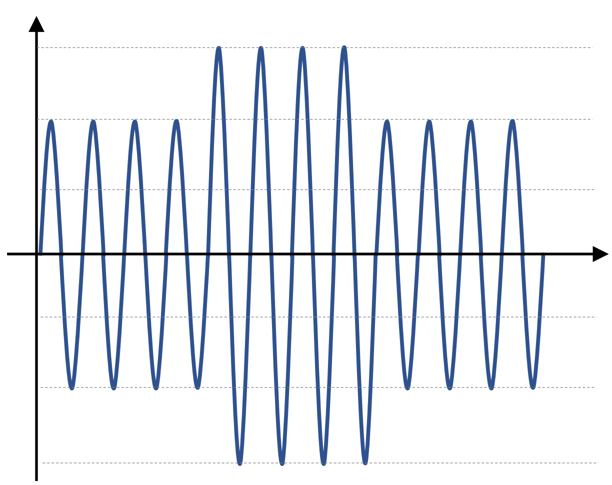

Fig. 6: AC voltage swell

### *Overvoltages*

An overvoltage is an increase in the AC rms voltage of greater than 10% (>1.1 p.u.) of the nominal rms voltage for a duration longer than one minute (Fig. 7). It results from switching off large loads, incorrect tap settings of distribution transformers, energizing of capacitor banks, AC line faults, and/or ungrounded or floating ground delta systems.

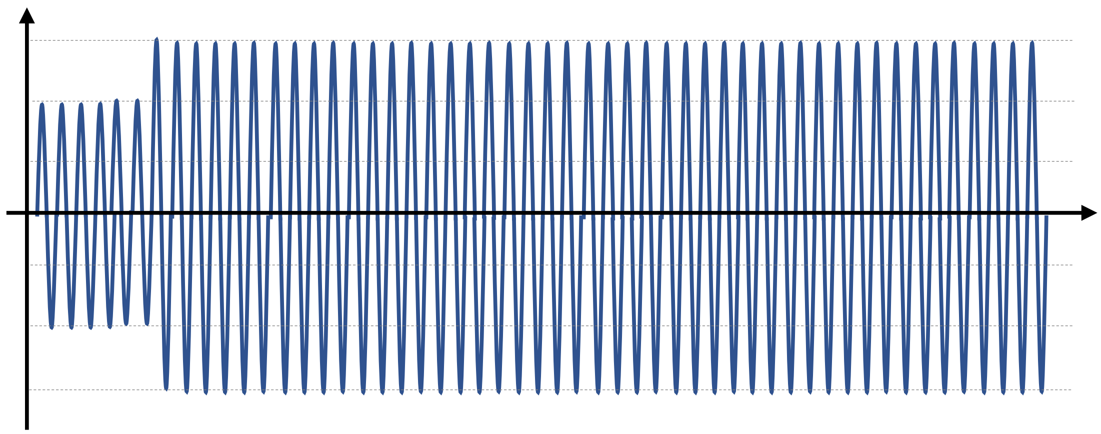

**Fig. 7: AC overvoltage**

Overvoltages can be classified depending on their durations as shown in Table 5 below.

**Table 5: Classification of Overvoltage according to IEEE 1159**

| Type of Overvoltage | Duration | Magnitude |
|---|---|---|
| Type **of Overvoltage** | Duration | Magnitude |
| **Instantaneous** | 0.5 – 30 cycles | 0.1 – 0.9 p.u. |
| **Momentary** | 30 cycles – 3 secs | 0.1 – 0.9 p.u. |

## Quantum Chargers' Enhanced AC Line Transient Immunity

The Quantum charger, ACT's flagship product, is the industry's first smart industrial charger appliance that features many advanced energy efficiency and energy management capabilities as well as communication and smart grid integration (Fig. 8). The Quantum charger is first industrial smart appliance that is highly efficient, internet protocol (IP) addressable, and can be controlled by external signals from the utility, end-user, or other authorized entity.

The Quantum charger's design encompasses many advanced protection functionalities aimed at enhancing the immunity of the chargers to AC power quality disturbances. The following is a summary of the key design features that yield enhanced immunity.


**Fig. 8: ACT Quantum chargers: Industry's first smart charging appliance**

***AC Input Protection to Voltage Spikes / Surges***

In order to provide extra immunity to AC voltage spikes / surges, the Quantum chargers' design include:

- A UL1449 compliant thermally protected phase to phase transient voltage suppression devices (TMOVs) capable of absorbing 400 Joules (200kW for 2 milliseconds) and up to 10,000 Amperes of transient current
- Two sections of phase to phase suppression capacitors
- A common mode/differential mode suppression filter inductor
- Phase to earth ground capacitor for common mode noise and transient suppression

***AC Input Protection to Voltage Swells / Overvoltages***

To provide protection for momentary voltage swells or extended overvoltages, the Quantum chargers' design feature the following:

- A proprietary converter topology that provides 40% voltage operating margins for input side semiconductor switches at high line and nearly 50% margin at nominal line. This large derating eliminates failures of these devices due to AC voltage swells and over-voltage conditions. This is especially critical in industrial installations where power quality is poor.
- Input DC protection to provide extra immunity to the downstream power devices and circuits. This includes:
    - A 1000V/1600V input rectifiers, providing 33% to 77% extra voltage margin at high line
    - Large DC input choke and supplemental inrush surge protection, which prevents large transient currents from flowing into the input circuit

- Nominal input side DC energy storage of 30 Joules, which absorbs low frequency AC input disturbances, thus reducing any stress to the input side semiconductor devices

- Advanced controls, which temporarily disables the power circuitry and pauses the charge cycle when an extended voltage swell or overvoltage condition is detected. The advanced controls continuously monitors the AC line voltage and automatically enables the power circuitry to resume the charge cycle once the AC line voltage recovers to nominal values.

### *AC Input Protection to Voltage Sags / Undervoltages*

To provide protection for momentary voltage sags or extended undervoltages, the Quantum chargers' design feature the following:

- A proprietary converter topology that provides 20% power derating, which allows the Quantum chargers to operate reliably at line voltages well below the 10% limit set by ANSI. This large derating eliminates failures of power devices due to AC voltage sags and under-voltage conditions, which is especially critical in industrial installations where power quality is poor.
- Advanced controls, which temporarily disables the power circuitry and pauses the charge cycle when an extended voltage sag or undervoltage condition is detected. The advanced controls continuously monitors the AC line voltage and automatically enables the power circuitry to resume the charge cycle once the AC line voltage recovers to nominal values.

## Conclusion

The Quantum chargers have been designed to provide extra immunity to AC line transients and surges. The enhanced immunity allows the Quantum chargers to work very reliably in industrial and commercial installations, where power quality issues are very frequent. Field deployment of Quantum chargers in installations with extreme power quality disturbances has proven very successful, making the Quantum chargers the most reliable and resilient industrial charger on the market.

### References


1) Joseph Seymour, "*The Seven Types of Power Problems*", White Paper 18, Schnieder Electric. https://goo.gl/Ue1cef
2) Kevin Olikara, "*Power Quality Issues, Impacts, and Mitigation for Industrial Customers*" Rockwell Automation, Inc. https://goo.gl/ERd09N
3) M. Paul, A. Chaudhury, S. Saikia, "*Hardware Implementation of Overvoltage and Under voltage Protection*", International Journal of Innovative Research In Electrical, Electronics, Instrumentation And Control Engineering, Vol. 3, Issue 6, June 2015.
4) *Transient Voltage Suppressors (TVS Diode) Applications Overview*, Application Note, Littlefuse. https://goo.gl/XY8KJs