6. Power Quality

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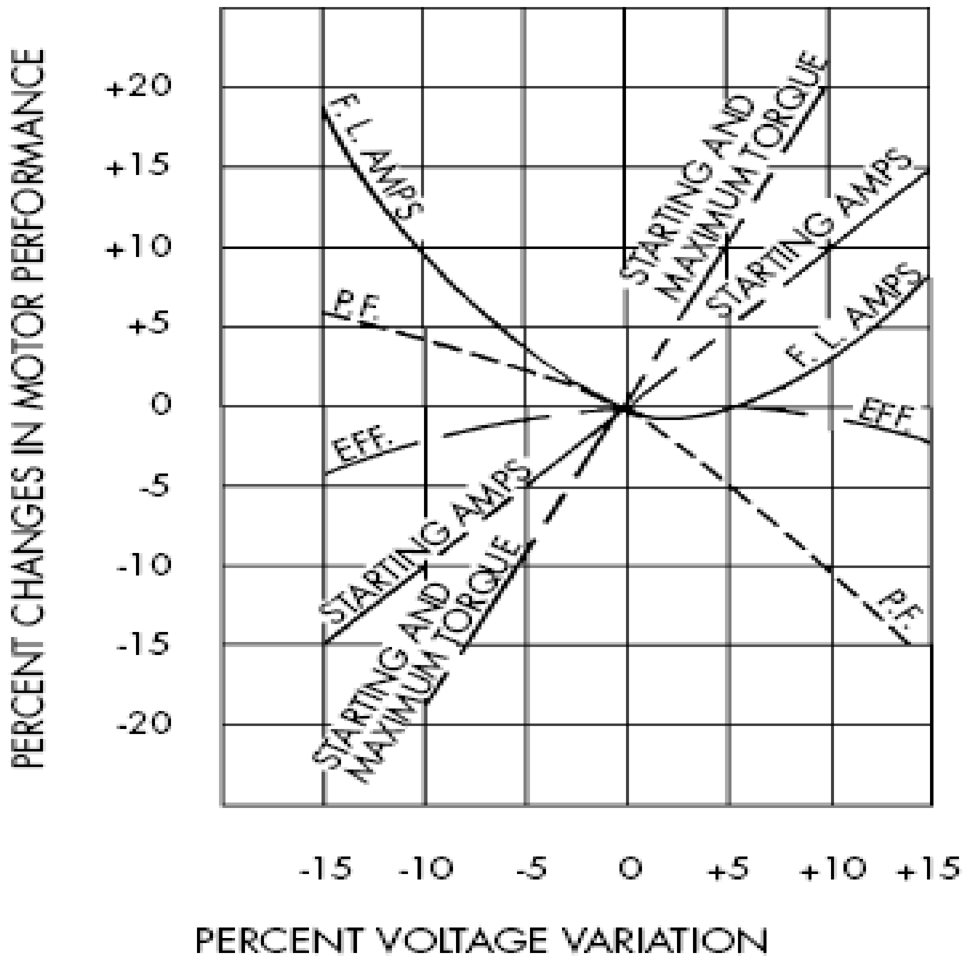
Discussed topics

- Voltage levels
- Voltage unbalance
- Power factor
- Harmonics

Power Quality

1. Maintain Voltage Levels

When operating at less than 95% of design voltage, motors typically lose 2 to 4 points of efficiency. Running a motor above its design voltage also reduces power factor and efficiency



Voltage Variation Effect on Motor Performance

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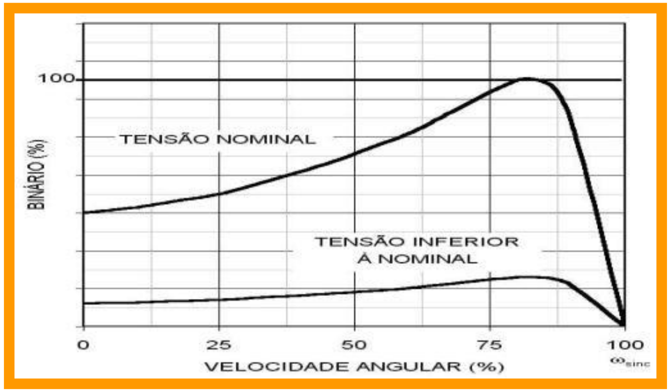
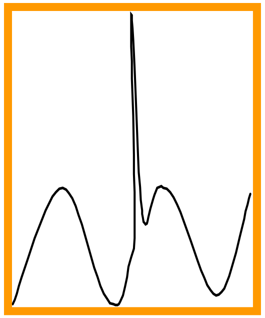
VOLTAGE AMPLITUDE REDUCTION



EFFECTS: EFFICENCY REDUCTION, TORQUE-SPEED CHANGE, MOTOR LIFETIME REDUCTION IF THEY ARE OPERATING AT FULL-LOAD.

VOLTAGE TRANSIENTS



EFFECTS: LIFETIME REDUCTION DUE TO VOLTAGE STRESS AND PARTIAL DISCHARGE.

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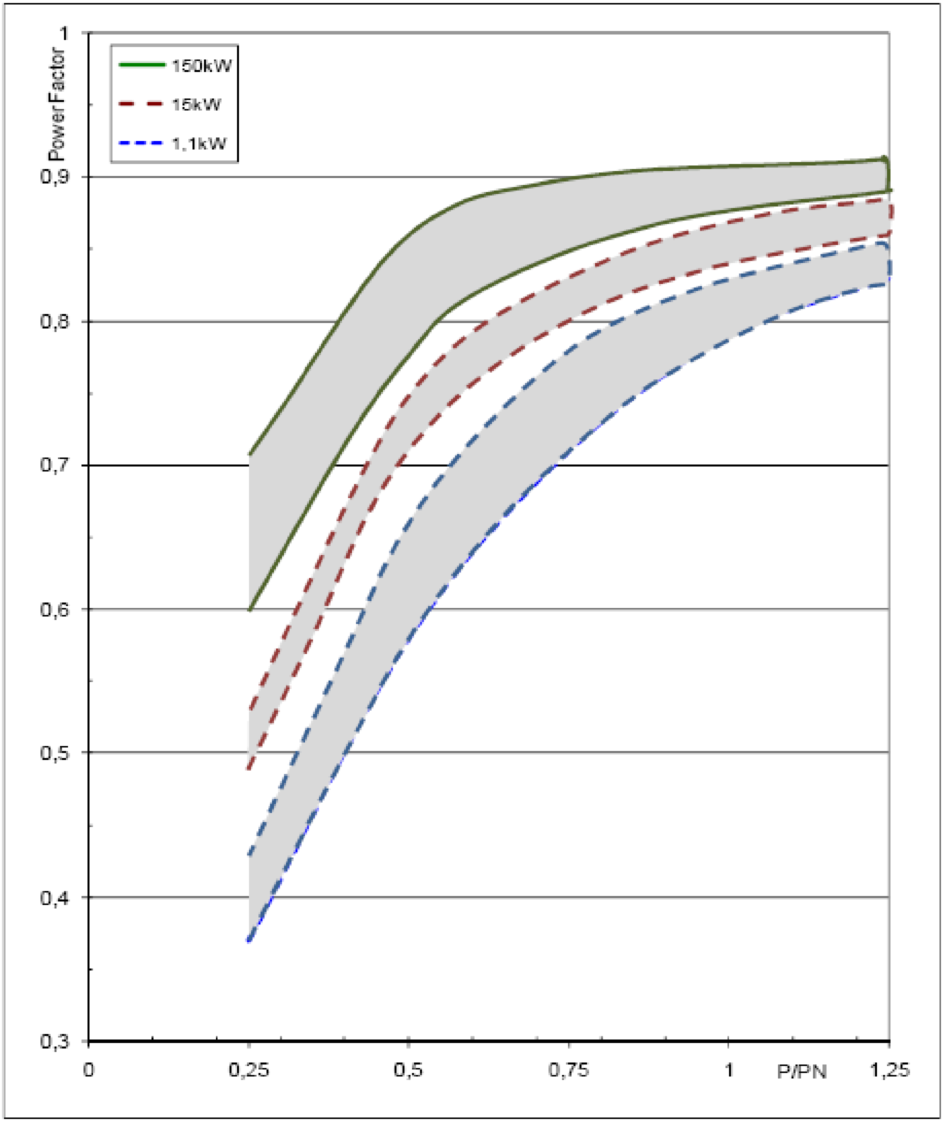
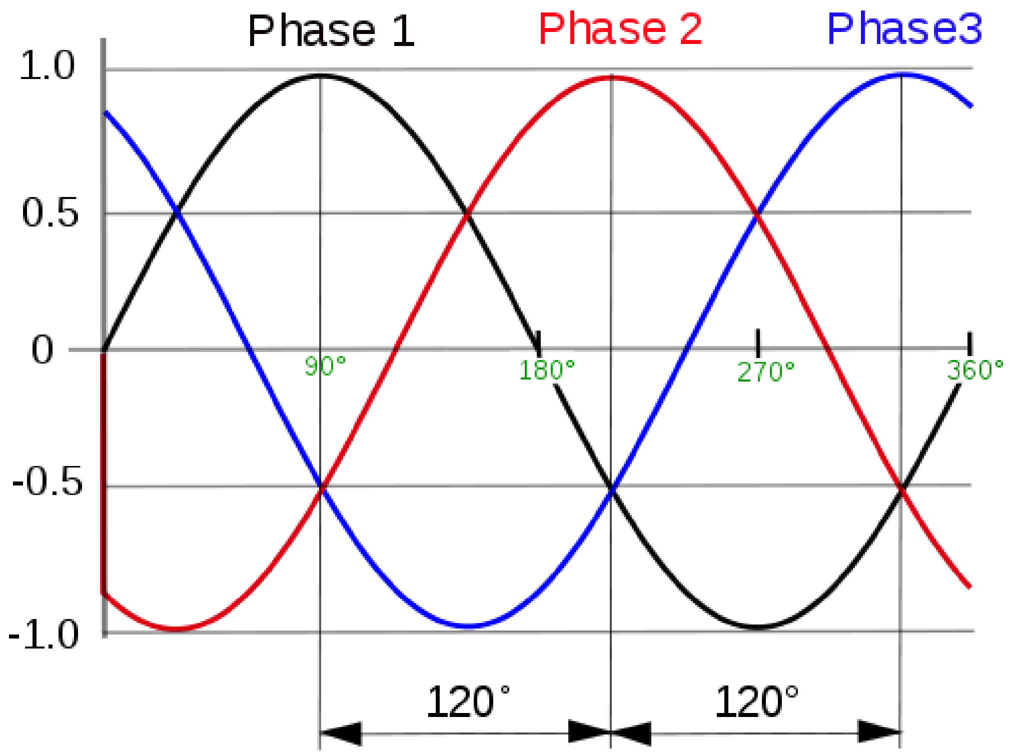
2. Maintain High Power Factor
Low power factor reduces the efficiency of the electrical distribution system both within and outside of your facility. Low power factor results when induction motors are operated at less than full load.



Typical Power Factor versus Load
Source: IEC 60034-31

Power Quality

Balanced system

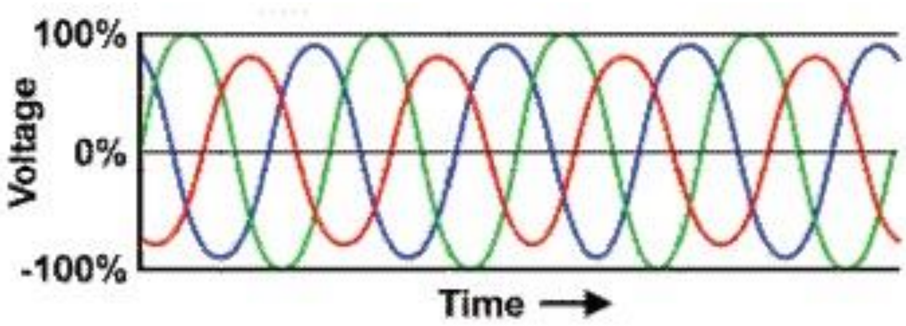


Voltage unbalance

Definition

Voltage unbalance (VU) is given by:

$$\%VU = \frac{max.\,voltage\ deviation\ from\ the\ avg.\,voltage}{avg.\,voltage} \times 100$$



Example

L1 = 600 V

L2 = 585 V

L3 = 609 V

$$Average\ Voltage = \frac{600 + 585 + 609}{3} = 598\ \mathrm{V}$$

$$Max.\ deviation\ from\ avg. = 598 - 585 = 13\ V$$

$$\boldsymbol{Voltage\ Unbalance = \frac{13}{598} \times 100 = 2,17\%}$$

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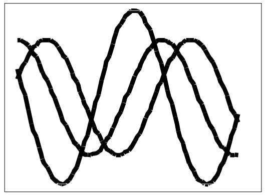
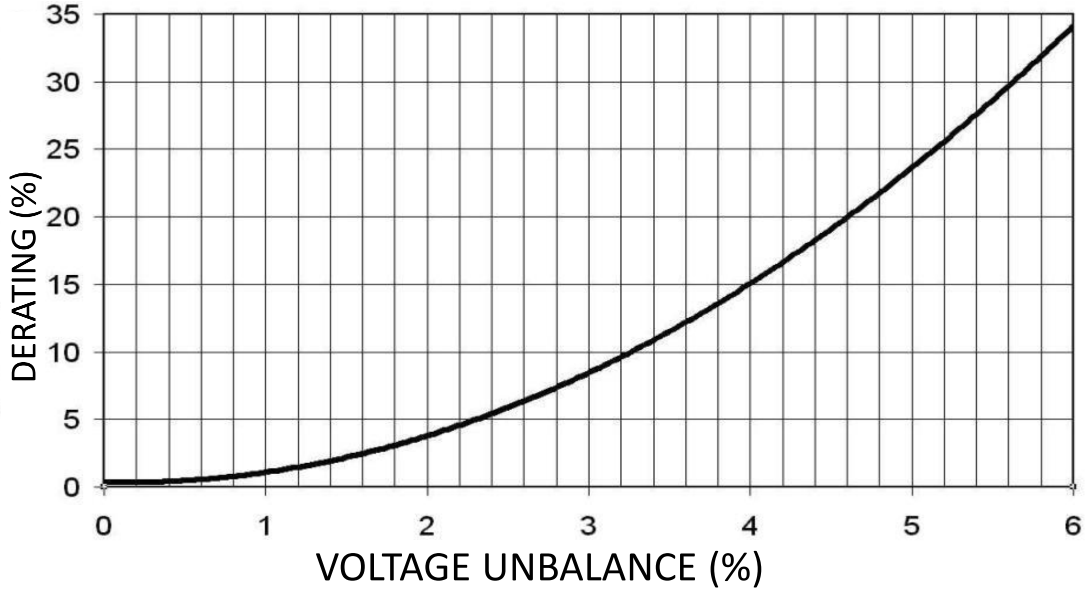
3. Minimize Phase Unbalance

An unbalanced system increases distribution system losses and reduces motor efficiency.





Exercise

- Assume a 100 kW motor operated at 75 % load, 8000 hours per year at a 2,5% voltage unbalance

Motor Efficiency* Under Conditions of Voltage Unbalance			
Motor Load % of Full	Motor Efficiency, %		
	Voltage Unbalance		
	Nominal	1%	2.5%
100	94.4	94.4	93.0
75	95.2	95.1	93.9
50	96.1	95.5	94.1

- Calculate the savings if corrective action was taken

Exercise

Savings = 100 x 0,75 x 8000 x (1/0,939 – 1/0,952) =

= 9000 kWh

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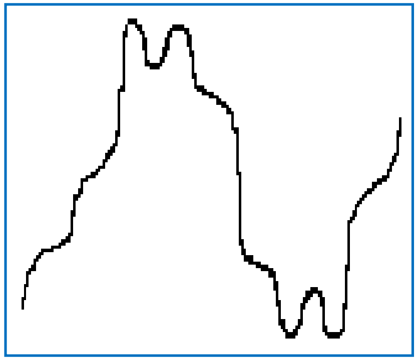
Voltage distortion can be quantified by the ***Total Harmonic Distortion***, THD:



$$THD = \frac{\sqrt{\sum_{k=2}^{n} V_k^2}}{V_{RMS}}$$

CAUSES: VSDs, rectifiers, furnaces, voltage controllers, variable impedance loads, saturated core load (transformers).

PQ - Standards

IEEE 519 – specifies THD ≤ 5%, and no individual harmonic >3%

EN 50160 – specifies THD ≤ 8%, 5th harmonic ≤ 6%, 7th harmonic ≤ 5%, 11th harmonic ≤ 3.5%, 13th harmonic ≤ 3%,

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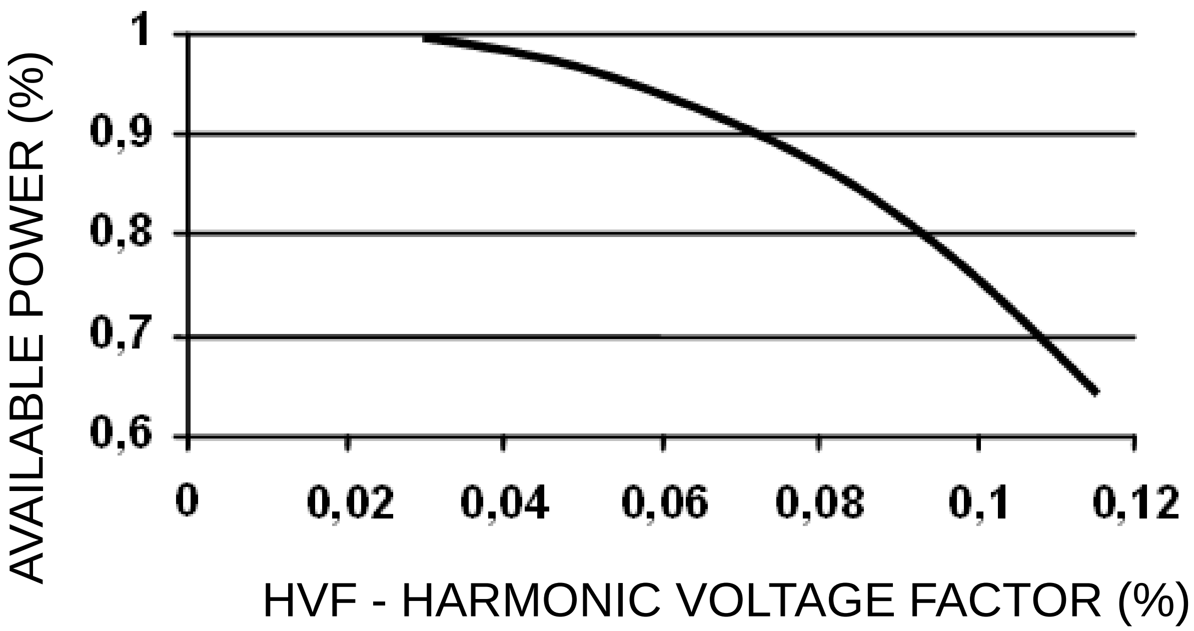
4. Maintain Good Power Quality

Distorted wave forms will degrade efficiency.



$$HVF = \sqrt{\sum_{n=5}^{n=\infty} \frac{(V_n)^2}{n}}$$

Effects of High Harmonic Levels

- poor power factor, i.e. high current for a given power,
- interference to equipment which is sensitive to voltage waveform,
- excessive heating of neutral conductors (single-phase loads only),
- excessive heating of induction motors,
- high acoustic noise from transformers, busbars, switchgear and so on,
- excessive heating of transformers and associated equipment, and
- damage to power factor correction capacitors.

Types of Harmonics

- Negative Sequence – 5th, 11th, 17th...
- Positive Sequence - 7th, 13th, 19th..

In unbalanced systems with neutral conductor

- Triplet (homopolar)-3rd, 6th, 9th...

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5. **Select Efficient Transformers**

   Install efficient and properly sized step-down transformers. Older, underloaded, or overloaded transformers are often inefficient.

6. **Identify and Eliminate Distribution System Losses**

   Regularly check for bad connections, poor grounding, and shorts to ground. Such problems are common sources of energy losses, hazardous, and reduce system reliability.

7. **Minimize Distribution System Resistance**

   Power cables that supply motors running near full load for many hours should be properly sized in new construction or during rewiring. This practice minimizes line losses and voltage drops.

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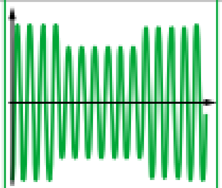
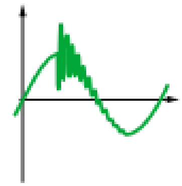
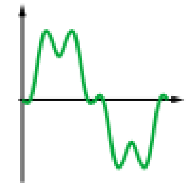
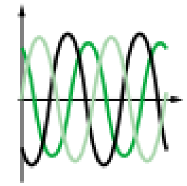
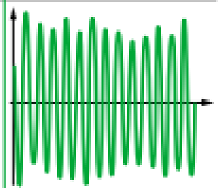
Disturbances	Voltage dips	Overvoltages	Harmonics	Unbalance	Voltage fluctuations
Characteristic waveforms					
Origin of disturbance					
■ **Power system**					
□ Insulation fault, break of the neutral conductor...	Occasional			Occasional	
□ Switching, ferroresonance		Occasional			
□ Lightning		Occasional			
■ **Equipment**					
□ Asynchronous motor	Occasional				
□ Synchronous motor	Occasional		Frequent		
□ Welding machine	Occasional		Frequent	Frequent	Frequent
□ Arc furnace	Occasional		Frequent	Frequent	Frequent
□ Converter		Frequent	Frequent		
□ Data processing loads			Frequent		
□ Lighting			Frequent		
□ Inverter			Frequent		
□ Capacitor bank	Occasional	Frequent	Frequent		Occasional

(light green) : Occasional phenomenon (grey) : Frequent phenomenon

Power Quality

Type of disturbance	Origins	Consequences	Examples of mitigation solutions (special equipment and modifications)
Voltage variations and fluctuations	Large load variations (welding machines, arc furnaces, etc.).	Fluctuation in the luminance of lamps (flicker).	Electromechanical reactive power compensator, real time reactive compensator, series electronic conditioner, tap changer.
Voltage dips	Short-circuit, switching of large loads (motor starting, etc.).	Disturbance or shutdown of process: loss of data, incorrect data, opening of contactors, locking of drives, slowdown or stalling of motors, extinguishing of discharge lamps.	UPS, real time reactive compensator, dynamic electronic voltage regulator, soft starter, series electronic conditioner. Increase the short-circuit power (Scc). Modify the discrimination of protective devices.
Interruptions	Short-circuit, overloads, maintenance, unwanted tripping.		UPS, mechanical source transfer, static transfer swtich, zero-time set, shunt circuit breaker, remote management.
Harmonics	Non-linear loads (adjustable speed drives, arc furnaces, welding machines, discharge lamps, fluorescent tubes, etc.).	Overloads (of neutral conductor, sources, etc.), unwanted tripping, accelerated ageing, degradation of energy efficiency, loss of productivity.	Anti-harmonic choke, passive or active filter, hybrid filter, line choke. Increase the Scc. Contain polluting loads. Derate the equipment.
Inter-harmonics	Fluctuating loads (arc furnaces, welding machines, etc.), frequency inverters.	Interruption of metering signals, flicker.	Series reactance.
Transient overvoltages	Operation of switchgear and capacitors, lightning.	Locking of drives, unwanted tripping, destruction of switchgear, fire, operating losses.	Surge arrester, surge diverter, controlled switching, pre-insertion resistor, line chokes, static automatic compensator.
Voltage unbalance	Unbalanced loads (large single-phase loads, etc.).	Inverse motor torque (vibration) and overheating of asynchronous machines.	Balance the loads. Shunt electronic compensator, dynamic electronic voltage regulator. Increase the Scc.

Power Quality Costs

Direct costs

- Some utilities charge a penalty for excessive reactive power (kVAr)
- Reactive power is unused power that increases peak power ant its costs
- Damage in the equipment
- Loss of production and raw material
- Salary costs during non-productive period
- Restarting costs

Indirect costs

- Inability to accomplish deadlines
- Loss of future orders

Power Quality Costs

- **Business Week (1991)** - 26,000 million USD per year in the United States
- **EPRI (1994)** - 400,000 million USD per year in the United States.
- **US Department of Energy (1995)** - 150,000 million USD per year for United States.
- **Fortune Magazine (1998)** - Around 10,000 million USD per year in United States.
- **E Source (2001)** - 60,000 to 80,000 USD per installation, per year for continuous process industries, financial services and food processing in the United States.
- **European Copper Institute (2001)** - 10,000 million EUR per year, in EU in industry and commerce.

Power Quality Costs

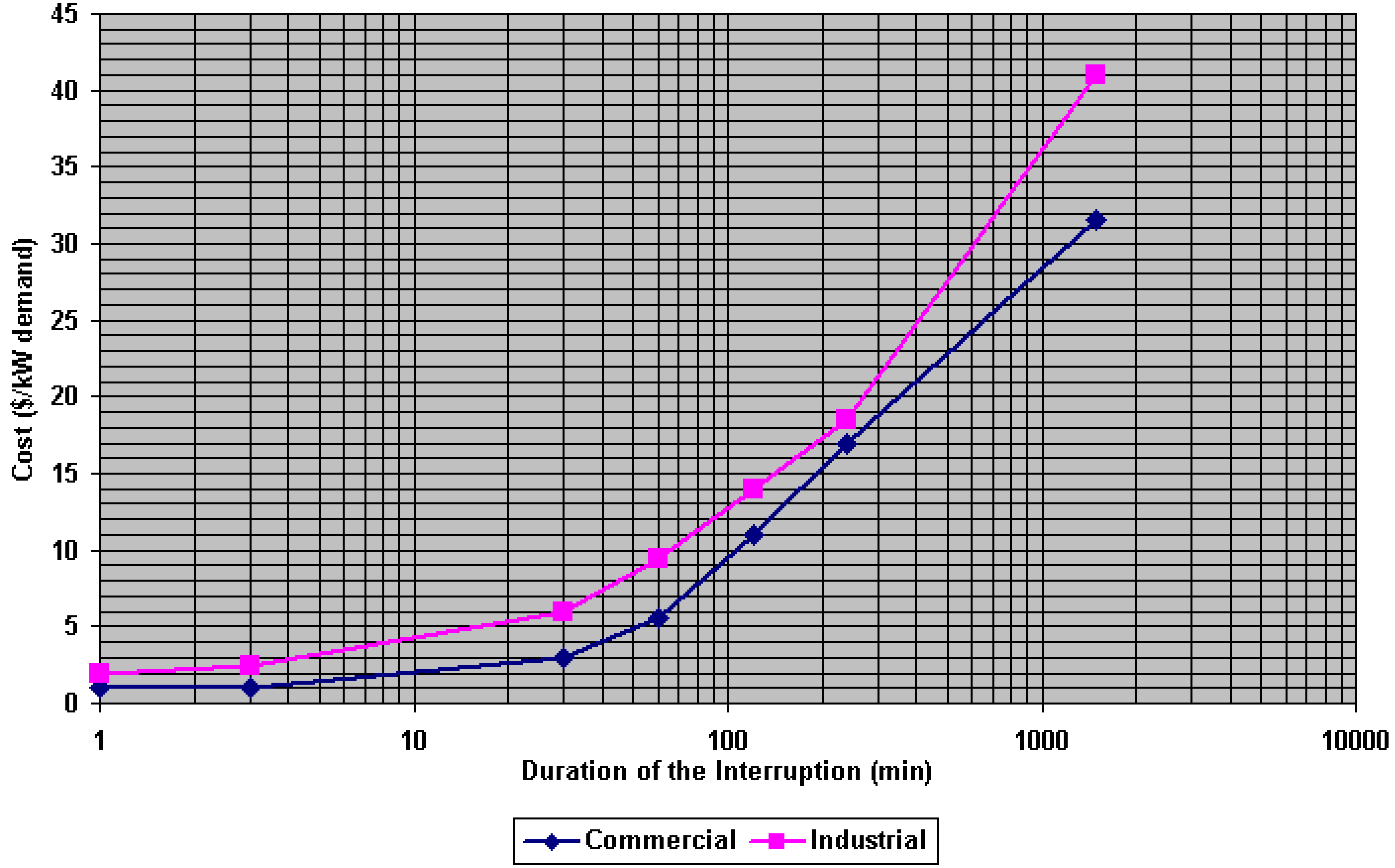
	Minimum	Maximum
Industrial		
Automobile manufacturing	5	7,5
Rubber and plastics	3	4,5
Textile	2	4
Paper	1,5	2,5
Printing (newspapers)	1	2
Petrochemical	3	5
Metal fabrication	2	4
Glass	4	6
Mining	2	4
Food processing	3	5
Pharmaceutical	5	50
Electronics	8	12
Semiconductor manufacturing	20	60
Services		
Communication, information processing	2	3
Hospitals, banks, civil services	0,5	1
Restaurants, bars, hotels	0,1	0,5
Commercial shops	1	10

Cost of momentary interruption (1 minute)

in $/kW demand

Source: Electrotek Concepts

Power Quality Costs



Costs of interruptions vs. duration