

EFFECTS OF VOLTAGE SAGS, SWELL AND OTHER DISTURBANCES ON ELECTRICAL EQUIPMENT AND THEIR ECONOMIC IMPLICATIONS

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ABSTRACT

Poor power quality has come to stay in most parts of the world. In most part of Africa, especially in Nigeria, it is almost normal not to have good clean power free from disturbances. If power equipment and loads could talk or express feelings, I am sure they would have made a big protest against the great injustices imposed on them. A survey was carried out amongst 15 multi-national companies in southwest Nigeria to ascertain the cause(s) and effects of poor power quality on electrical equipment and its economic implications. The survey revealed that 9 out of 15 of those companies loose an average of 5 variable speed (AC) drives every year owing to poor power quality. It also revealed that the most common disturbances faced are voltage sag and swell. This paper is aimed at stating some of the predominant power disturbance parameters, their sources and causes, the effect they have on electrical equipment, and their cost/economic implications. It also identifies some practical solutions and methods of addressing poor power quality issues

INTRODUCTION

Most people take the electrical supply for granted and expect it to be available at the flick of a switch. However, some businesses like share dealing houses, hospitals and continuous process lines, are so reliant on electricity that they have to provide safeguards to ensure that an emergency supply is always available. Generally, in industry, power quality is very low on the list of priorities and so very little attention is given to it, **until something goes wrong**. Much of the electrical equipment in an industrial facility requires high-quality electricity; it will not tolerate sags, swells, transients, or harmonics, and it certainly will not tolerate power outages, no matter how short-lived. Recognizing the limitations of grid-delivered power and the fact that 80 percent of all power quality and reliability problems occur inside end-user's facilities, it behooves all maintenance and reliability managers to understand the power quality susceptibilities within their facilities and of their key equipment. The remaining part of the paper will analyze each type of power defect with an explanation of how the problems occur and suggested preventative measures that can be considered.

POWER QUALITY PARAMETERS

Even the best distribution systems are subject to changes in system voltage from time-to-time. Voltage changes can range from small voltage fluctuations of short duration to a complete outage for an extended period of time. The following industry terms can be used to describe given voltage conditions.

Voltage dip: A voltage dip is used to refer to short-term reduction in voltage of less than half a second.

Voltage sag: Voltage sag is used to relate long-term reduction in voltage.

Voltage swell: Voltage swell is an increase in voltage outside normal rated tolerance of an equipment.

Voitage 'spikes', 'impulses' or 'surges': These are terms used to describe abrupt, very brief increases in voltage value

Voltage transients: They are temporary, undesirable voltages that appear on the power supply line. Transients are high over-voltage disturbances (up to 20KV) that last for a very short time (milliseconds or nanoseconds). Hence, the term 'spike' can also be used.

Harmonics: The *fundamental frequency* of the AC electric power distribution system is 50 Hz. A *harmonic frequency* is any sinusoidal frequency, which is a multiple of the *fundamental frequency*. Harmonic frequencies can be **even** or **odd multiples** of the sinusoidal fundamental frequency.

The following sections will discuss the causes and symptoms of each power disturbance parameter and the methods of preventing/minimizing their effects on power equipment.

Voltage dips, sags and surges

Most electrical power generating authorities have an obligation to supply consumers from the grid at a constant voltage (typically within +/- 6% of nominal). However, sometimes this is not practical, particularly in rural locations. Sometimes voltage sags are caused by the power supplier during times of heavy demand, while dips are often

caused by auto closers, operating within one second of fault detection. It is also possible for heavy plant to pull down the supply voltage during start-up. Compressors and pumps are good examples of loads, which require a high start-up current and switch in and out on a frequent basis, causing the supply voltage to dip. A dip is used to refer to a short-term reduction of less than half a second, whilst sag relates to a long-term voltage reduction.

Causes of dips, sags and surges

1. Rural location remote from power source
2. Long distance from a distribution transformer with interposed loads
3. Unreliable grid system
4. Power distributors tolerances not suitable for voltage sensitive equipment
5. Switching of heavy loads
6. Unbalanced load on a three phase system
7. Equipment not suitable for local supply

Methods of dealing with dips, sags and surges

1. Transformer with a tap changer
2. Constant voltage (ferro-resonant) transformer
3. Servo controlled voltage stabilizer
4. Switch mode power supply
5. Saturable reactor
6. Soft starters on larger electrical equipment
7. Connect larger loads to points of common coupling
8. Choose equipment with dip resilience

Symptoms of dips, sags and surges

1. Production rates fluctuates
2. Equipment does not operate correctly
3. Dimming of lighting systems
4. Variable speed drives close down to prevent damage
5. Relays and contactors drop out
6. Unreliable data in equipment test

Transients and spikes

Transients are high over-voltage disturbances (up to 20 kV) that last for a very short time (milliseconds or nanoseconds). Hence the term "spikes" can also be used. They are potentially destructive and can cause electronic systems to fail. In about 80% of cases transients can be attributed to on-site activities.

Causes of transients and spikes

1. Lightning
2. Switching-on heavy or reactive equipment such as motors, transformers, motor drives or power factor correction equipment.
3. Arc welding
4. Electric grid switching

Methods of preventing transients

1. Good earthing
2. Chokes or ferrites
3. Transient voltage surge suppressors

Effects of transients

1. Damage of electronic equipment
2. Corruption of data
3. System failure
4. Rejection of work through process interaction

Harmonic pollution

The vast majority of radiated emission problems are caused by voltages and currents with non-sinusoidal wave forms. Digital circuits and switch mode power supplies, in particular, generate almost square waveforms with fast rise times. The problem with a square waveform is that it really comprises a collection of sine waves at different frequencies, added together. The various frequencies are all multiples of the main or fundamental frequency and so there are first harmonics which have twice the fundamental frequency, second harmonics which have three times the fundamental frequency and so on (e.g. fundamental = 50Hz, 1st = 100Hz, 2nd = 150Hz). Wave forms which are perfectly symmetrical only have odd harmonics. Asymmetrical wave forms have both even and odd harmonics.

Harmonics are undesirable for many reasons but because effects of harmonics on the mains supply are cumulative, one the most serious problems is the overloading of supply cables.

Nowadays, computers, televisions, fluorescent tubes with electronic ballasts and inverter drives for motors have a switch mode power supply inside them. This produces a DC voltage and then chops it up again into high frequency square waves. Capacitors are used to store power and smooth the DC.

Consequently, current flows only for a short time when the capacitors require topping up and there is a resulting high peak current but with a low RMS current load. These peaks from different equipment on the supply are cumulative.

With the proliferation of electronic equipment, particularly those listed above, this has caused the regulations on harmonic pollution to be tightened by the Electricity Supply Authorities. Without these restrictions it would have been necessary to replace the entire supply cable network.

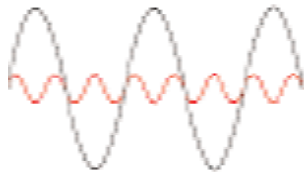
The flow of current at low frequency, through a conductor, is equally distributed across its cross-sectional area. However at higher frequencies the current tends to concentrate towards the surface of the cable. This phenomenon is known as the "skin effect". As a consequence the impedance of the conductor rises and this

has the effect of increasing the voltage drop and harmonic distortion. Long lines also mean higher impedance and so the voltage disturbances from inrush currents, when a large motor starts-up for instance become more significant. Switch mode power supplies and variable speed drives connected to end of a long cable run will also result in higher harmonic voltage distortion.

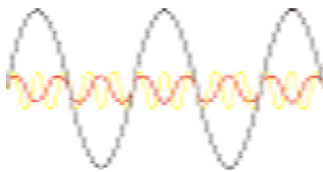
Take a 50Hz sine wave



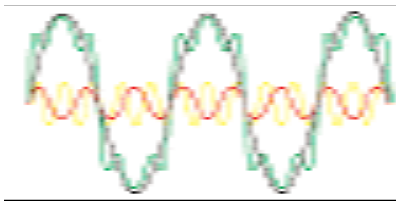
Add some 3rd harmonic



Add some 5th harmonic



The result is a distorted sine wave (shown in green)



Causes of harmonic pollution

1. Switch mode power supplies
2. Televisions
3. Computers
4. Fluorescent lamps with electronic ballasts
5. Energy saving bulbs
6. Variable speed drives
7. Thyristor controls for heating and ovens
8. Welding equipment
9. Rectifiers
10. Light dimmers

11. Small Uninterruptible power supplies
12. Phase angle controls

Methods of preventing harmonic pollution

1. Passive filters
2. Input chokes
3. Delta/star isolation transformers
4. Equipment with built-in power factor correction
5. Active conditioners
6. Avoidance of long cable runs to suspect equipment

Symptoms of harmonic pollution

1. Overheating of conductors
2. Overheating of transformers at moderate load
3. Overheating of motors
4. Incorrect operation of process control equipment using zero crossing synchronization
5. Nuisance tripping of protective devices
6. Current flowing in neutral conductor due to triplen causing unbalance of the three phases
7. Incorrect power measurement
8. Over stressing of power factor correction capacitors
9. Supply sine wave distortion
10. Skin effect in conductors

COST/ECONOMIC IMPLICATIONS OF POOR POWER QUALITY

Clearly, in a business environment, the equipment in use has to be resilient to the normal characteristic defects of the supply and this is not the case with off-the-shelf equipment. The cost of correction is much lower if corrective action is taken at the design stage of the equipment but this requires knowledge of the nature and probability of defects. It is this knowledge that is missing. This is, however, the most cost effective approach.

Some equipment makers are recognizing the problem but the competitive market means that manufacturers will only respond to customers' requirements. Until customers understand the problems and realize that equipment suppliers can provide a solution, they will not specify improved performance. The exception is the variable speed drive market where manufacturers are actively promoting products with enhanced dip ride through.

Implications of poor power quality

Some of the implications of power quality especially related to power factor and harmonics are:

1. Increase in line & equipment current leading to additional ohmic losses
2. Increase in line & equipment current leading to blocked capacity and/or increased capital investment.

3. Increased losses leading to higher operating temperatures and consequent reduction in life of equipment.
4. Premature failure of equipment due to increased electrical and thermal stresses.
5. Mal function of equipment
6. Poor quality of production
7. Unplanned outages leading to loss of production.

General benefits of power quality improvement

1. Reduction in line & equipment currents and losses and hence lower energy bills
2. Release of blocked capacity and consequent avoided cost of capital investment
3. Improvement in power factor and avoided penalty for low power factor or incentive for high power factor.
4. Reduction in maximum demand and reduction in demand charges.
5. Tax benefits such as accelerated depreciation benefits for installation of power conditioning / energy saving devices.
6. Improvement in voltage profile and consequent efficient operation of power equipment.
7. Reduction in harmonic distortion and consequent reduction in copper loss, core loss and stray loss.
8. Prevention of malfunction of equipment and avoided loss of production.
9. Elimination of unplanned outages and reduction in loss of production and revenue.
10. Reduction / elimination of failure of equipment due to reduced electrical and thermal stress.
11. Enhanced life / reliability of equipment due to lower operating temperature due to lower losses

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CONCLUSION

As already highlighted, the various power disturbance parameters can have very serious cost implications if not tackled. Equipment manufacturers are saddled with the responsibility to incorporate, from design stage, devices that could help minimize the effects of poor power quality. This could be expensive but in special cases where the need justifies the expense, it may be possible to arrange an alternative power source aside the grid where the various power disturbance parameters could be minimized.

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