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Study of Effects of Harmonics on Power Quality and its Monitoring

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Abstract: *With rapid growth in power electronics in recent times, Power quality become very emerging issue for power engineers as well as consulting engineers. It deals with utility and facility of network interconnections. This paper describes about the extent of voltage variation, current variation and frequency variation in power system. It deals with the power interruptions which is a major problem of power quality. The factors causing power deficiency is described in detail. By the help of this paper we can understand about the power quality as how it is best and how it became worse. We can also know about the importance of power quality and how it affects the power system.*

Keywords: *Harmonics, Power quality (PQ), power interruption, overvoltage, PQ monitoring*

I. Introduction

The term power quality can be described as the extent of variation of voltage, current and frequency. It is defined as the pure sinusoidal waveform of declared voltage and frequency. The pure sinusoidal wave become ideal now as it can only be seen in books. As we know we cannot conveniently store electrical energy anywhere so it needs a continuous flow and hence cannot be put through quality assurance checks before it is used. This creates problems in power quality known as power deficiency. There are five types of power deficiencies, each with different causes and effects and, of course, different cost implications. The estimated power quality problem causes around 10 billion euro in European countries per annum with 5% relative increment.

II. Power Quality Issue

The power quality maintains some important tasks in the power system. Increased system integration and complexity leading to proliferation of sophisticated sensitive electronic equipment, increasing emphasis on the efficiency and reliability. Growing awareness of users, Time and cost associated with 'quality power'. The power deficiency is a result of distortion in sine wave. The culprits of distorting sine wave are as follows

- nonlinear devices
- electronic chokes, CFL
- single phase power supplies (SMPS)
- Three phase converters, VFD, DC drives, UPS
- Arc furnaces

There is a paradox that performance and control of digital and nonlinear devices require clean (meaning sine wave) supply but conditioners themselves are polluters. The power quality is best at initial stages but when we talk about distribution system it gets worse. Most problems are caused by grounding and wiring. Poor power quality is due to the extreme demand of power for higher efficiency in various electronic devices. Most sensitive loads are at the branch circuit level and the voltage event monitoring can be done at the receptacle.

2.1 Power Interruption

Power interruption is the most significant problem of power quality. It continues for a few cycles to few hours. The variation may vary from 2-3 cycles to 1 hour but the disruption caused by it remains the same. During the critical conditions, considering the installations of power distribution, complete shutdown can take place from a single on site component or equipment or any cable connection. This shutdown can affect many areas. So in order to protect from these types of problems, two actions are preferred to be taken like, Design to eliminate single power failure and Identifying risk at single points and availability of power backup at those places.

2.1.1 Basic Design Conditions to Overcome Power Interruptions

In order to overcome the power interruptions some basic designs are needed. In the basic design we should consider some parameters on which power interruptions depend.

- **Safety:** The power system should be the safest one.
- **Reliability:** The power system should be designed in such a way that it can respond and recover any fault as fast as possible. It should have certain features which are consistent when used at its maximum and compatible with plant requirements and justifiable cost.
- **Flexibility:** This term means when there is improvement in system requirements, the power system adapt it very soon.
- **Maintenance:** Inspection and repairing of system should be done at regular interval for the proper maintenance.
- **Simplicity of Operation:** The operation of the system should be simple to implement to meet the system requirements.
- **Firm Cost:** All the above points should be considered and the best of it should be selected in addition to the initial cost of the system.

2.2 Over Voltage/Under Voltage

The supply voltage above the rated voltage of the system is overvoltage and the supply voltage below the rated voltage is undervoltage. These conditions take place when there is presence of over loaded generating system in the distribution network.

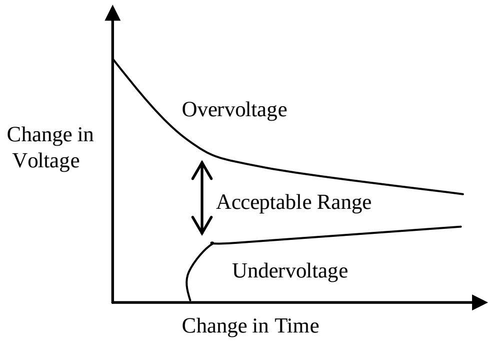

Fig. 1. Levels of Voltages

The dynamic characteristics of the system must recognize the proper utilization of voltage supply in all parts of the equipment under all operational conditions. For the proper regulation and control compensators are used which raise the voltage when load increases and lower the voltage as load decreases. These variations are generally occur in primary system. The modern equipment can tolerate large supply voltages and frequency bands typically -5% to +5% of voltage and -3% to +3% of frequency.

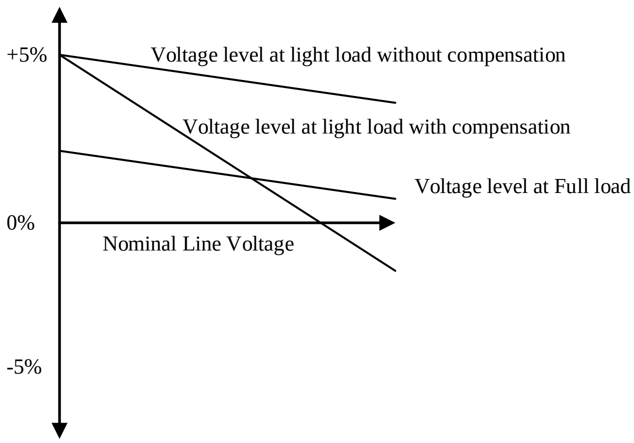

Fig. 2. Effect of compensation on primary distribution system voltage.

Table 1.Voltage Profile

Voltage Magnitude	Duration
Over Voltage Range	
>140%	1 msecs
120-140%	3 msecs
110-120%	0.5 msecs

Normal Range	
90-110%	Continuous
Under voltage Range	
<70%	20 msecs
70-80%	0.5 secs
80-90%	10 secs

2.3 Voltage Dips/ Sags

Voltage dips are the short term reductions in the RMS magnitude of supply voltage lasting from fraction of seconds to several seconds. Voltage dips occurs in two forms: swell and sag. Voltage swell occurs when a major load is disconnected. For the correction of this auto tap changing devices are used. It is operate with delay to bring it to safe limits. Within this time voltage sag and swell occurs. Voltage sag occurs at the time of starting of heavy motor. It lasts for few numbers of cycles. Other loads also affect when voltage is already low.

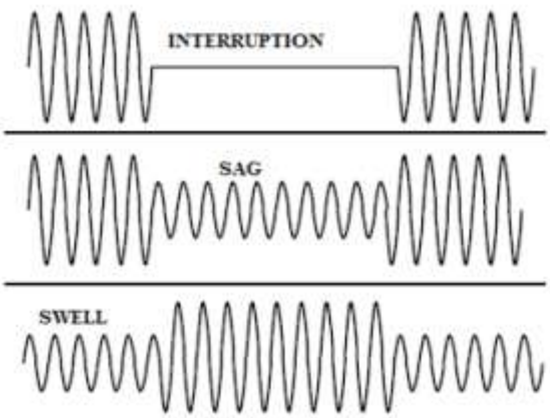

Fig. 3. Voltage Unbalance

Table 2. Voltage Unbalance

Categories Defined In IEEE- 1159		
	Duration	**Voltage Magnitude**
Short-Duration Variations		
Instantaneous		
Sag	10ms to 600ms	0.1 to 0.1pu
Swell	10ms to 600ms	1.1 to 1.8pu
Momentary		
Interruption	10ms to 3s	< 0.1pu
Sag	600ms to 3s	0.1 to 0.9pu
Swell	600ms to 3s	1.1 to 1.8pu
Temporary		
Interruption	10s to 1min	< 0.1pu
Sag	10s to 1min	0.1 to 0.9pu
Swell	10s to 1min	1.1 to 1.8pu
Long Duration Variations		
Sustained Interruption	> 1min	0.0pu
Under voltage	> 1min	0.8 to 0.9pu
Over voltage	> 1min	1.1 to 1.2pu

2.4 Transients

Transients are disturbances of very short duration (upto a few milliseconds) but high magnitude (upto several thousand volts) with a very fast rising time. Transients occur due to lightening strokes or switching of heavy and reactive loads. The damage results catastrophic failure of electrical plant or corruption of data within computers or network cabling. Insulation failure also occurs a little.

Protective devices are used in networks to prevent system from transients and kept it to a safe level. An earthing system with low impedance is designed over a wide range of frequency in order to prevent system from transients.

2.4.1 Causes & Effects of Transient

- Utility transformer tap switching
- Capacitors switching on
- Motors switching off
- Switch and relay contact " bounce"
- Damage semiconductor junctions
- Corrupt data signals

2.5 Harmonics

Harmonics are multiples of fundamental frequency. Harmonics are caused due to the distortion of normal sine wave of voltage and current. Any non-sinusoidal periodic signal contains harmonics. It is caused by nonlinear loads on electricity supply system. Voltage harmonics are created by current harmonics which are generated by non-linear load. Harmonics greatly increases the eddy current losses in the transformer as it proportional to the square of frequency of the system. There are even and odd harmonics also .even harmonics (2,4,6..) are not present even in case of non-sinusoidal waveform provided half cycle symmetry exists. Odd harmonics may be present even if even harmonics are absent.
Generation of the harmonics above the limits which is prescribed in Standards, is of great concern from both point of view i.e. power companies and power consumers. Power companies would never like to put themselves in situation to pay penalties or in a position of responsibility. On the other-side, due to problems caused by harmonics, power consumers do not prefer expense and inconvenience which may be due to the presence of interference, loss of life of equipment.

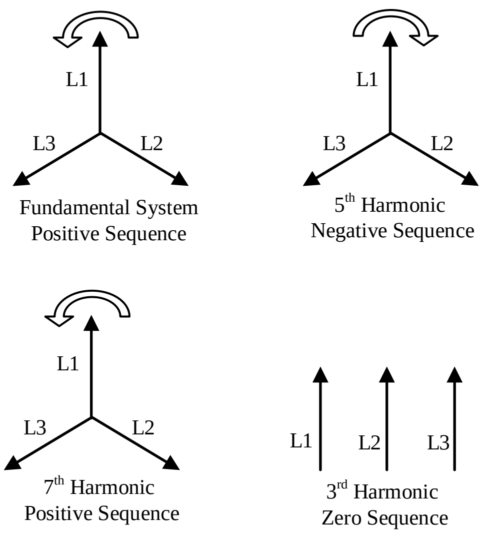

Fig. 4. Harmonic Sequences

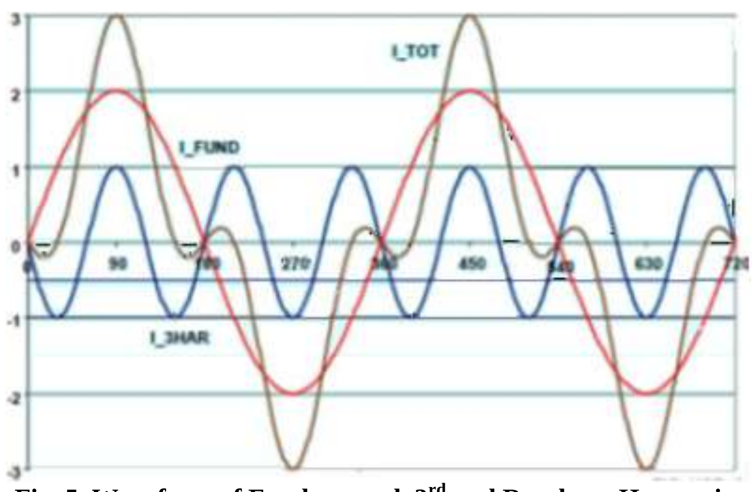

Fig. 5. Waveform of Fundamental, 3^{rd} and Resultant Harmonics

Table 3. Harmonic Magnitudes

Non Multiple of 3		Multiple of 3		Even Harmonics	
Order n	%	Order n	%	Order n	%
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.5	15	0.3	6	0.5
13	3	21	0.2	8	0.5
17	2	>21	0.2	10	0.2
19	1.5			12	0.2
23	1.5			>12	0.2
25	1.5				
>25	0.2				

2.5.1 Problems with Harmonics

Overheating: Neutrals, transformers, motor, capacitor, Potentially inaccurate measurement of current and voltage, Flat-topped voltage reduces power supply, Harmonic frequencies combine with the fundamental sine wave to form distorted wave form.

2.5.2 Creators of Harmonics

- Computer loads
- Light dimmers
- Fluorescent lamps
- Power electronic equipment
- Generators

Table 4. Classification of Harmonics

Harmonics	Frequency	Sequence
1^{st}	**60**	+
2^{nd}	**120**	**-**
3^{rd}	**180**	**0**
4^{th}	**240**	+
5^{th}	**300**	**-**
6^{th}	**360**	**0**
7^{th}	**420**	+
8^{th}	**480**	**-**
9^{th}	**540**	**0**

2.5.3 Effects of Harmonics

Harmonics in power systems can be the source of a variety of unwelcome effects. For example, harmonics can cause signal interference, over-voltages, data loss, and circuit breaker failure, as well as equipment heating, malfunction, and damage. Harmonics have been known to be responsible for noise on both telephone and data transmission lines, and they can induce malfunction of relays and meters. Presence of harmonics can cause excessive heating in transformers and capacitors, which have adverse effect on life of equipments or even can cause failure of equipments; circuit breakers can trip or malfunctioning occur; computers can fail and metering can give false readings. Due to harmonics, flickering effect can occur in lighting and in electronic displays. If the appropriate reasons for the above symptoms are not known then it is required to investigate the harmonic distortion of the electricity distribution at the plant. These effects are likely to show up in the customer's plant before they show on the utility system.

2.5.4 Effects of Harmonic Sequences

Table 5. Effects of Harmonic Sequences

Sequence	Rotation	Effects
Positive	Forward	Heating of circuit breakers, conductors lugs etc.
Negative	Reverse	Heating of conductors, motor problems.
Zero	None	Heating of conductor, current adds in neutral to 3ph-4 wire system.

III. Power Quality Monitoring

The increased concern for PQ has resulted significant advances in monitoring equipment that are used to characterized disturbances and variation in PQ. Power monitoring helps in analyzing disturbances and waveform, gives PQ information about statistical summaries and PQ characteristics. It also helps in characterizing sensitivity of the equipment used to know about PQ variations. PQ variations such as momentary interruptions, voltage sags, capacitor switching transients, and harmonic distortion can impact customer operations, causing equipment malfunctions and significant costs in lost production and downtime.

3.1 Objectives

• Quantify the quality of power
• Provide an early warning
• Remedial actions are provided

3.2 Power Quality Measurement Techniques

• **Oscilloscopes** – These are used to record waveforms with high frequency transients valuable for PQ monitoring.
• **Disturbance recorders/ Power quality analyser** – It is a part of protection relays. These are portable meters used to control units of SCADA.
• **Harmonic meters**– It provide detailed harmonic information about the voltage or current being measured.
• **Multimeters**– It is used to conveniently check the voltages and currents throughout the system provide a true rms reading.

3.3 Power Quality Enhancement Techniques

• Passive tuned / active harmonic filters.
• Reactive power compensation – switched capacitor, static var compensators
• Power flow control – flexible ac transmission systems (FACTS)
• Surge suppressors Use of power conditioners – UPS, Voltage stabilizers, BESS, SSVR, Transfer switch
• Proper sizing of electrical equipment
• Proper earthing practices

3.4 Industrial Applications of PQ Monitoring

• Energy and demand profiling with identification of opportunities for energy savings and demand reduction.
• Harmonics evaluations to identify transformer loading concerns
• Harmonic problems indicating misoperation of equipment (such as converters), and resonance.
• Power factor correction evaluation to identify proper operation of capacitor banks, switching concerns, resonance concerns, and optimizing performance to minimize electric bills.
• Short-circuit protection evaluation to evaluate proper operation of protective devices based on short-circuit current characteristics, time-current curves, etc.
• Voltage sag impacts evaluation to identify sensitive equipment

Table 6. Limits of Disturbances

Type of Disturbance	Acceptable Limits	Monitoring Period	Acceptable Percentage
Frequency variation	49.5 Hz – 50.5 Hz	1 week	95%
Slow voltage variation	+/- 10%	1 week	95%
Voltage dips	10-100 per year	1 year	100%
Short Interruption voltage	10-100 per year	1 year	100%
Long interruption voltage	10-50 per year	1 year	100%
Voltage unbalance	2%-3%	1 week	95%
Harmonic voltages	THD < 8%	1 week	95%

IV. Conclusion

The harmonics are unavoidable part of output sine wave but effort is to mitigate to acceptable limits or even better and maximize the system performance. This paper dealt with the various aspects of power quality and the problems which hampers the quality of power. Analysis of about almost all Power Quality issues in detail like power interruption, voltage dips, transients and harmonics can be carried out by monitoring it at various stages. Thus steps can be taken so as to how we can solve such problems. There is a brief discussion on power monitoring and enhancing which help to study the dimensions of power quality in detail. Thus by adopting use of proper devices the power quality can be maintained to improve the overall system performance

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