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Various Factors Responsible for Degradation of Power Quality in Power Sector

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Abstract

Electrical power is the basic and urgent need of the country due to the industrial revolution. Every sector whether it is industrial, commercial or domestic depends profoundly on power because all require power for their existence in this world. As the number of industries employing non-linear loads is increasing day by day and is expected to increase dramatically in the years ahead, it has become essential to set up criteria for limiting problems associated with these loads from system voltage degradation. These loads generally add harmonics into the supply and hence all the other consumers in the vicinity of these loads get affected. In this paper, the various power quality problems along with the monitoring of these various loads connected at the consumer end have been discussed. Further, it will also discuss the harmonic distortion problems associated with power quality which creates several disturbances in the power system. The main thought has been impressed upon the factors responsible for degradation of power quality, the power quality indices, harmonic measurements in case of non-linear loads and related IEEE standards for current and voltage limits.

Keywords: Power Quality, Harmonics, Voltage Sag, Voltage Swell, Power factor, Total harmonic distortion.

1. Introduction

The power quality has to ensure the continuity of supply in transmission and distribution networks and should aim to compensate customers for long term supply interruptions and create incentives to reduce the total time duration of these interruptions. The power quality concept is exceedingly imperious to industrial and commercial designs of power system. The non-linear loads are increasing day by day especially in case of electronic devices for the power system control [1]. For the both consumers and the utility which supplies them, the power quality issues are different. When the large number of non-linear loads like induction or arc furnaces is connected in the vicinity of each other, the quality of power is badly affected. These non-linear industrial loads are usually connected in high voltage networks and can affect a large number of consumers connected to the same interlinked network. If a facility has more than 15% non-linear load, then a harmonic study should be performed before applying the power quality solutions. Even the most advanced transmission and distribution systems are not able to provide electrical energy with the desired level of reliability for the proper functioning of the loads in modern society [2]. Harmonics are the odd multiples of fundamental frequency present in the voltage/current waveform. Due to the presence of harmonics, the waveform gets distorted and this becomes a potential source for poor power quality.

2. Power Quality Characterization at Various Levels

As none of the device is 100% immune, thus all devices are liable to power quality. As of now, no power system network exists in which there are no power quality problems. The immunity of equipment has a close but opposite relationship with power quality. Thus proper optimization between the two should be there. Many problems may be avoided if proper care should be taken to balance these two indices during the designing process of any facility. The following table I shows different categorization of equipment immunity and their corresponding power quality indices.

Table I: Different Equipment Immunity Indices.

S. No.	Category	Equipment immunity issues	Corresponding Power Quality Indices
1	Low	Data processing equipment, Signal conditioning, Medical equipment	Main switchboard, Lighting power distribution boards
2	Medium	Solid state relays, PLCs, Variable speed drives	HVAC control panels
3	High	Transformers, Motors, Heating loads, Lighting etc.	Panels supplying VSDs, elevators, lifts, large motors

The power quality problems can be mitigated at the various levels if certain preventive measures can be taken as shown in the Table II below.

Table 2: Different Levels Of Power Quality Problems.

S. No.	Event Level	Proposed Preventive Measure
1	Transmission	Assure grid accuracy
2	Distribution	Develop certain codes and standards
3	Interfacing	Develop advanced interface devices
4	Load	Make end use devices less sensitive

Thus to minimize the level of PQ problems, adequate planning and maintenance is required at the transmission and distribution level. A USA based working group on quality of supply named as Council of European Regulators (CEER) refers continuity of supply as reliability and voltage quality as power quality. According to International Electro-technical Commission (IEC), the poor power quality is due to certain reasons that include interruptions, flicker, voltage unbalance, voltage sags (dips), voltage swells, frequency variation, harmonics, noise, voltage spike and switching disturbances. The various categories of power supply variations are shown in the Table III

Table 3: Various Categories Of Power Supply Variations.

Cause	Categories	Time Duration	Type
Transient	Impulsive Oscillatory	50 ns-1 ms 0.3 ms- 5µs	
Short duration variations	Voltage sag Voltage swell	0.5- 30 cycles	Instantaneous
Long duration variations		>1 min	Undervoltage, overvoltage
Voltage Unbalance		Steady state	
Waveform Distortion	Harmonics	Steady state	
Voltage fluctuation		Intermittent	

3. Observation of Various Power Quality Problems

The power quality is basically observed through the data collection and the type of cause i.e. voltage sag, voltage swell, interruption, harmonics etc. The equipment for every cause must have determined features so that the observation can be done in a specific way [3]. Power quality observation includes various concerns like organization and description of electrical instabilities, broadcast of instabilities, quantity movements, i.e. augmenting the number of observing points. The PQ observation could be mainly at two levels:

1. **Observation at system level**: The PQ can be measured at the global level and the voltage in every bus is measured and it is being assured that the voltage sag is within the acceptable limits.
2. **Observation at local level**: In this case, the PQ is being monitored at the local level i.e. it is being assured that whether the utility is supplying quality power as mentioned in the contract and to identify if the THD is within the acceptable limits etc.

Out of the many concerns of PQ, the main concerns are voltage sag and voltage swell. The voltage sags are resulted by abrupt increases in loads such as short circuits or faults due to motors starting or turning on of electric heaters. They are also caused by sharp increase in the source impedance typically caused by a loose connection. A typical voltage sag phenomenon is as shown in figure 1.

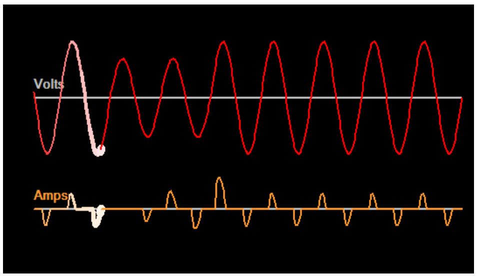

Fig. 1: Voltage sag phenomenon.

Voltage swells are generally caused by switching off any large load in the circuit or due to large capacitor bank activation. This generally happens when the voltage regulator is not working properly. Another reason for this is caused by any loose neutral connections in the main circuit [4, 5]. Voltage swell is quite dependent upon the system impedance, location of the fault or any other grounding issues resulting in the equipment failure due to overheating.

4. Harmonics Measurement & Its Effect on Power Quality

As earlier discussed, the large non-linear loads result in the production of harmonics thereby degrades the power quality [6]. Harmonics obstruct with the sensitive electronic equipment and networks. Various standards by IEEE and IEC have been adopted for the harmonic reduction techniques based upon the certain international standards. One of these standards is IEC 61000-3-2 which deals with the performance of any individual device connected in public domain. It puts a limit on every device to draw current harmonics from the supply mains. For the different types of equipment, this standard defines four different classes as shown in the Table IV and every class has different harmonic limit which is restricted and depending upon the power drawn by a device.

Table 4: Various Classes of Equipment.

S. No.	Class of Equipment	Categories
1	Class A	Balanced three phase equipment, Household appliances except class D equipment, Light dimmers, Audio devices, Incandescent lamps, Any other equipment other than B, C or D
2	Class B	Personal arc welding equipment, Portable mechanical tools
3	Class C	Lighting devices
4	Class D	Computers, Laptops, TV sets

Total harmonic distortion (THD) is one measure of the total distortion on waveform. It is defined as the root mean square (RMS) value sum of the harmonics, shared by one of two values either the fundamental or the RMS value of the total waveform. Due to this non-sinusoidal nature of waveforms, the devices attached to them in the power system perform poorly. As a result of this, the neutral conductors may overheat and transformers and motors become less efficient [7]. For the indication of harmonic severity and its waveform content, there are several definite measures used in practice [8]. The total harmonic distortion in current is given by the formula:

$$(THD_i) = \left[\frac{\sqrt{\sum_{n=2}^{\infty} I_n^2}}{I_1} \right];$$

where, I_1: Fundamental component of current; n: Harmonic order and I_n: Harmonic current.

The expression of power factor for non-sinusoidal quantities is given by:

$$PF = \frac{V_S I_{S1} \cos\phi_1}{V_S I_S} = \frac{I_{S1}}{I_S} \cos\phi_1$$

where, I_{s1}= fundamental component of current expressed as RMS value.

In the case of linear sinusoidal circuits having pure sinusoidal waveforms, the cosine angle between the voltage and current is measured as displacement power factor (DPF) instead of power factor, the expression of which is given by:

$$DPF = \cos\phi_1$$

Thus, the power factor due to non-sinusoidal current is expressed by:

$$PF = \frac{I_{S1}}{I_S} DPF$$

The RMS value of current and the power factor are expressed in terms of Total harmonic distortion expressed by the formula:

$$PF = \frac{1}{\sqrt{1 + THD_i^2}} DPF$$

where

$$I_S = I_{S1} \sqrt{\left(1 + THD_i^2\right)}$$

with the high harmonic current distortion. It can also conclude that power quality has direct impact on the power factor. The consequence of THD on voltage distortion has been shown in the Table V.

Table 5: Effect of THD On Voltage Distortion Limit.

Bus Voltage at Power Control Centre	**Individual Voltage distortion (%)**	**THD (%)**
Less than 69 kV	3	5
69-161 kV	1.5	2.5
More than 161 kV	1	1.5

Thus it has been clearly shown that, as the level of voltage increases, THD value decreases. Various schemes have been developed to monitor power quality. The compensation for voltage or current harmonics does not yield unity power factor. The best solution to this is to optimize the PF and THD. Thus, THD can be restricted within the specified limits while optimizing the power factor [9].

5. IEEE Standards for Voltage & Current Harmonics Limits

In order to measure the power quality, it is necessary to measure current, voltage, frequency, harmonic distortion and nature of waveform as power quality problems are not only restricted to harmonic distortion. The standard IEEE 1159 categorized various electromagnetic occurrences in power system i.e. impulses, oscillations, sags, swell, interruptions, under-voltages, over-voltages, harmonics, noise, flicker and frequency variation etc [10-11]. As per several standards of IEEE for non-linear loads, both current and voltage harmonics limits have been mentioned [12]. These standards define the various distortion limits. As shown in the following tables, the voltage distortion limits are meant for less than 69 kV as shown in Table V and current distortion limit in Table VI.

The limits of both the harmonics have been prescribed as per IEEE standards but the main dominant effect is due to odd harmonics in terms of current distortion [13]. The distortion limits are $I_{SC}/I_L<20$ for all power generation equipment, where, I_{SC} is the maximum short circuit current at PCC and I_L is the maximum fundamental frequency of load current at PCC.

Table 6: Current Harmonic Limits.

I_{SC}/I_L	h<11	11≤h<17	17≤h<23	23≤h<25	THD (%)
<20	4.0	2.0	1.5	0.6	5
20-50	7.0	3.5	2.5	1.0	8
50-100	10	4.5	4.0	1.5	12
100-1000	12	5.5	5.0	2.0	15

To measure the various disturbance levels, various standards have been adopted such as IEEE 1995, IEEE 1996, IEC 1999 etc. However, to record the level of harmonics at PCC, IEEE has modified the standards to IEEE 519 in which certain limits have been specified so that the other users can not be affected in the same vicinity. For individual harmonics, the THD limits have been restricted to 3% for individual consumers and the limit for voltage distortion is 5%. The limits under discussion are somehow different according to IEC in which the THD limit is 8% for individual consumers and also depends upon supply frequency.

6. Conclusion

For the consistent and economic operation of power system, the voltage and current waveforms should be pure sinusoidal and does not include any harmonics. But due to the increase in non-linear system loads, the waveforms get distorted from their original values results in increase in losses thereby decreasing the system efficiency. So, in this paper, an attempt has been made to discuss various types of loads that are responsible for power quality degradation and how their monitoring is to be done. The effect of harmonics on the power factor and hence power quality has also been discussed. The various distortion limits have been discussed as per IEEE recommendations.

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