Harmonic Measurement and Analysis of Variable Frequency Drive (vfd) in Industry

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Abstract- Utility of non-linear load leads to generation of harmonics in industry which is affecting the power quality as well as performance of devices like motors and controllers etc. Harmonic Measurement and analysis to obtain the harmonic content of current and voltage has become vital task in context with increasing power quality. This paper discusses the effect of harmonics on power system and the need of Identification of power system signals. Paper also highlights the importance of Harmonic Measurement and Analysis of Power Quantities. As a real case study the Variable Frequency Drive (VFD) data from industry is taken for analysis of harmonic contents voltage, current and power and results are discussed.

Keywords— Harmonics, Harmonic Measurement, Power Analysis, VFD.

I. INTRODUCTION

In electrical power system the impact of non-linear loads has been increasing during the last decades. Presently, power system and power quality have been concerned about harmonic pollution generated by modern electronic devices such as adjustable speed drivers, controlled rectifier etc. [1]. In ideal situation, the electric power in a network is supplied at a constant system frequency, and at specified voltage magnitudes known as the fundamental frequency, however, in practice under different circumstances the frequency and voltages are deviated from their designated values. The deviation of a wave form from its perfect sinusoid is generally expressed in terms of harmonics.

Harmonics in power systems is nothing but the existence of signals, superimposed on the fundamental signal, whose frequencies are integer numbers of the fundamental frequency. The presence of harmonics in the voltage or current waveform leads to a distorted signal for voltage or current, and the signal becomes non-sinusoidal signal which causes malfunctions or damage on load. Harmonic measurement is one of the well-known aspects of power quality monitoring and control [3]. To address the problem of harmonic measurement in non-stationary scenarios, a number of signal processing techniques have been proposed in recent years such as, Fast Fourier transform (FFT)[4]-[5] ,application of adaptive filters[7]-[9]. SVD [11] [14]. And wavelet based technique of [16] .Harmonic measurement and analysis in power systems is thus a major concern of power system administrators as well as engineers.

The paper is organized as follows: Section II describes the Effect of Harmonics on power system. In Section III A brief summary of Importance and need for identification of harmonic contents in power system signals for system performance , safety and power quality monitoring in power system is presented. Impact of harmonics on Variable frequency drive is presented in Section IV. Section V presents IEEE-519 Recommended harmonic limits. As a real case study the VFD drive data from industry taken and analyzed in section VI. Section VII concludes the paper.

II. EFFECTS OF HARMONCS

Due to the dramatic increase in the usage of nonlinear loads in industrial applications (mainly regarding Variable Frequency Drives or VFDs), the power system harmonics problems has increased its significance. This brings a big obstacle against the wide application of VFDs. The presence of harmonics on power system causes voltage and current distortion which leads to aging of Electrical appliances and damages to electrical apparatus. The effects of Harmonics are listed below.

1. Overheating of Electrical Equipment
2. Communication Interference
3. Resonance
4. Other (Installation of Capacitor Bank)

1. Overheating of Electrical Equipment

It is common to refer to heating as I^2R losses. Electrical equipment can be overheated by distorted load current that cause higher eddy current losses

inside the equipment. Skin effect causes harmonic current to flow uniformly across entire cross-sectional area of the winding conductor of transformer .Other results of heating are:
a) Overheating of generators, motors, transformers, and power cables that lead to early equipment failures
b) Excessive losses
c) Overheating of neutral conductors, and other electrical distribution equipment
d) Capacitor failures, tripping of circuit breakers and loss of synchronization on timing circuits.

2．Communication Interference

Magnetic (or electrostatic) coupling [between electrical power circuits and communication circuits can cause communication interference. Current flowing in the power circuit produces a magnetic (or electrostatic field that will induce a current (or voltage) in the nearby conductors of the communication circuit. The amount of interference will depend upon the magnitude of the induced current (or voltage), frequency [17], and the efficiency of the magnetic (electrostatic) coupling. Other types of communication interference are
a) Reduction of equipment operating reliability and service life
b) Induced line noise
c) Interference to communication systems, and sensitive electronic devices
d) Nuisance tripping to protection Relays and plant shutdown.

3. Resonance

Resonance occurs when a harmonic frequency produced by a non-linear load closely coincides with a power system natural frequency. There are two forms of resonance which can occur: parallel resonance and series resonance. Parallel resonance occurs when the natural frequency of the parallel combination of capacitor banks and the system inductance falls at or near a harmonic frequency. This can cause substantial amplification of the harmonic current that flows between the capacitors and the system inductance and lead to capacitor fuse blowing or failure or transformer overheating. Series resonance is a result of a series combination of inductance and capacitance and presents a low impedance path for harmonic currents at the natural frequency. The effect of a series resonance can be a high voltage distortion level between the inductance and capacitance. The interaction between capacitive and inductive devices at some harmonic frequency causes unexpectedly large circulating current in some parts of the circuit. Over voltage and excessive current leads to failure of capacitor banks and oil filled cables. Power factor correction capacitors with cable or apparatus

inductance may set up current amplifying resonance. A resonance condition can cause a current waveform to have zero crossings occur more than once every half-cycle the presence of harmonics because it is sensing a peak value that does not directly correspond to the rms value of the wave shape. Other consequences are:
a) Misoperation of electronic equipment
b) Inaccurate meter readings and errors in measuring equipment.
c) Misoperation of protective relays
d) Interference with motor controllers and telephone circuits.

4. Other (Installation of Capacitor Bank)

The application of capacitors on a power system in the presence of harmonic generating equipment produce a harmonic resonance condition [18]. Capacitive reactance decreases directly with frequency and inductive reactance increases directly with frequency. At the resonant frequency of any inductive-capacitive *(LC)* circuit, the inductive reactance will equal the capacitive reactance. In actual electrical systems utilizing power factor correction capacitors, both series and parallel resonance or a combination of the two may occur. Occurrence of resonance may cause such problems as
a) Capacitor bank and insulated cable failures
b) Excessive capacitor fuse operation, and
c) Dielectric breakdown or reactive power overload.

II．NEED OF FAST AND ACCURATE IDENTIFICATION OF FUNDAMENTAL AND HARMONIC QUANTITIES

In industrial and commercial power system fast and accurate identification of the signal is required for evaluation of initial and future system performance. It is also essential to study system reliability and finding its ability to grow with production for operating requirements. It is also required to ensure whether the system will operate safely, economically, and efficiently over the expected life of the system or not depending on following:

a) Power Quantities: In a power system, different measures of power quantities such as power frequency 60/50 Hz or fundamental of active, reactive, , and apparent powers are defined these three basic quantities are the quintessence of power flow in electrical networks and should be calculated based on the information embedded in voltage and current signals [19].

b) Detection of fundamental frequency: A power signal when distorted is consists of fundamental and one or more harmonics. Fundamental voltage and

current components should be properly detected to get fundamental power, harmonic and unbalanced quantities in many applications.

c) Analysis and power Quality Monitoring: A distorted wave consists of 5th and 7th harmonic and several other higher harmonics. In certain complex condition it consists of interharmonics and sub harmonics in such cases the energy of the signal at each constituting component is required for analysis and quality monitoring of the system.

A. Importance of Harmonic Measurement

Harmonic measurements are an important part of the overall investigation for a number of reasons. Most importantly, the measurements must be used to characterize the level of harmonic generation for the existing nonlinear loads as it provide a means for verifying the harmonic model. The specific objectives of the measurements include:

1. Determine the harmonic generation characteristics of the variable - frequency drives. Which can be done by performing the current measurements a variety of locations within the plant. Three- phase measurements can made so that characteristic and non - characteristic (triplen) harmonic components can be determined.

2. Determine system response characteristics for particular conditions and voltage measurements are used in conjunction with the current measurements, both to characterize the system response for specific system conditions. These conditions are then be the basis for verifying the analytical models.

3. Determine the background harmonic voltage and current levels.

B. Purpose of Harmonic Analysis

Harmonic Analysis/ studies are required in the following cases:

1.Ensuring system compatibility with the international standards as IEEE STD 519-1992 in order to meet the utility company requirements.

2. Solving a problem arising from a harmonics related issue (e.g. nuisance tripping of protection devices, etc).

3. Expansion of an existing electrical system by adding new harmonic sources (e.g. VFD's).

4. The analytical techniques used to analyze the measured data. There are two domains to analyze the harmonic contents, the frequency domain and the time domain. The frequency domain is used when the purpose of the study is checking the compatibility with the international standards. The time domain is used when a better understanding of the system wave shape and characteristics is required.

5. The presentation of the analyzed data.

III. VARIABLE FREQUENCY DRIVE

Variable frequency drives (VFDs) are widely used in industry for important loads in their operations [20]. VFD has great advantages such as speed control, energy saving and motor's starting current limitation. In spite of advanced technology and improved reliability of modem VFDs, they are considered not only as harmonic sources but also interharmonic sources. VFD converts 60 Hz power, for example, to a new frequency in two stages: the rectifier stage and the inverter stage. The conversion process incorporates three functions:

a) Rectifier stage: A full-wave, solid-state rectifier converts three-phase 60 Hz power from a standard or higher utility supply to either fixed or adjustable DC voltage. The system may include transformers if higher supply voltages are used.

b) Inverter stage: Electronic switches power transistors or thyristors - switch the rectified DC on and off, and produce a current or voltage waveform at the desired new frequency. The amount of distortion depends on the design of the inverter and filter.

c) Control system: An electronic circuit receives feedback information from the driven motor and adjusts the output voltage or frequency to the selected values. Usually the output voltage is regulated to produce a constant ratio of voltage to frequency (V/Hz). Controllers may incorporate many complex control functions
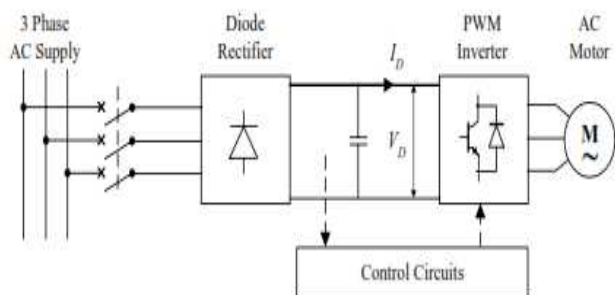

Fig.1 Variable Frequency Drive

A. Harmonics Produced By Variable Frequency Drive

The pulse number of the rectifier is the determining factor in what the characteristic power system harmonics will be or a particular drive. The harmonics produced by a six-pulse rectifier will be the 5th, 7th, llth, 13th, 23rd, 25th, etc. Their magnitudes are roughly the inverse of the harmonic order times the magnitude of the fundamental (e.g., the 5th harmonic is about one fifth of the fundamental current). A twelve-pulse drive will exhibit harmonics at the llth, 13th, 23rd, 25th, etc. Twelve-pulse drives will produce small amounts of 5th, 7th, 17th, and 19th harmonics (typically on the order of 10% of the levels
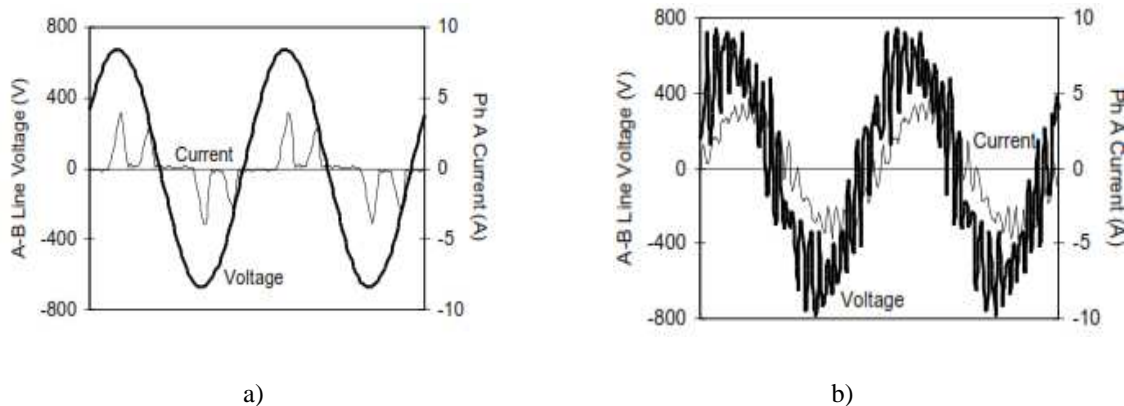
for a six-pulse drive).

a)   b)

Fig.2 Variable Frequency Drive a) line and b) load side waveform

B. Applications

Variable speed drives are used for two main reasons:

b) To allow accurate and continuous process control over a wide range of speeds.

To improve the efficiency of motor-driven equipment by m

IV. IEEE-519 EVALUATION OF HARMONIC DISTORTION AND RECOMMENDED HARMONIC LIMIT

To minimize the impact of facility harmonic distortion on utility power system and neighboring facilities, IEEE standard was developed in 1982 and updated in 1992.[22] IEEE 519 standard propose limits of current harmonic injection from end user / customer to supply grid so that voltage harmonic levels on overall power system remains within acceptable limit.[26] The practices are used for guidance in the design of power systems with non-

A. Current Distortion limits.

Table. I Current Distortion limits.

linear loads, such as adjustable speed drives and uninterruptible power supplies. The standard also discusses power system response characteristics, the effects of harmonics, methods for harmonic control, and provides recommended limits for harmonic current and voltage distortions.The following chart indicates the limits for harmonic current distortion imposed by this standard. The limits are based up on ratio of available short circuits current (Isc) at PCC to maximum demand load current (IL) The analysis is generally performed at the point of where facility power is connected to utility power system. This point generally called as PCC.

Maximum Harmonic current distortion (I_h) in % of I_L for Vn<69KV					
Isc/IL	h<11	11 ≤h<17	17 ≤h23	23 ≤h<35	TDD
<20	4	2	1.5	0.6	5%
20<50	7	3.5	2.5	1	8%
50<100	10	4.5	4	1.5	12%
100<1000	12	5.5	5	2	15%
1000 UP	15	7	6	2.5	20%

B. Voltage Distortion limits

Table. II Voltage Distortion limit

Bus Voltage at PCC (Vn)	Individual Harmonic Voltage Distortion (%)	Total Voltage Distortion THD Vn (%)
Vn <69 KV	3.0	5.0

V. CASESTUDY: Variable frequency Drive

Measurements were carried out at a typical Automotive Industry plant which is receiving power <1300 kVA @ 22 kV Voltage level and are served through transformers of 1 & 2 MVA each. Feeding the total load of the plant.. This modern plant is employing large No's. AC VFD for important loads in their operations. These drives are typically 6 Pulse. The predominant harmonic currents generated by these drives are typically 5th , 7th , 9th , and 11 th . It is a common practise to install capacitors banks across loads for power factor improvement this arrangement has lead to formation of resonant circuit with transformer inductance and further increase harmonic levels in the circuit. During power analysis same is witnessed in following Table III

Table III. Summary of Harmonic analysis

Parameters	Reading at PCC	
	With Capacitor ON	With Capacitor OFF
Voltage. (V)	22.3 KV	21.92 KV
Current. (I)	24. 39 Amps	33.33 Amps
Active Power (KW) Max.	932 KW	928 KW.
Apparent Power (KVA)Max	942 KVA	1266 KVA.
THD i %	16.10%	5.30%
THD v %	Nil	Nil
Predominant Harmonics		
5th	3. 66 Amps	1.72 Amps
7th	0. 42 Amps	0.3 4 Amps.

VI. CONCLUSION

This paper presented Harmonic measurement and analysis as one of the well-known aspects of power quality monitoring and control. From analysis of harmonics it is observed that Present harmonic levels at PCC are exceeding recommended levels. And 5th and 7th order harmonic are amplified due to use of PF improvement capacitors.

Also the information collected during an analysis can be useful for many applications.
1. Check for harmonics after system modifications
2. Look for harmonics or a tendency for harmonics on power system.
3. Provides data for harmonic filter design to reduce harmonics being injected in distribution system
4.THD level of < 5 % can be achieved by using properly designed filters under all working loads at PCC.
5. Develop a database for future studies.

Considerable information beyond a listing of harmonics is available from a harmonic measurement and analysis study.

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