Effect of harmonics on active power flow and apparent power in the power system

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ABSTRACT : *This paper presents an analytical method of calculating total harmonic active and apparent power in the power system in harmonic environment. Starting from the harmonic measurement strategies, the effect on true power factor is discussed. The harmonic active power flow in the system and accordingly, the locations of the sources of particular harmonics are found. Also, numerical results are obtained with reference to a case study of a steel industry with induction furnace as a nonlinear load.*
Keywords - *Active harmonic power, power flow, total apparent power.*

1. INTRODUCTION

A non-sinusoidal or distorted waveform is a mixture of periodic supply power frequency component and also aperiodic components such as constant dc offsets, decaying dc offsets & periodic harmonic components. The harmonics have frequencies which are whole multiples of supply power frequency. Each harmonic has four parameters such as order, magnitude, phase angle and sequence. The phase sequences are as follows:

Phase sequences   +   -   0   +   -   0   +   -   0 ...
Order of harm.   1   2   3   4   5   6   7   8   9 …

Harmonics are generated to a small extent and at low distortion level by generation, transmission & distribution equipments and to larger extent by the industrial & domestic loads like induction & arc furnaces, static power convertors, PCs & TV receivers. But harmonic currents generally flow towards supply because the source impedance is low. Traditionally, saturation of transformer core using energization is the main source of harmonics in power utility but increase in use of FACTs will add further contribution to harmonic distortion.

2. HARMONIC MEASUREMENTS

Harmonic distortion is a characteristic of the steady state voltage and current. It is not a disturbance.Therefore,characterizing harmonic distortion levels is accomplished with profiles of harmonic distortion over a time of 24hrs.Typically,harmonic current and voltages must be measured for every 10minutes or 15 minutes span for 24hrs. For most applications, it is sufficient to consider the harmonic range from 2nd to 25th but most standards specify upto 50th.

The amount of current /voltage distortion at the PCC depends upon several facts such as voltage level, type of non linear loads and its percentage composition in the total load. In most cases, measuring harmonics in any one phase is indicative of the harmonic content in the other phases if it is three phase balanced industrial load. However, typical office load is unbalanced, so individual phases must be measured.

Harmonic measurements should be made under a variety of load conditions. Harmonics may not be produced continuously, but the addition of high power equipment may be the occasion for drastic increase in harmonics .A reduction in plant loads may increase harmonics. Peak load periods may be a time of lower harmonics, because the high current leads may shunt off some harmonic currents.

While measurement of harmonic voltages and currents, it is important to note phase angles because harmonics with similar phase angles will superimpose, raising the harmonic level, while those with opposite phase angles will compensate each other, thereby lowering the harmonic level. Also, to evaluate harmonic flows throughout the system, to identify harmonic source and sinks, phase angles of each harmonic are required.

2.1 Harmonics and power factor

Power factor is a measure of how efficiently a load utilizes the current from AC power system. There are some utility rate schedules that offer incentives to large customers to improve power factor near 1 as it will improve overall efficiency. The largest contributors to low p.f. are reactive loads. But harmonics can also have an adverse impact on p.f. True power factor is the ratio of active power and apparent power. Displacement power factor is defined as cosine of phase angle difference between voltage and current. For sinusoidal voltage and current situation,

$$PF_{TRUE} = PF_{DISP}.$$

For non-sinusoidal voltage & current,

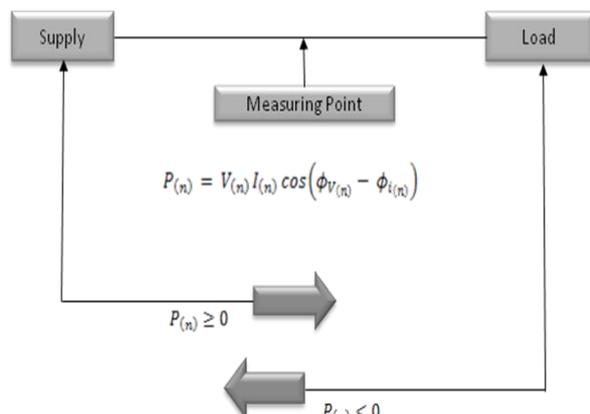$PF_{DIST} = (1/\sqrt{1+(THD_V)^2}) \times (1/\sqrt{1+(THD_I)^2})$

Except for extreme cases where THD_V exceeds 10%,

$PF_{DIST} = (1/\sqrt{1+(THD_I)^2})$

$PF_{TRUE} = PF_{DISP} \times PF_{DIST}$

Increase in current distortion will lower true power factor.

2.2 Harmonics and active power flow

Fig. 1.0 Principle of locating nth harmonic source on the basis of its active power measurement.

According to the direction of active power flow method, the dominant source of a given harmonic can be located by determining the direction of active power flow at various points of the system. A linear load supplied with distorted voltage draws active power for each harmonic. In this case, active power calculated is positive.(Active power of nth harmonic,P(n)>=0).If non linear loads exists at the customer side, the active power for some harmonics can be supplied to the network. Active power calculated is negative. (P (n) < 0).

Accordingly, voltage distortion source can be located at-
i. upstream of PCC
ii. downstream of PCC
iii. Both sides of PCC

2.3.Total apparent power

Suggestions given by an IEEE working group on harmonics, separates the fundamental quantities P1 & Q1 from rest of apparent power component .Separation of fundamental voltage & current harmonics from total rms values as,

$$V^2 = V_1^2 + V_H^2 = V_1^2 + \sum_{H \neq 1} V_H^2 \tag{1}$$

$$I^2 = I_1^2 + I_H^2 = I_1^2 + \sum_{H \neq 1} I_H^2 \tag{2}$$

By multiplication,total system apparent power S is expressed in the following form,

$$S^2 = (VI)^2 = (V_1 I_1)^2 + (V_1 I_H)^2 + (V_H I_1)^2 + (V_H I_H)^2 \tag{3}$$

$$\text{Also,} (V_1 I_1)^2 = S_1^2 = P_1^2 + Q_1^2 = (V_1 I_1 \cos\phi_1)^2 + (V_1 I_1 \sin\phi_1)^2 \tag{4}$$

where S1,P1,Q1 are fundamental apparent ,active and reactive powers respectively.

Three remaining parts of equation (3) is called as non fundamental power and defined as

$$S_N^2 = (V_1 I_H)^2 + (V_H I_1)^2 + (V_H I_H)^2 = S^2 - S_1^2$$

$$= V_1^2 \sum_{H \neq 1} I_H^2 + I_1^2 \sum V_H^2 + \sum V_H^2 . \sum I_H^2 \tag{5}$$

Harmonic apparent power S_H is given as,

$$S_H^2 = (V_H I_H)^2 = P_H^2 + N_H^2$$

$$P_H = \sum_{H \neq 1} V_H . I_H . \cos\phi_H \tag{6}$$

$$N_H = S_H^2 - P_H^2 = (\sum V_H^2 . \sum I_H^2) - P_H^2 \tag{7}$$

where P_H= total harmonic power

N_H=total non active power

3. CASE STUDY

To validate above, a case study of an industry having harmonic problems is considered. The industry considered is a steel industry having induction furnaces as a nonlinear load. Harmonic analysis is done at the various locations and at various load conditions in the plant that is both at H.V. side and L.V. side. The harmonic analyzer is connected on the H.V.side of 33KV incomer bus. The harmonic voltages and currents upto 15th order are recorded with phase angles. The furnace load is considered as a balanced ,hence single phase analysis is carried out.Table no.1 shows the readings.Also,the harmonic powers of each order is calculated.Fig.1 shows the graph for active powers calculated.

Table No.1 Readings for phase B

Harmonic Order	Voltage Harmonic (Volts)		Current Harmonic (Amp)	
2	10.62	177°	0.12	117°
3	77.88	140°	0.23	149°
4	19.47	119°	0.04	135°
5	196.47	80°	0.13	52°
6	10.62	121°	0.03	217°
7	40.71	360°	0.03	8°
8	17.7	102°	0.04	287°
9	21.44	169°	0.1	19°
10	35.4	151°	0.27	303°
11	131	71°	1.79	287°
12	44.25	187°	0.33	95°
13	60.18	43°	0.64	280°
14	3.54	156°	0.008	164°
15	46.02	125°	0.1	47°

Table No.2 System data

$V_{rms} = 17709V$	$V_1 = 17700V \angle 195°$	$V_{thd} = 2.39\%$
$I_{rms} = 44.040A$	$I_1 = 44.002A \angle 181°$	$I_{thd} = 5.08\%$
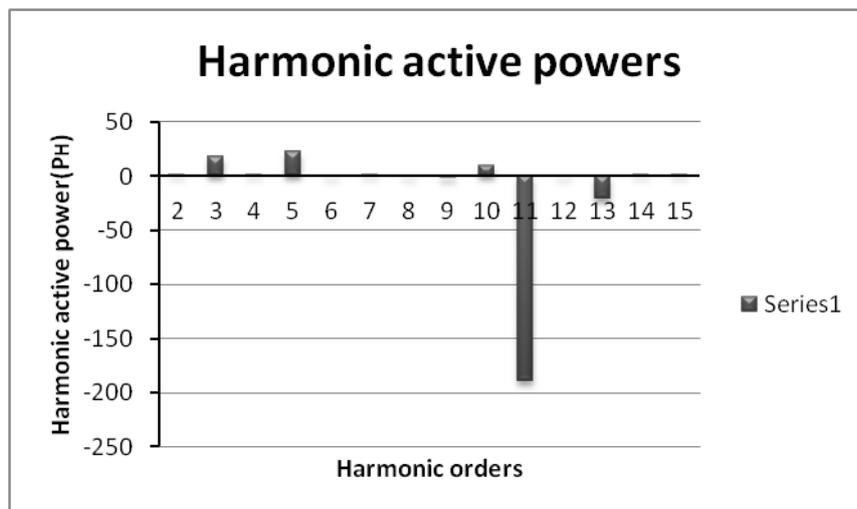
Fig 1: "Graph of harmonic active powers"

The graph indicates that some harmonic active powers are positive and some are negative. The negative active powers indicate that the load is harmonic source of that particular order. In this case, load is producing 6th, 8th,

9th, 11th, 12th and 13th harmonics.11th harmonic is dominent.Also,the $3^{rd},5^{th}$ and small 10th harmonics are found to be produced on generation or utility side.

3.1 Result

Now, using "equation (3),(7)", total apparent ,active and non-active powers are calculated. Table 2 shows the results obtained,

Table No. 3: Results obtained

Total system apparent power,S(KVA)	$V_{rms}I_{rms}$	779.904KVA
Fundamental apparent power S_1(KVA)	$V_1.I_1$	778.835KVA
Non fundamental apparent power S_N(KVA)	Calculated by $S_N{}^2 = S^2 - S_1{}^2$	32.385KVA
Total harmonic active power, P_H	$P_H = \sum V_H.I_H.\cos\square_H$	-160.4W
Total non active power,N_H (VA)	$N_H = S_H{}^2 - P_H{}^2 = (\sum V_H{}^2.\sum I_H{}^2) - P_H{}^2$	287.860VA
Total harmonic apparent power,S_H	$S_H{}^2 = (V_H I_H)^2 = P_H{}^2 + N_H{}^2$	239.03VA
Cross product power	$V_1{}^2\sum I_H{}^2$	1223.324KVA^2
Cross product power	$I_1{}^2\sum V_H{}^2$	142.938KVA^2

The total apparent power calculated from equations (3),(5) is
S=779.712KVA
This value is very close to the actual value calculated from the rms values.
Total active power calculated=755.540KW
True power factor calculated from total apparent and active power=P/S=0.969 (8)
Also,displacement power factor(PF_{DISP})=0.97
Distortion power factor(PF_{DIST}) =0.999
True power factor(PF_{TRUE})=0.969 (9)
From (8) and (9),the values calculated from either methods are exactly matching.

4. CONCLUSION

The sources and sinks of particular harmonic currents can be located on either utility or customer side according to the flow of harmonic active power in the system. Also analytically total apparent power in harmonic environment can be calculated. The harmonics has a considerable effect on the system power factor. Therefore, for non-sinusoidal waveforms the power factor should be derived from apparent power. This will permit establishing new concepts of tariffs penalizing not only the demand of reactive power but also the contribution to waveform distortion. Further study can be carried out for finding the distortion power and reactive power in the system by considering interharmonics.

REFERENCES

[1] Massimo Ailello,Antonio Cataliotti,Valentina Cosentino,Salvatore Nuccio, " A power quality instrument for harmonics interharmonics and amplitude disturbances measurements ".*Proceedings.XVII IMEKO World Congress,June 22-27,2003,Dubrovnik,Croatia.*
[2] Sankaran, C. (1995-10-01). "Effects of harmonics on power systems". *Electrical Construction and Maintenance Magazine*. Penton Media, Inc.. Retrieved 2008-09-05.
[3] Almoataz Youssef Abdelaziz. "Sources and Mitigation of Harmonics in Industrial Electrical Power Systems: State of the Art" *The Online Journal on Power and Energy Engineering (OJPEE)* 3.4 (2012): 320-332.
[4] Jos Arrillaga & Neville R. Watson, Power System Harmonics, 2nd edition, 2007, John Wiley & Sons
    [5] IEEE, Recommended Practice and Requirements for Harmonics Control in Electrical power Systems, ANSI/ IEEE 519-1992
[6]] Jos Arrillaga, Neville R. Watson and S.Chen, Power system quality assessment,1st 2000 edition, John Wiley & Sons.