ENERGY BILLING WITH DISTORTED SIGNALS

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***Abstract* - This paper aims to present a new point of view about the active power measurement, for billing purposes, measured at the Point of Common Coupling (PCC) between the utility and the consumer when harmonic distortions are involved. Depending on the origin of it, the active power can result in higher or lower values in comparison to the fundamental component. The consequences are higher costs for the consumer or losses for the electric utility. Using computational simulations and theoretical analysis, these aspects are evaluated and compared.**

***Keywords* - Harmonic distortions, demand charge, power quality, active power, harmonic direction.**

I. INTRODUCTION

The active power from distorted voltage and distorted current has harmonic components besides the fundamental component. Depending on the origin of the harmonic distortions, the active power due to this sum can result in higher or lower values in comparison to the fundamental component value. Such difference results in a higher or lower energy and demand billing and consequently, higher costs for the consumer or losses for the electric utility. Besides the financial issue, the one in disadvantage deals with the harmful effects of the harmonics generated by the other. Using theoretical analysis and computational simulations, the influence of the distortions from the electric utility or from the consumer are evaluated and compared.

II. ACTIVE POWER CALCULATION

Despite the fact that there is no consensus about decomposition methods for electric power in nonsinusoidal conditions [1-5], active power is well-defined as shown below (1). This paper is based on the definitions and formulations specified in the IEEE Std. 1459-2010 [6].

$$P = \frac{1}{kT}\int_{\tau}^{\tau+kT} p\,dt = P_1 + P_h \qquad (1)$$

Where, k is a positive integer number, T is the instantaneous power wave's period and τ is the measurement starting time.

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III. MEASUREMENT AND REGULATION

The existing electric energy meters are divided in two groups: electromechanical and electronic. Both are designed to work in purely sinusoidal conditions because standards and regulations do not include nonsinusoidal waveforms. So in the presence of harmonics, the measurement results depend on the specific project of each meter [7].

Some developed works [8-13] show that both electromechanical and electronic meters are affected by voltage and current distortions.

It is very important to adopt an appropriate methodology for consumer billing and measurement in the presence of harmonics and so, to define the technical specifications that meters must follow when used with nonsinusoidal waveforms to avoid troubles in the trade between the utility and the consumers.

IV. ANALYSIS

In case 01 the consumer consists only of linear loads and all the harmonic content at the PCC is responsibility of the utility. This situation is shown in Figure 1.

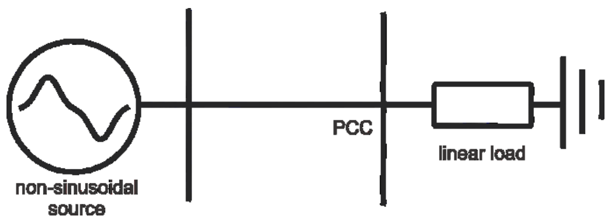

Figure 1 - Distorted source supplying a linear load.

This way, despite of the fact that the consumer does not have any nonlinear load, an active power greater than the fundamental will be maintained. Therefore, in cases where the harmonic distortions are utility's responsibility and the consumer is harmed by the harmonic current circulation through its electrical system.

The second analyzed case studies a situation in which the consumer has nonlinear loads and the utility provides a purely sinusoidal voltage. In this case, the consumer is responsible for the whole harmonic content at the PCC. This case is shown in Figure 2.

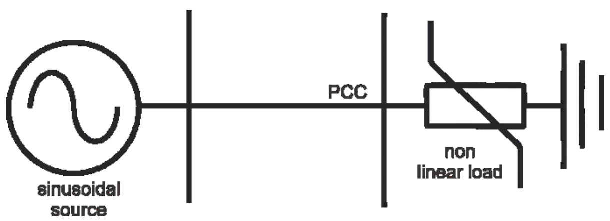

Figure 2 - Sinusoidal source with nonlinear load.

In this case, as the direction of the Harmonic Active Power can be of opposite direction to the Fundamental Active Power, there will be a reduction in the value of the active power measurement. Thus, the utility will be harmed because its system will get disturbed with the presence of harmonic distortion and also because the consumer's nonlinear loads contribute to an electric energy billing reduction.

V. COMPUTATIONAL ASSESSMENT

The evaluation process is supported by a computer program [14] that employs simulation techniques based on the frequency domain. In this tool, a hypothetical electrical arrangement was modeled and parameterized and consists, essentially, by a supplying network defined by its short-circuit impedance and a consumption characterized by an equivalent load with resistive, capacitive and inductive parts, and also by nonlinear components. Figure 3 shows the arrangement and the corresponding parameters. The analyzed cases are shown in Table I.

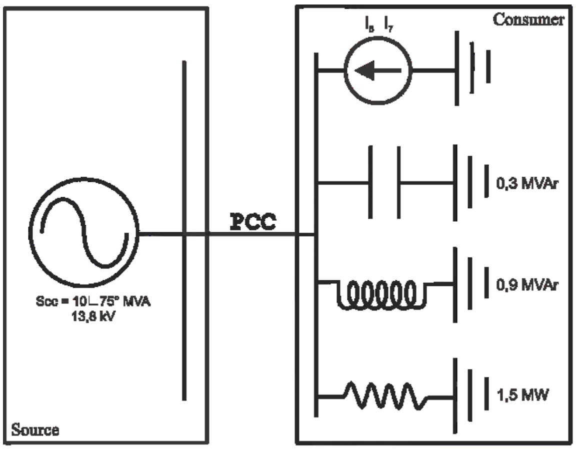

Figure 3 - System's electrical parameters

TABLE I
Evaluated Cases

CASE	*RESPONSIBLE*	*I_5[A]*	*I_7[A]*	*V_5%*	*V_7%*
1	-	0	0	0	0
2	Consumer	5	3	0	0
3	Consumer	7	5	0	0
4	Supplier	0	0	4	3
5	Supplier	0	0	8	6

The results from the computational simulations are shown on Tables II and III. They present the measured values at the PCC.

TABLE II
Voltage, current and total distortion

CASE	*V1[kV]*	*V_{rms}[kV]*	*THDV%*	*I1[A]*	*I_{rms}[A]*	*THDI%*
1	13,800	13,800	0,00	67,59	67,59	0,00
2	13,800	13,845	8,04	67,59	67,89	9,51
3	13,800	13,898	11,94	67,59	68,23	13,80
4	13,800	13,817	5,00	67,59	67,74	6,76
5	13,800	13,869	10,00	67,59	68,20	13,51

TABLE III
Power factor and active power

CASE	*FP_1*	*FP*	*P_1[kW]*	*P[kW]*	*P_C[kW]*
1	0,928	0,928	1500,000	1500,000	1500,000
2	0,928	0,921	1500,000	1499,389	1509,696
3	0,928	0,912	1500,000	1498,714	1521,369
4	0,928	0,928	1500,000	1503,750	1503,750
5	0,928	0,925	1500,000	1515,000	1515,000

For a detailed comparison, the percentage difference between the active powers (Fundamental Active Power, P_1, and Active Power Absorbed by the Consumer, P_c) is presented. The Total Active Power (P), calculated by the average of the instantaneous power's waveform was adopted as reference. Table IV presents these values.

TABLE IV
Percentage difference between the active powers

CASE	*P[kW]*	$\Delta P_1\% = \frac{P_1}{P} - 1$	$\Delta P_2\% = \frac{P_C}{P} - 1$
1	1500,000	0,000	0,000
2	1499,389	0,041	0,687
3	1498,714	0,086	1,512
4	1503,750	-0,249	0,000
5	1515,000	-0,990	0,000

VI. CONCLUSIONS

When the utility is responsible for the harmonic distortions at the PCC, as in cases 4 and 5, the Fundamental Active Power (P_1) billing is the fairest. This is due the fact that the Total Active Power (P) has a higher value, due to the increase in Active Harmonic Power (P_H), unwanted portion by the consumer and responsibility of the supplier.

For cases 2 and 3, in which the consumer is responsible for the harmonic distortions, the Active Harmonic Power flow has an opposite direction compared to the direction of the Fundamental Active Power (P_1), thus, the value of the Total Active Power (P) will have its value decremented. In these cases, the measurement of Total Active Power (P) for electric energy billing harms the electric utility, since, besides being responsible for harmonic distortions, the consumer have its billing reduced.

The Total Active Power's (P) value is highly influenced by the harmonic distortion at the PCC. Therefore, the measurement of Fundamental Active Power (P_1), for electric energy billing, is shown as the best alternative in nonsinusoidal conditions as because it prevents further damage to the relationship between utility and consumer.

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