PERFORMANCE EVALUATION OF ENERGY METERS IN NONSINUSOIDAL ENVIRONMENT BASED ON IEEE 1459 STANDARD

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ABSTRACT

The objective of this work is to study the effects of harmonics on energy meters. This study is carried out based on IEEE 1459 standard through extensive tests on some energy meters installed at Gilan utility consumers. First, a review on IEEE 1459 standard on power definitions will be given. The definitions are then evaluated for a compact Fluorescent Lamp (CFL) as a harmonic generating load. Then, the results of the performance evaluation of two energy meters are presented for different linear and nonlinear loads based on IEEE1459 standard power definitions.

Two different test procedures are performed for this purpose. In the first series of tests, a harmonic polluted voltage is applied to a linear resistive load, and the calculated energy values by the energy meters are evaluated.In the second series of tests, the voltage is applied to some nonlinear loads, and the performance evaluation of the energy meters is presented. The precision and correctness of the measured power quantities are then discussed. Based on IEEE 1459 standard power definitions, it is recommended to use the Non-active power term instead of the reactive power for large consumers.

INTRODUCTION

Widespread use of nonlinear loads has resulted in harmonic pollution in power networks. Harmonics result in extra losses in power network equipment such as transformers and capacitor banks [1-3]. They may also result in damage to sensitive equipment through possible series or parallel harmonic resonances [4]. Harmonic may also cause malfunctioning of protection relays and energy meters [5, 6].

But the important thing is the effect of harmonics on the electricity consumption bill. Energy meters are important devices in industries based on which the cost of electricity is calculated. Normally, energy meters in residential customers determine only the active part of power due to the fact that no large var-consuming devices are employed in residential customers. However, industrial energy meters determine both active and reactive powers. When three-phase loads are linear and balanced, three-phase or even single-phase based power calculation yield the same results. However, when the loads become nonlinear or unbalanced, the procedures based on which power quantities are calculated become of concern. IEEE 1459 standard studies power quantities in non-sinusoidal environments [7].

Normally, the result of voltage harmonic is low in most networks, and therefore, its effect on measurement devices can be neglected. But, the level of current harmonics can be high enough to affect the performance of energy meters.

In this paper, first power definitions in a harmonic environment based on 1459 IEEE standard are revised.

Two types of energy meters are selected, and the following tests are performed. First, the effect of harmonic on the calculated active power is investigated for the test meters. The second study is the effect of harmonics on the calculated reactive meters. The loads for the tests are CFLs and CFLs in parallel with an induction motor.

POWER DEFINITION IN A HARMONIC INVIROMENT BASED ON IEEE STD. 1459

Std. 1459IEEE investigates power definitions in sinusoidal and non-sinusoidal environments. What follows is a summary of this draft.

Power definition for non-sinusoidal single phase mode

In single phase systems which contain non-linear loads, the following equation can be considered:

$$v(t) = \sqrt{2}V_1 \cos(\omega t - \alpha_1) + \sum_{h\neq 1} \sqrt{2}V_h \cos(\omega t - \alpha_h) = v_1 + v_h$$

$$i(t) = \sqrt{2}i_1 \cos(\omega t - \beta_1) + \sum_{h\neq 1} \sqrt{2}V_h \cos(\omega t - \beta_h) = i_1 + i_h$$

The rms value of the voltage and current are:

$$V^2 = V_1^2 + V_H^2$$

$$I^2 = I_1^2 + I_H^2$$

Harmonic indices can now be presented as:

$$THD_V = \frac{V_H}{V_1} = \sqrt{(\frac{V}{V_1})^2 - 1}$$

$$THD_I = \frac{I_H}{I_1} = \sqrt{(\frac{I}{I_1})^2 - 1}$$

Active power consumption is defined and calculated as:

$$p = \frac{1}{T}\int_T p(t)dt = P_1 + P_H$$

In which P_1,P_H are the fundamental and harmonic power respectively and:

$$p_1 = \frac{1}{T}\int_T v_1 i_1 dt = V_1 I_1 \cos\theta_1$$

$$p_h = \sum_{h\neq 1} V_h I_h \cos(\theta_h) = P_1 - P_H$$

$$\theta_h = \alpha_1 - \beta_h$$

Total apparent power is defined as:

$$S^2 = (VI)^2 = (V_1 I_1)^2 + (V_1 I_H)^2 + (V_H I_1)^2 + (V_H I_H)^2 =$$

$$S_1^2 + S_N^2$$

In which:

$$S_N^2 = D_I^2 + D_V^2 + S_H^2 : non-fundamental-apparent-power$$

$$D_I = V_1 I_H = S_1 THD_I : current-distortion-power$$

$$D_V = V_H I_1 = S_1 THD_V : voltage-distortion-power$$

$$S_H = V_H I_H = S_1 THD_I THD_V : harmonic-apparentpower$$

Current distortion power i.e. D_I is the main component apparent power. The apparent distortion power can be divided into two harmonic active power and harmonic distortion power as:

$$S_H^2 = P_H^2 + D_H^2$$

Fundamental component apparent power can also be divided into two active and reactive power at the fundamental frequency as:

$$S_1^2 = P_1^2 + Q_1^2$$

in which:

$$Q_1 = V_1 I_1 \sin\theta_1$$

In some reports, the reactive power is defined for the harmonic components as:

$$Q_B = \sum_{h\neq 1} V_h I_h \sin(\theta_h) = Q_1 + Q_{BH}$$

$$Q_{BH} = \sum_{h\neq 1} V_h I_h \sin(\theta_h)$$

Q_b is the reactive power and is called Budeano reactive power. Based on the above definitions, power factor is:

$$PF = \frac{P}{S} = \frac{P_1 + P_H}{\sqrt{S_1^2 + S_N^2}} = \frac{(\frac{P_1}{S_1})(1 + \frac{P_H}{P_1})}{\sqrt{1 + \frac{S_N^2}{S_1^2}}} = PF_1$$

$$K = \frac{(1 + \frac{P_H}{P_1})}{\sqrt{1 + (\frac{S_N^2}{S_1^2})}}$$

$$PF = \frac{1}{\sqrt{1 + THD_I^2}} PF_1 : THD_V < 10\% and THD_I > 40\%$$

PF_1 is the same as the known displacement factor or the main component power factor.

As the above equations show, power factor decreasesasa result of three components D_I, D_V and S_H in single phase harmonic systems. Therefore, increasing the power factor to one (unit power factor), requires these three components are fully compensated. It is also shown in this standard that the Budeano reactive power cannotrepresent the line losses appropriately.

Power calculation for a CFL based on 1459 ieee

In this section, 40W CFLsare selected and supplied by harmonic sources, and the resulted current harmonics and different power definitions are measured/calculated. The results are summarized in table 1.

STUDIED TESTS RESULT ON MEASURING DEVICES

In this part, two types of energy meters which are mostly used for large customers and industrial loads are selected. Since, these meters work based on single-phase calculation, the loads are selected as single-phase. But, the study can be extended to three-phase meters as well. As the reference device, a calibrated power quality analyzer, i.e. Chauvin Arnux 8334, is used in parallel

Table 1.Results of CFL powr calculatoin based on IEEE Std.1459

h	Fund	3	5	7	9	11	13	15	17	19	I	I_k	THD_k
Amp(A)	0.150	0.116	0.074	0.063	0.067	0.058	0.046	0.043	0.040	0.032	0.244	0.193	128.83
Amp(%)	100	77.14	49.31	42.04	44.78	38.87	30.42	28.64	26.8	21.65	163.1	128.8	
θ(deg)	14.98	-135	92.5	-20.9	-150.4	74.08	-50.6	-172	57.6	-58.3			
h	Fund	3	5	7	9	11	13	15	17	19	V	V_k	THD_k
Amp(V)	220	6.79	5.15	0	2.88	0	0	0	0	0	220.22	8.99	4.09
Amp(%)	100	3.1	2.34	0	1.31	0	0	0	0	0	100.1	4.09	
θ(deg)	0	76.32	177.3	0	129.21	0	0	0	0	0			
h	Fund	3	5	7	9	11	13	15	17	19			
P(W)	31.88	-0.67	0.03	0	0.03	0	0	0	0	0	$P = 31.28, P_h = -0.61$		
Q(VAR)	-8.53	-0.41	0.38	0	-0.19	0	0	0	0	0	$Q_B = -8.75, Q_{BH} = -0.22$		
S=53.73 VA, S_1=33 VA D_I=42.46 VA, D_v=1.35 VA, S_N=42.4 VA							PF₁=0.96 PF=0.56						

with the test meters.

Three tests are conducted for each meter. The first test investigates meterserror when the source contains voltage harmonics under linear load conditions to determine the effect of suppliers power quality on the measuring process of the meters.

Other two tests study the meters performance when the supply voltage is sinusoidal, but the loads are nonlinear with different degree of nonlinearity. These tests show the meter errors in different cases.

The test meters are able to display the active power value; however it is further required to determine active and reactive powersover a specific period of time.

Test 1

The objective of this test is to study the harmonic environment effect on active power measuring while the supplier voltage has harmonic component and the load is linear. For this purpose, along with a sinusoidal voltage of 230 V and 50 Hz frequency, a harmonic component of 30 % from the 3th to the 19th harmonic is applied. This is applied voltage to a resistive linear load (6 Tungsten lamps of 100w). In this case, the active power has two components which are the main and harmonic ones and the harmonic component power is 9% power of the main component.

Active power recording errorsof the metersare presented in Figs.1 and 2. It can be seen from these figures that type 1 meter can measure active power with negligible error for up to the 15th harmonic. But, for harmonics higher than the 15th one, this error increase considerably.

Type 2 meter can read the active power for all the harmonics with negligible error.

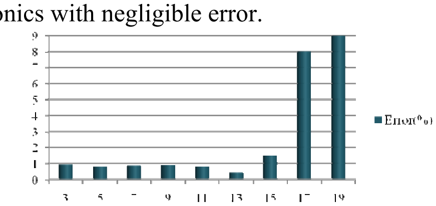

Fig. 1.Active Power measurement error in Type1 meter.

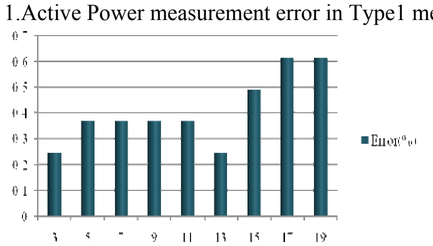

Fig.2.Active Power measurement error in Type2 meter.

Test 2

The objective of this test is to study the reactive power measuring methods by the meters. A sinusoidal voltage of 50 Hz and 220 V is applied to a non-linear load including 15 40-WCFLs. The load voltage and current waveforms and the load voltage are shown in Fig. 3.

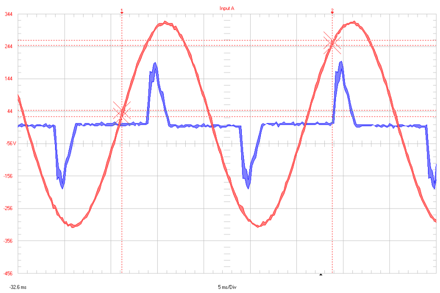

Fig. 3.Voltage /currentwaveformsfot test 2.

Table 2.Results of test 2.

	Type 1			Type 2		
Title	Measured	Reference	Error (%)	Measured	Reference	Error (%)
V(V)	220	220.4	0.18	219.8	220.6	0.36
I(A)	2.46	2.514	2.15	2.53	2.53	0
P(W)	315.6	313.8	0.57	317.65	319.5	-0.36
Q(Var)	No registered	456.2(N) -194(Q_B)	--	-113.97	459.7(N) -116.2(Q_B)	1.91
PF	--	0.56 (Lead)	--	0.55	0.56 (Lead)	1.79

The results of active and reactive power recording by the meters are compared in Table 2. For the reference reactive power, the two values of Budeano reactive power and Nonactive power are determined. The Nonactive power is defined as:

$$N = \sqrt{S^2 - P^2}$$

The results show that both measure active power with acceptable accuracy. Both meters consider the reactive power as a negative value.

Type 1 meter is not able to record the negative reactive power, But Type 2 meter can. However, this negative value does not have any effect on the customer' electricity bill. In other words, this kind of load is treated the same as a linear load. It can be also stated that Type 2 meter, measuresthe reactive energy based on Budeano reactive power, while there is a considerable difference between the Budeano reactive power and the Non-active power.

Test 3

In this test, 15 CFLs are connected in parallel with an inductive single phase motor with the following specifications:

50Hz, 230V,0.08hp,1380rpm,0.96A.

At no load, the meter has the following measured specifications.

The measured values by the test meters are compared with reference values in Table 4.

Table 3.Characteristic of the single phase motor at no load.

V(V)	I(A)	P(W)	Q(Var)	S(VA)	PF	DPF	TAN
220.6	0.669	38.46	142.46	146.6	0.26	0.26	3.719

Considering the reactive power value it can be said that the significant reactive power of the inductive motor is compensated by the CFLs reactive power. In other words, since this load set has a low power factor, and although the metersmeasurethe Budeano reactive power, a low value of reactive energy is recorded for this energy.

Table4: Results of test 3

	Type 1			Type 2		
Title	Measured	Reference	Err (%)	Measured	Reference	Err (%)
V(V)	221	220.2	-0.4	219.8	220.4	0.27
I(A)	2.518	2.57	2	2.646	2.63	-0.61
P(W)	362	351	-3.14	359.14	359.9	0.21
Q(Var)	35.36	442.4(N) 29.2(Q_B)	-21.1	22.8	439.2(N) 28.7(Q_B)	20.55
PF	0.65	0.63 (Lag)	-3.26	0.63	0.64 (Lag)	1.5625

Fig. 4 shows the voltage and current waveforms for this test.

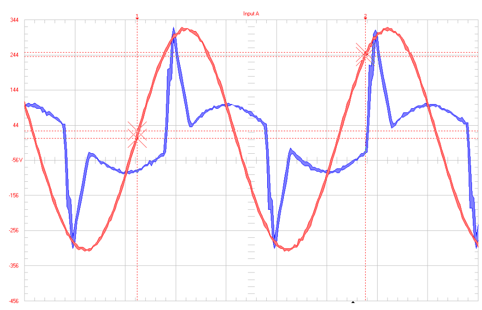

Fig. 4.Voltage and current waveformsfor test 3.

CONCLUSION

From the performed testes, the following conclusions can be made.

1. The meters can acceptably measure active power even in harmonic environments. Some meters may result in error at the supply voltage contains high order of harmonics. Therefore, in locations with high degree of voltage THD, care must be taken when the meters data are used for billing purposes.
2. In large customers with active and reactive meters, themethods of reactive power calculation used by the meter must be known. For the same loads, Budeano and Non-active power result in two different values.
3. It seems that the Non-active power will be a better term for billing purposes, because it considers the effect of all disturbing terms in load voltage and current signals.

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