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Accuracy and reliability of electricity meters in the measurement of electricity depending on the power factor

***Abstract**. Much effort has been made to enhance the accuracy and reliability of electrical meters for the goals of electrical measurement. The formerly approved regulations specifically stipulate the requirements for accuracy and reliability at reference conditions resulting from traditional effect such as temperature or humidity. However, the technical advance of electronics and stricter measurements demand the inclusion of such influences as electromagnetic fields, harmonics in current and voltage circuits etc. The paper addresses reliability of electrical power measurement in households with the effect of harmonics, which to generate network appliances to switching sources.*

***Streszczenie.** Zwiększeniu dokładności i wiarygodności pomiaru energii elektrycznej zostało w ostatnich latach poświęcone wiele wysiłku. We wcześniejszych normach dokładnie są wymienione wymagania dotyczące dokładności i niezawodności w warunkach odniesienia do tradycyjnych wielkości wpływających, takich jak temperatura i wilgotność. W nowych wymaganiach uwzględniono także wpływ pola elektromagnetycznego jak i wpływ obecności harmonicznych. W pracy skoncentrowano się na wiarygodności pomiaru energii w gospodarstwach domowych z uwzględnieniem obecności harmonicznych. (**Dokładność i niezawodność liczników energii elektrycznej w pomiarach energii elektrycznej w zależności od wartości współczynnika mocy w sieci**).*

Keywords: Accuracy, reliability, induction and static electricity meter, power factor, statistics analysis.
Słowa kluczowe: Dokładność, indukcyjny i elektroniczny licznik energii elektrycznej, współczynnika mocy, analiza statystyczna.

Introduction

Electricity meters are indispensable parts of every regular consumption point as they measure supplied power and thus help to assess its cost.

The range of electricity meters used is wide [4]. There is a classic electromechanical induction meter which has a worm gear that drives the register, and a solid-state meter which contains zero moveable parts. Obviously, the principle of measuring electricity is different in each electrometer.

The findings in this paper are based on comparison of these two types of measurement. We compared two electricity meters both with the degree of accuracy 2, one inductive electricity meter and one solid-state electricity meter. Both meters were regularly calibrated by a metrological centre with K18 authorization to ensure accuracy of measured values. Next, each meter was tested for different amounts of load. Every single load level was measured 10 times in compliance with reference conditions of a metrological lab [2]. Measuring errors of both meters are in Fig.1. Datasets used as a basis for reliability of measurement analysis with harmonics in network are circled in black. Concerning the datasets, our aim is to find any possible dependencies, statistically significant phenomena, deviations, or outliers. The producers could use these data to address the issues of design and development of electricity meters, especially enhancing their accuracy and reliability of measurement.

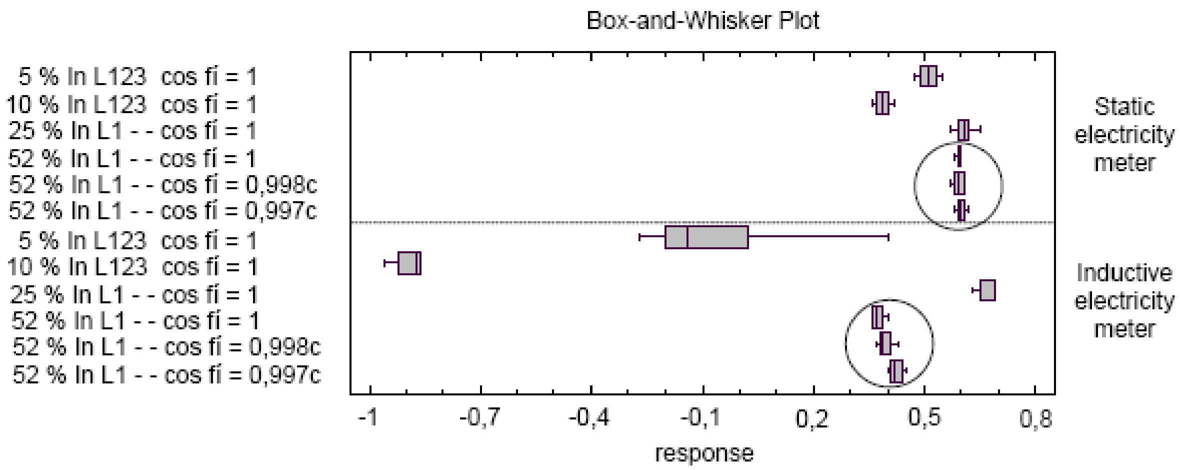

Fig.1. Original measured values of inductance and solid-state electricity meters with different loads

Equality of mean values testing

The analysis assumes that different samples originate from the same dataset of normal distribution. It tests the hypothesis H_0: $\mu_1 = \mu_2 = \mu_3$ (μ - mean value), to be compared with alternative hypothesis (H_A) which assumes that the mean values of these samples are not the same (H_A: does not hold for H_0). This analysis can be conducted in two ways, either by the ANOVA or by the Kruskal – Wallis test. Concerning the ANOVA, the analyzed datasets must have normal distribution N (μ,σ^2) with the same ranges [1]. The datasets were analyzed for the I_n values of 52 % and phase shift of $cos\ \varphi = 1$, $cos\ \varphi = 0{,}998c$ and $cos\ \varphi = 0{,}997c$.

Normality Testing

There are many types of normality tests, e.g. chi-square test, Shapiro – Wilk test, Kolmogorov – Smirnov test or Anderson – Darling test.

Solid-state electricity meter:

Goodness-of-Fit Tests for 52% In cos φ = 1:

EDF Statistic	Value	Modified Form	P-Value
Kolmogorov-Smirnov D	0,302412	1,03457	<0.05
Anderson-Darling A^2	0,947049	1,03939	0,0099

Goodness-of-Fit Tests for 52% In cos φ = 0,998c:

EDF Statistic	Value	Modified Form	P-Value
Kolmogorov-Smirnov D	0,172458	0,589993	>=0.10
Anderson-Darling A^2	0,434644	0,477022	0,2375

Goodness-of-Fit Tests for 52% In cos φ = 0,997c:

EDF Statistic	Value	Modified Form	P-Value
Kolmogorov-Smirnov D	0,172489	0,590099	>=0.10
Anderson-Darling A^2	0,337259	0,370142	0,4252

Inductance electricity meter:

Goodness-of-Fit Tests for 52% In cos φ = 1:

EDF Statistic	Value	Modified Form	P-Value
Kolmogorov-Smirnov D	0,236954	0,810637	>=0.10
Anderson-Darling A^2	0,798037	0,875846	0,0249

Goodness-of-Fit Tests for 52% In cos φ = 0,998c:

EDF Statistic	Value	Modified Form	P-Value
Kolmogorov-Smirnov D	0,242503	0,82962	<0.10
Anderson-Darling A^2	0,669125	0,734365	0,0556

Goodness-of-Fit Tests for 52% In cos φ = 0,997c:

EDF Statistic	Value	Modified Form	P-Value
Kolmogorov-Smirnov D	0,169921	0,581311	>=0.10
Anderson-Darling A^2	0,284343	0,312066	0,5506

To test the normality of data we used the last two. The Kolmogorov – Smirnov test is used to verify a hypothesis that the sample originates from a distribution with a continuous distribution function *F(x)*. The sample range in this test is usually small, in our case the number of data is 10. The Anderson – Darling test is a modification of the Kolmogorov – Smirnov test and is applied to identify the distribution from the sample dataset, in other words it shows whether the random sample originates from the basic set of a selected sample. The main difference is that the Anderson – Darling test has specific limit values for every distribution.

The analysis using the Kolmogorov – Smirnov and Anderson – Darling tests proved that not all the used datasets satisfy the assumption of normal distribution by 100 %. The datasets which do not satisfy normality requirements or are ambiguous are circled in black colour. It is worth noticing that these black-circled P-values computed in Statgraphics software are only slightly over the maximum of 0,05 significance level, where H_0 null hypothesis is not yet rejected. Also, they can be slightly lower than the minimum 0,01 significance level where H_0 null hypothesis is already rejected. The interval from 0,01 to 0,05 is ambiguous. As the findings of normality testing were unambiguous, the data are further tested by means of the ANOVA which presupposes normality of datasets and by the Kruskal – Wallis test which does not presuppose data normality.

ANOVA – Analysis of Variance

Solid-state electricity meter:

Analysis Summary

Sample 1: 52% In cos φ = 1
Sample 2: 52% In cos φ = 0,998c
Sample 3: 52% In cos φ = 0,997c

ANOVA Table

Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between groups	0,000426667	2	0,000213333	1,22	0,3102
Within groups	0,00471	27	0,000174444		
Total (Corr.)	0,00513667	29			

P_{value} > 0,05 and we can state that the H_0 hypothesis of equality of means is not rejected on 0,05 significance level, which means that compared mean values are not significantly different. The result confirms the calculated Fisher's ratio significantly reaching 1.

The test proves that solid-state electricity meters in sample datasets are insensitive to the amount of voltage phase shift in relation to flowing current.

The differences in measured values, or more precisely datasets measured with the same load but different phase shifts in relation to flowing current are illustrated in Fig.2.

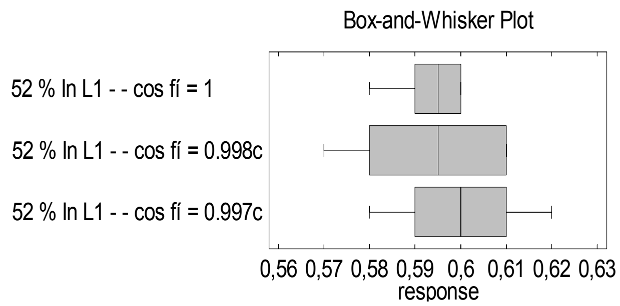

Fig.2. Box-and-whisker plot – solid-state electricity meter

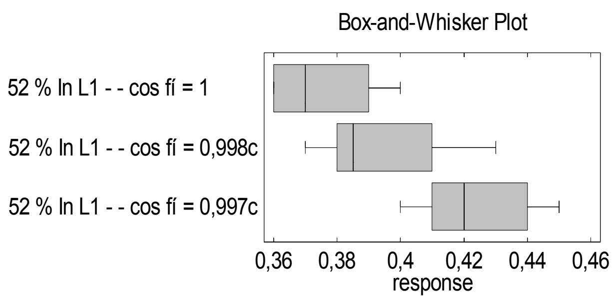

Fig.3. Box-and-whisker plot – inductance electricity meter

Inductance electricity meter:
Analysis Summary

Sample 1: 52% In cos φ = 1
Sample 2: 52% In cos φ = 0,998c
Sample 3: 52% In cos φ = 0,997c

ANOVA Table
Analysis of Variance

Source	Sum of Squares	Df	Mean Square	F-Ratio	P-Value
Between gr.	0,01142	2	0,00571	18,33	0,0000
Within gr.	0,00841	27	0,000311481		
Total (Corr.)	0,01983	29			

$P_{value} = 0 \Rightarrow \ll 0{,}05$ and we can reject the equality of H_0 means hypothesis on 0,05 significance level, which means that the compared means differ. The observation is confirmed by the level of calculated Fisher's ratio.

The test proves that inductance electricity meters in sample datasets are sensitive to the amount of voltage phase shift in relation to flowing current.

The differences in measured values, or more precisely datasets measured with the same load but different phase shifts in relation to flowing current are illustrated in Fig.3.

Equality of medians testing

The analysis of means conducted in section „ANOVA – Analysis of Variance" by means of ANOVA table assumes normal distribution, which nonetheless had not been unambiguously proved or disproved by the normality test in section „Normality Testing". For that reason we used the non-parametric Kruskal – Wallis test, which does not assume normal distribution unlike the parametric tests. However, its lower sensitivity is a disadvantage here.

Solid-state electricity meter:
Analysis Summary

Sample 1: 52% In cos φ = 1
Sample 2: 52% In cos φ = 0,998c
Sample 3: 52% In cos φ = 0,997c

Kruskal-Wallis Test

	Sample Size	Average Rank
52% In cos φ = 1	10	13,4
52% In cos φ = 0,998c	10	14,4
52% In cos φ = 0,997c	10	18,7

Test statistic = 2,1629 P-Value = 0,339104

The Kruskal – Wallis test for equality of medians of sample datasets proved the aforementioned results of the ANOVA (section „ANOVA – Analysis of Variance") does not reject the equality of medians hypothesis. It proves that the compared means do not significantly differ, i.e. the solid-state electricity meter in sample datasets is insensitive to the amount of voltage phase shift in relation to flowing current.

Inductance electricity meter:
Analysis Summary

Sample 1: 52% In cos φ = 1
Sample 2: 52% In cos φ = 0,998c
Sample 3: 52% In cos φ = 0,997c

Kruskal-Wallis Test

	Sample Size	Average Rank
52% In cos φ = 1	10	8,4
52% In cos φ = 0,998c	10	13,95
52% In cos φ = 0,997c	10	25,15

Test statistic = 16,6693 P-Value = 0,000240055

Here, the Kruskal – Wallis test for T equality of medians of sample datasets also proved the aforementioned results of the ANOVA (section „ANOVA – Analysis of Variance"). It rejects the equality of medians hypothesis which proves that the compared means significantly differ. Inductance electricity meter in sample datasets is sensitive to the amount of voltage phase shift in relation to flowing current.

To determine the datasets which significantly differ in terms of statistics, the post hoc analysis can be conducted.

Post hoc analysis

To complete the analysis of an inductance electricity meter, we need to identify those datasets that differ from each other, or more precisely signal a statistically significant deviation of sample means. They were identified by means of multiple range test (MRT) which assumes data normality and Nemenyi method which does not assume data normality.

Multiple Range Test Procedure

Multiple Range Tests

Method: 95,0 percent LSD

	Count	Mean	Homog. groups
52% In cos φ = 1	10	0,376	X
52% In cos φ = 0,998c	10	0,392	X
52% In cos φ = 0,997c	10	0,423	X

Contrast	Difference
52% In cos φ = 1 - 52% In cos φ = 0,998c	-0,016
52% In cos φ = 1 - 52% In cos φ = 0,997c	*-0,047
52% In cos φ = 0,998c - 52% In cos φ = 0,997c	*-0,031

In this method a two-sample test is applied for each pair of sample means. The test results show that only first two datasets are closest to the equality of medians or mean values, i.e. measured errors with *cos φ* = 1 and *cos φ* = 0,998c. Other test results show statistically significant deviations of sample means, which confirms the difference of compared datasets (see Fig.3.).

Table 1. Nemenyi method – test results

Post hoc analysis for Kruskal – Wallis test				© Martina Litschmannová, 2011				
Significance value 0,05								
|*tr-ts*| (critical value)								
r\s	1	2	3	4	5	6	7	8
1	-	4,188 (9,4)	14,188 (9,4)					
2	4,188 (9,4)	-	10 (9,4)					
3	14,188 (9,4)	10 (9,4)	-					

Nemenyi method

The Nemenyi method can be used for multiple comparisons (post hoc analysis) in case of balanced classification where the samples have the same range but do not satisfy normality assumption. The testing results are shown in Table 1 by means of an MS Excel 2010 applet. [3]

Conclusion

The aim of this paper is to address the issues of accuracy and reliability of electrical meters with respect to the power factor. We based our research on comparison of two datasets acquired by measuring on two types of electrical meters (conductive and solid-state). In the introduction of this paper, we illustrated the measured load levels of each meter and their position in the tolerance range of the degree of accuracy 2. The differences in measuring abilities of each meter caused by different designs and measuring systems are obvious.

The following section analyzes statistical tests and testing methods which determine the effect of $\cos\varphi$ (voltage-current phase shift) on measured values. Supposing normality of datasets, we conducted a multi-sample analysis of mean values by means of the ANOVA. The test proved that the solid-state electricity meters in selected sample datasets are insensitive to the voltage-current phase shift, while the conductive electricity meters are sensitive. However, further normality testing of datasets proved that either type of electricity meters has one dataset which does not satisfy the assumption of data normality. Therefore, the non-parametric Kruskal – Wallis test of equality of medians was conducted. This test, unlike the ANOVA, does not assume normal distribution. The test proved our earlier findings. The testing found differences in mean values and medians of both types of meters. The differences were further specified and identified as identical in post hoc testing by means of the multiple range test (MRT) and the Nemenyi test.

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