A VIRTUAL INSTRUMENT FOR MEASUREMENT IN NONSINUSOIDAL CONDITIONS

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Abstract - *On the methodological level, and also in measurement practice, significant errors have been noted in the measurement of electric quantities in distorted periodic systems, depending on the technological realization of the electronic measuring device or system. The paper describes a virtual instrument approach to the measurement of complex periodic electric signals, and particularly the power factor of “power saving” compact fluorescence bulbs. The analysis of the results also indicates that, in processing signals with a high harmonic distortion, it is necessary to pay attention not only to the measurement uncertainties but also to the dynamics of the measuring instruments that are used.*

Keywords – Nonsinusoidal conditions, virtual instrument, power factor measurement.

1. INTRODUCTION

Due to the rapid development of power electronics and electronically controlled loading, power plants and a growing number of consumers, increasing quantities of electrical power are being transmitted and used in the conditions of distorted current and voltage. The existing situation has not been accompanied, especially in Yugoslavia, by relevant studies of the methodology of measuring such electric quantities.

The measurement of electric quantities in alternating current circuits of industrial frequency can truly be accompanied with some problems, particularly when highly distorted measuring signals are at stake. Depending of the level of distortion of the measuring signals, the applied measurement methods and instruments, the accuracy of measurement can be seriously degraded [1].

On the methodological level, and also in measurement practice, significant deviations of precision have been noted in the measurement of electric quantities in distorted periodic systems, depending on the technological realization of the electronic measuring device or system. Electronic instruments are constructed so as to measure one of the three characteristic values of the alternating current or voltage signals: maximum value (peak detector), average value (averaging detector) or effective value (root mean square - RMS – detector). Even a greater amount of confusion, of which the scale user often remains unaware, is caused by the fact that all of these instruments are being adjusted and calibrated so that, in the conditions of simple periodic, “sinusoidal” signals, they show the effective value (instruments for measuring the maximum value use the multiplication factor of 0.707, while instruments for measuring the average value at full wave rectification use the multiplication factor of 1.1100). The use of different types of instruments in purely sinusoidal conditions will show congruence within the declared classes of precision; however, the same instruments, used in the conditions of significant harmonic distortions, will show considerable variance, and will frequently even show results void of any physical sense. The purpose of this project is, among other things, to warn that caution is needed when opting for a specific methodology, technology, instrumentation and interpretation of results in the relevant area of electrical measurements.

The research of measurement methods has shown that, in the case of periodic signals, it is most appropriate to measure the true effective valueV RMS (TRUE RMS) of signal *v*, according to the definition:

$$V_{RMS} = \sqrt{\frac{1}{T}\int_0^T v^2 dt} \qquad (1)$$

The methods of measuring the true effective value vary from absolute (effective value is measured on the basis of measuring Joule’s losses, or measuring temperature), analog (instruments with soft iron, electro-dynamic instruments), analog-digital (True RMS to DC converters + A/D converters) to purely digital (quantification according to level and time and integration).

The development of measuring devices evolved through a number of technological phases: from analog, electronic, digital, microprocessor to the intelligent instruments. In the mid nineties of the twentieth century, a special class of instruments was developed - virtual instruments (VI) – which are realized as application software packages with the functions of a measuring instrument on the PC hardware base. In the measurement of distorted periodic quantities, VI

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have shown some advantages, particularly in the conditions of highly distorted measuring signals.

2. DEFINITION OF THE PROBLEM

The enormous consumption of electric power for heating and lighting residential and business buildings has caused the distortions of the periodic and annual load diagrams, the increase of operational costs, the imports of considerable amounts of electric power, and has gravely undermined the operational reliability and security of the electric power system in Serbia, especially during the winter periods. Detailed analysis has shown that the massive use of "power saving" compact fluorescence bulbs (CFB) in place of classical light bulbs with a glowing fiber would contribute to significant savings of electric power. The analysis of the CFB reactive energy consumption has raised the problem of measuring electric quantities in highly distorted alternating systems.

The measurement of power in the case of highly distorted periodic signals is far more complex [2]. Let the instantaneous values of voltage *u* and current *i*, be represented through the development in Fourrie's order:

$$u(t) = \sum_{h=1}^{\infty} \sqrt{2} U_h \sin(h\omega_0 t + \theta_h)$$
$$i(t) = \sum_{h=1}^{\infty} \sqrt{2} I_h \sin(h\omega_0 t + \varphi_h) \quad (2)$$

where *h* represents the harmonic order, $wo=2\pi f$ circular frequency, and θh and φh represent the phased angles of voltage and current, respectively.

Proceeding from these phrases, active power is defined as:

$$P = \sum_{h=1}^{\infty} U_h I_h \cos(\theta_h - \varphi_h) = \sum_{h=1}^{\infty} P_{hh} \quad (3)$$

where *Phh* indicates active power resulting from the product of the *h* harmonic order of voltage and the *h* harmonic order for current.

Apparent power is:

$$S = U_{ef} I_{ef} = \sqrt{\sum_{h=1}^{\infty} U_h^2} \sqrt{\sum_{k=1}^{\infty} I_k^2} = \sqrt{\sum_{h=1}^{\infty}\sum_{k=1}^{\infty} S_{hk}^2} \quad (4)$$

where *Shk* represents apperent power resulting from the product of the *h* harmonic order for voltage and the *k* harmonic order for current.

The standard definition of the power factor also assumes simple periodic values of voltage and current, and is reduced to $cos\varphi$, or the phased angle of current with respect to voltage. The definition of the power factor in the conditions of distorted periodic signals becomes complex, and the realization of measurement is far more complex as well. In the case of non-sinus wave forms, and proceeding from (3) and (4), the power factor λ is defined as:

$$\lambda = \frac{P}{S} = \frac{\sum_{h=1}^{\infty} P_{hh}}{\sqrt{\sum_{h=1}^{\infty}\sum_{k=1}^{\infty} S_{hk}^2}} \quad (5)$$

The above analysis indicates that, in the case of measuring complex periodic electric signals, in addition to the measurement error, attention must also be paid to the dynamics (quantification by time) of the applied electronic instruments. In order to measure as correctly, and as effectively, as possible the electric values, and particularly the power factor, of a larger number of CFB with different characteristics and by different producers, and to test the possibilities for the application of the VI technology in this area, an effort was made towards the realization of a VI for measuring complex periodic electric signals.

3. THE VIRTUAL INSTRUMENT REALIZATION

Virtual instruments (VI) constitute the latest generation in the development of electrical measurement instrumentation. Although references do not yet offer an agreed single, strictly formal, definition of the VI notion [3], it is possible to find closer determinants of focusing on two major approaches:

- -multipurpose hardware integrated with specifically developed software on a PC platform constitutes an instrument with defined metrological characteristics, which neither the hardware nor the software used possess individually,
- -application software package which has the appearance and functional characteristics of a measurement instrument, but which is not a real measuring instrument (the reason for introducing "virtual" as qualifier).

Both of the above determinants imply realization on a certain PC platform and the use of the available hardware and software computer resources [4].

The paper further describes the procedure of creating a VI with the following basic functions: harmonic current and voltage analysis, true effective value measurement, digital power analyzer and power factor measurement. The requirement of measuring power in a single phased highly distorted system stressed the need for using hardware with a minimum of two channel measurement, error of less than +/- 0.5%, and dynamics in the kHz or MHz frequency range. The following hardware and software resources were used:

HARDWARE:

- Scope meter, 50MHz, type FLUKE 97,
-Pentium III Personal Computer,
-Serial communication RS232

SOFTWARE:

-LabView/CVI programs in a Windows environment, with the realized functions: :
-Measurement of the effective values of current and voltage,
-Harmonic analysis of current and voltage,

-Power analyzer,

-Measurement of the power factor.

Fig.1 shows a bloc scheme of electric measurement in a simple serial circuit where CFB is loaded from a single phased source (220V, 50Hz network) through auto (AT) and isolation (IT) transformers, and voltage and current are measured (with the assistance of resistance Rs) by a Scope meter, Fluke97, on measurement channels A and B, respectively. In order to expand the possibilities of measurement and to create a VI with the planned functions, Fluke97 instrument was linked, through serial connection RS 232, to a standard PC running the Windows operational system.

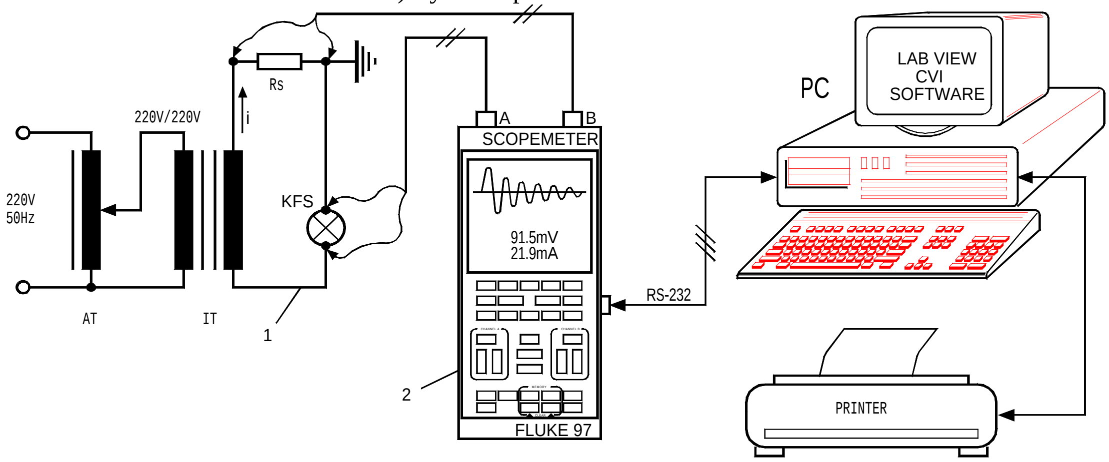

Fig.1 - Realization of the virtual instrument: 1 – electrical scheme; 2 – standard instrument; 3 – application software (VI).

The realization of the VI provided the conditions for quality and effective measurement of electrical signals in the circuit, presented in Fig.1, with CFB as the load.

4. POWER FACTOR MEASUREMENT

The established VI was used as a system for measuring the CFB power factor. The main purpose was to measure the power factor of individual CFB of different models and by different producers. Although the use of CFB provides obvious savings of active energy, attention must also be paid to the consumption of reactive energy, whose excessive presence in the system causes instances of greater losses and instability. According to the block scheme of Fig.1, and with the use of the expanded mathematical model described in equations from (1) to (5), harmonic analysis and power analysis were made, and the power factor of a considerable number of CFB was measured. As an example, Fig.2 and 3 show the measurement results of electric quantities for CFB with low ("bad") and high ("good") power factors, respectively.

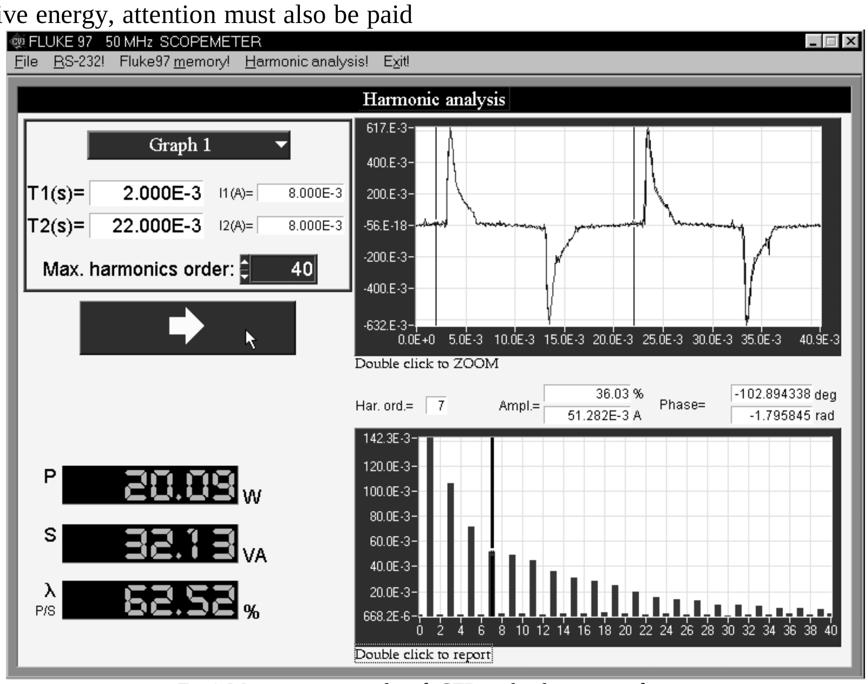

Fig.2 Measurement results of CFB with a low power factor.

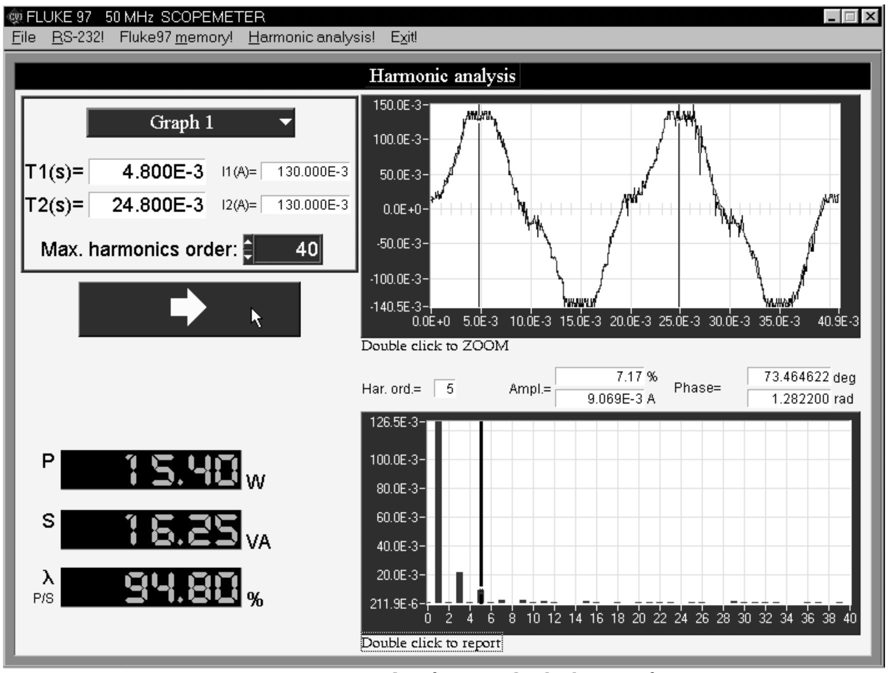

Fig.3 Measurement results of CFB with a high power factor.

Fig.2 shows a very high current distortion, with the significant presence of higher harmonics (for example: harmonic of the 7th order has an amplitude of approximately 36% relative to the amplitude of the basic harmonic), accompanied with the power factor of only λ=0.62. Fig.3 shows the CFB measurement results with a considerably smaller current distortion (a better solution in the control section of CFB power electronics), accompanied with a considerably smaller harmonic content and a very good power factor of λ=0.95. The attractiveness (precision, flexibility, effectiveness) of measuring with a VI is immediately evident as compared to the classical approach to power factor measurement by the classical cosφ- meter.

The following descriptive analysis is provided to facilitate the understanding of the impact of the dynamics of measurement on precision in determining the power factor. Let us assume that for the cases described in Fig.2 and 3, based on equation (5) and real measurement results, power factors λ_1 and λ_2 are being calculated respectively, taking into consideration:

A) Only the first current and voltage harmonic (λ_{1A} and λ_{2A}).

B) All current and voltage harmonics to the 5th order (λ_{1B} and λ_{2B}).

C) All the measured current and voltage harmonics (λ_{1C} and λ_{2C}).

Under the above assumptions, the following values of the power factor were calculated:

λ_{1A} = 0.95 λ_{1B} = 0.71 λ_{1C} = 0.62

λ_{2A} = 0.96 λ_{2B} = 0.954 λ_{2C} = 0.95

There is an evident quantitative difference among the obtained results depending on the order of the calculated harmonics. The difference is much more prominent in signals with a greater distortion. The above analysis does not only point to quantitative differences, but also to the possibility of deriving qualitatively false conclusions. The measurement of the first harmonic only leads to the false conclusion that both CFB have a more or less equal, good, power factor!? Correct measurement, with the calculation of all the measured higher sharmonics, points to a completely different conclusion: CFB in Fig.2 has a bad (λ=0.62) power factor, and CFB in Fig.3 has a good (λ= 0.95) power factor.

It is also necessary to underline that when the signals are very distorted (like the current signal in Fig.2) the share of harmonics of a high order (for example over 40, which corresponds to frequency in the kHz range) can amount to even several percent, which requires caution in the interpretation of the uncertainties in the measurement results.

5. CONCLUSION

The paper describes a modern approach to the measurement of complex periodic electric signals. This topic is gaining in topicality in view of the continued trends of accelerated development and the application of controlled power and power electronics. The classical methodology and/or instrumentation are often unable to provide satisfactory answers to the real measurement requirements in the conditions of high distortions of the measuring signals. The authors have drawn attention to the possibility of applying the VI technology in this area of measurement, which they have applied to the analysis of CFB. As compared to classical instruments, VI have a much greater potential for achieving precision, flexibility and effectiveness of measurement. The measurement results show a significant difference in the power factors of different CFB (from 60% to 95%). The analysis of the results also indicates that, in processing a signal with a high harmonic distortion (example: Fig.2), it is necessary to pay attention not only to the measurement uncertainties but also to the dynamics (inertia for analog, and quantification by time for digital instruments) of the measuring instruments that are used.

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