COMPLETE SYSTEM TO TEST MEASUREMENT ERRORS IN ACTIVE ELECTRICAL ENERGY METERS UNDER HARMONIC DISTORTION CONDITTION

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***Abstract* – This paper presents a new complete measurement system to test measurement errors in active electrical energy meters operating under harmonic distortion, and also considering balanced and unbalanced voltage waveforms conditions. A standard energy meter equipment with accuracy class of 0.1% is adopted as reference in the determination of measured errors from experimental tests. The features of proposed system include the capability of provide stable and prespecified programmed profiles of voltage and current waveforms, with displacement and harmonic distortion controls. There are database of current and voltage waveforms, admitted for testing, and obtained by measurements in consumers with different load characteristics (industrial, commercial, agricultural, and residential). The admitted voltage unbalances were of 3% and 5%. In addition, the system is also capable of register automatically all information regarding experimental tests and control all procedures through an interactive manager software with graphic user interface. In order to illustrate the proposed system some results of extensive experimental tests are presented, performed to determine the effect of harmonic distortion and unbalance of voltage on two-phase and three-phase electromechanically active electrical energy meters (induction type) from different manufactures.**

***Keywords* – watt-hour meter test system, watt-hour measurement errors, non-sinusoidal operations, unbalanced voltage waveform, induction type watt-hour meter.**

I. INTRODUCTION

The evolution of industrial processes and widespread applications of electronically controlled loads, such as, electronic energy processors (switched converters, speed drives for electric machines, welds equipments), and devices in the commercial and housing sections (personal computers, entertainment devices, electronic ballasts with low power factor), have increased the harmonics distortion in the power systems [1-3].

These non-linear loads present high harmonic content in the current waveforms required from the AC net, resulting in: distortion in the voltage power system waveform, power factor reduction, high level of the third harmonic content in the neutral current, excessive displacement of current and voltage and EMI (electromagnetic interferences) [2].

The electromechanically watt-hour meters of induction type are the regular devices used for measuring active power by the utility. However, manufactures calibrate induction watt-hour meters using pure sinusoidal waveforms at normal current values, because they are designed to operate with a pure sinusoidal current and voltage waveforms [3-4].

In the real world, energy meters are generally not exposed to balanced or purely sinusoidal conditions, and measurement errors in energy meter occurs caused by harmonic distortion in the current and in the supply voltage. These effects can represent a substantial economic impact for the utility and for the customer, especially when large quantities are interchanged [5].

Thus, several works have been analyzed the behavior of these type of energy meters in sinusoidal and non-sinusoidal conditions using theoretical models in time domain and in frequency domain to predict the measuring errors. However, all these models also present "errors" due the complexity in representing all the parametric operation influences of these induction meters, mainly when applied to non-sinusoidal conditions [6-10].

Therefore, a complete experimental analysis can be the most acceptable approach to eliminate the drawbacks usually presented in the theoretical analyses.

Usually, in the experimental analysis of energy meters considering harmonic distortion, harmonic waveform generators are used together with power sources to reproduce actual distorted voltage and current waveforms observed in the electric energy distribution systems. Therefore, the high cost related in using two of these arranges (one for voltage and one for current), and the complexity of keeping stable the synchronism of required displacement angle between the two system represent negative aspects.

This paper proposes a new complete measurement system to test measurement errors in active electrical energy meters of induction type operating under harmonic distortion, and also considering balanced and unbalanced voltage waveforms conditions. In addition, manager software with graphic user interface, provide the control of all processes and register automatically all information concerning experimental tests, performing a high accuracy system to test induction type watt-hour meters.

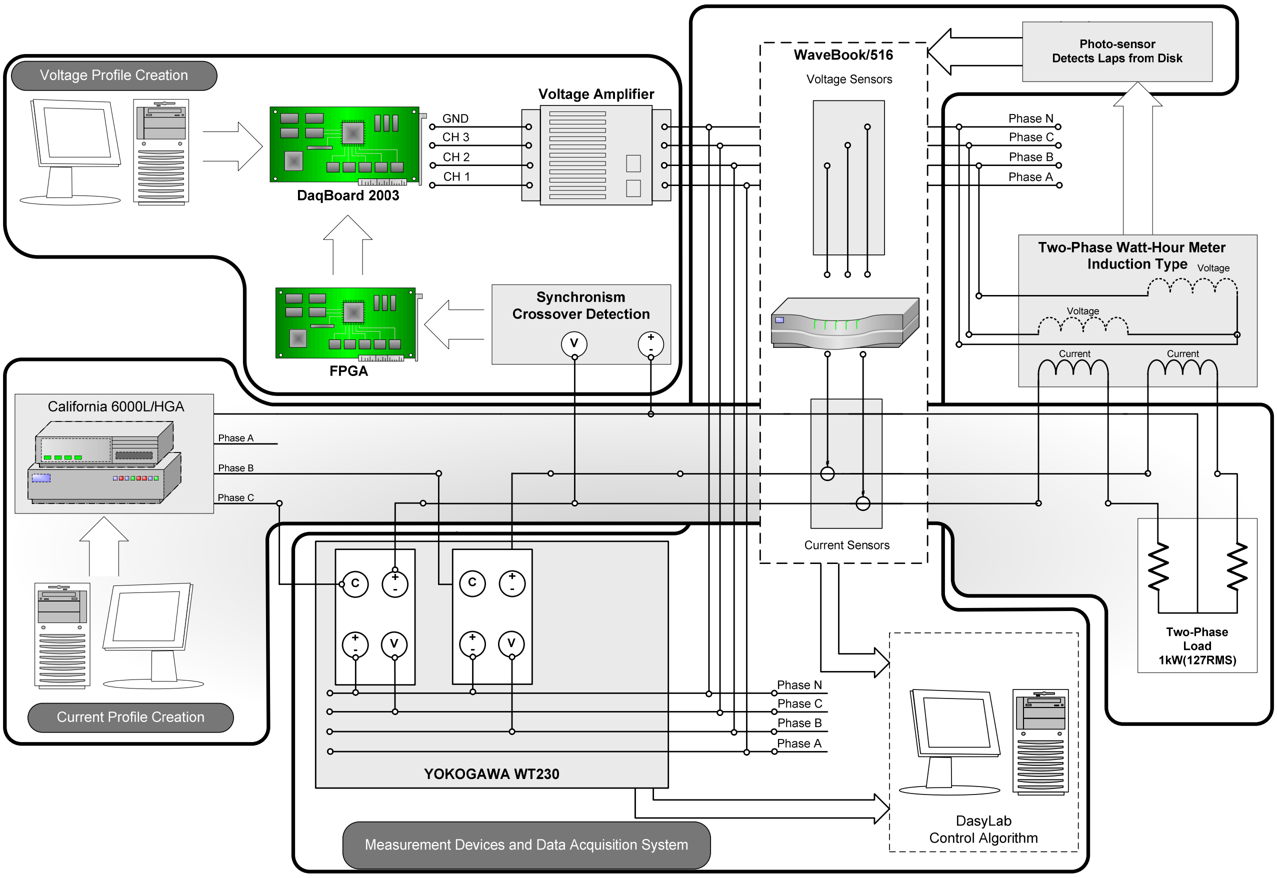


Fig. 1 – Blocks Diagram for the proposed measurement system, two-phase inductor meter configuration example.

Figure 2 – General view of experimental set-up for meter tests.

II. ARCHITECTURE OF PROPOSED SYSTEM

A block diagram of the whole system and a general view of experimental set-up for watt-hour meter tests are shown in Figs. 1 and 2, considering the example for two-phases meters tests.

The system architecture is based in one three-phase harmonic generator, one three-phase power source, one low signal 16 bits digital-analog PCI card, one voltage amplifier, one FPGA to control the synchronism, one 8- analog channel 16 bits data acquisition system with voltage and currents probes, one photo-sensor, one standard watt-hour meter equipment, used as reference for measurements, and one microcomputer to execute the manager application.

It should be noticed that the input current and voltage meter terminals, usually connected in the watt-hour meter of induction type, must be disconnected, in order to permit feeding current and voltage waveforms from different sources in this approach.

Basically, the proposed system devices can be divided in categories according with their purpose: create current waveform, create voltage waveform, data acquisition and sensors, process control, reference and test meters.

A) Current Waveform

The methodology consists in create a current waveform using a voltage waveform connected to a purely resistive load. So, the resultant current waveforms are feed in the current terminals of the meter under test. In this way, the current waveform profile is imposed from a voltage waveform profile.

A 6kVA three-phase power source model 6000L connected to a waveform generator HGA (both California Instruments) feeding a three-phase resistive load accomplish the current generation task (one phase is suppressed for two-phase applications). The HGA device provides the reference waveform for the power source to follow. Considering the fundamental component with frequency of 60 Hz, the pair is capable to represent voltage waveforms with harmonic components until the fiftieth order.

B) Voltage Waveforms

The methodology is based on the reconstruction of desired voltage waveform from information provided by harmonic decomposition of the required voltage profile. The voltage waveforms were generated as low-voltage signals by digital-analog converters, and after they were amplified by the voltage amplifier.

In discrete time domain, considering a sample rate at 50 kHz, each voltage waveform profile has 833 points of resolution during a period of 60Hz and the three-phase system created by means of discrete data phase-shift of 240º and 120º degrees. After, the discrete points considering units in volts are codified using integer binary representation with words of 12 bits. The base used in the conversion is related with the gain provided by the voltage amplifier stage, in the waveforms generated by the device digital-analog converter PCI device (DaqBoard 2003 - Iotech), in order to guarantee that the voltage waveforms delivered in the output terminals of voltage amplifier be equal 127V rms in all voltage profiles.

The developed AC three-phase voltage amplifier for this system is shown in Fig 3. It has an output power of 20W, input AC waveform with amplitude range of [-5V, 5V], and is capable to deliver the required output voltage waveforms with 127V rms with bandwidth response for signals with frequencies from 60Hz until 5 kHz.

It should be noticed that with this set-up the costs related with the requirement of another high power three-phase source plus harmonic generator are minimized.

C) Data Acquisition and Sensors

The acquisition and control system is composed by a PC microcomputer executing software developed in the DasyLab environment, a GPIB communication board, a data acquisition system WaveBook/516 with four voltage sensors and three current sensors, a photo-sensor connected to the test meter, and a Yokogawa WT230 used as a standard meter.

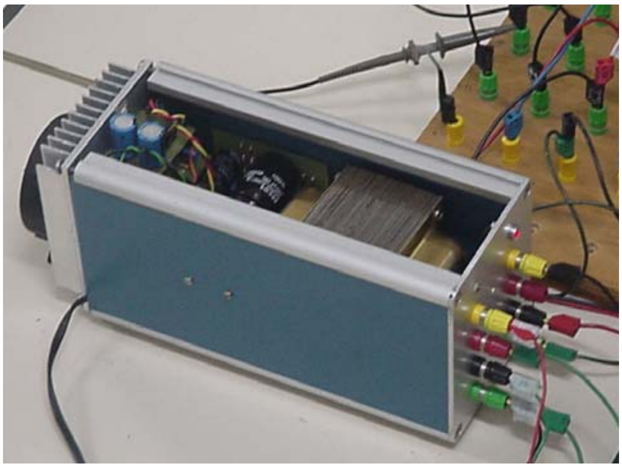


Fig. 3 – AC Three-phase voltage amplifier.

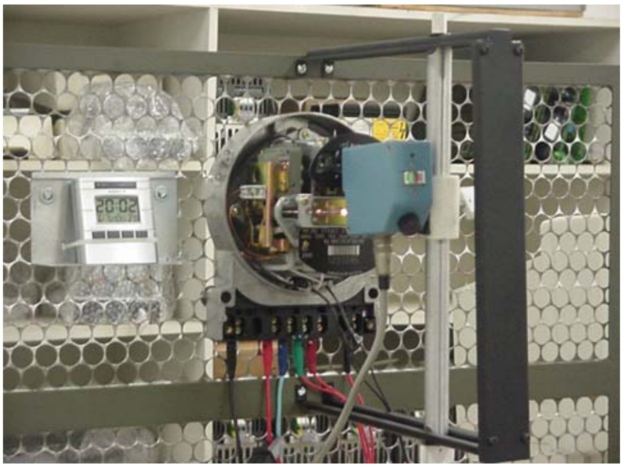


Fig. 4 – Photo-sensor coupled in meter under test.

A highly accurate standard meter is necessary for calculating and recording the exact watt-hour that the test meter is measuring, in order to evaluate the resultant measuring errors. In this way, a Yokogawa WT230 class 0.1% (power/voltage/current) was adopted as reference watt-hour meter. The device also provides additional standard values to be used as reference in computations (active power, rms voltage and current in each phase).

Furthermore, the induction watt-hour meters do not include a special analog/digital signal informing the measured active power, thus a communication means was needed to register this information.

A photo-sensor was used to acquire the proportional information related with watt-hour measured. Each time that the sensor detects a mark related with one lap from induction meter disk, it creates a TTL pulse signal. So, the control system detects and count the number of rise edges of these pulses to derive the proportional information related with measured active power according with disk constant (kWh/lap) from tested meter. Figure 4 shows the photo-sensor detecting the disk meter information in a two-phase induction meter.

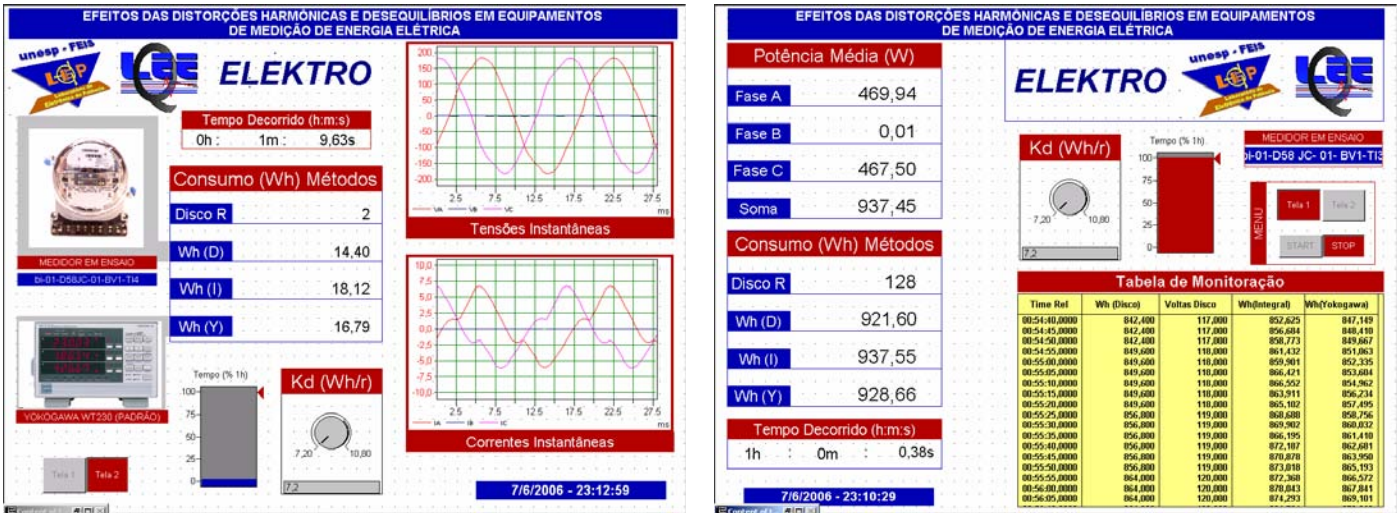
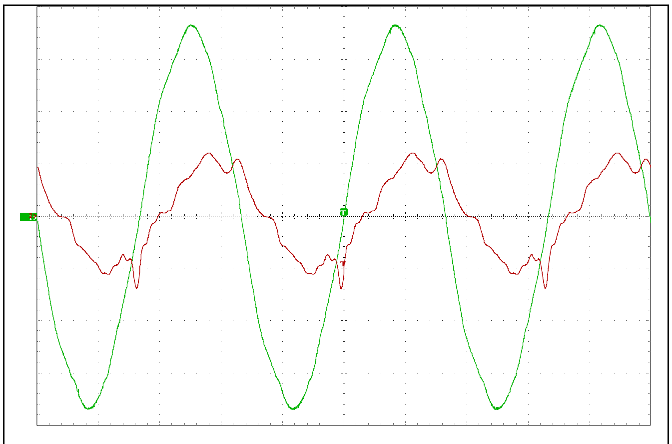


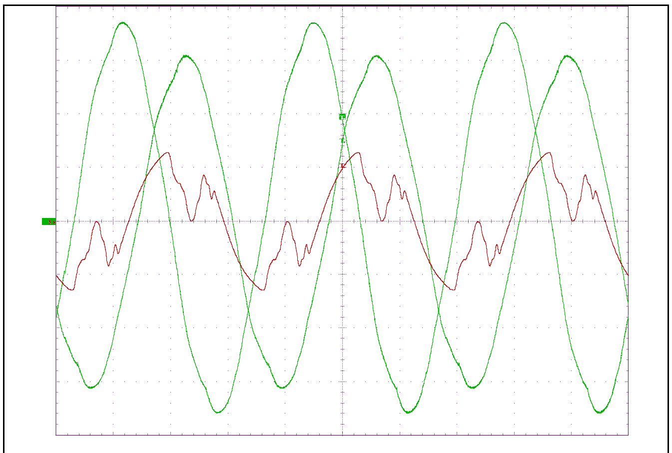
Figure 5 – Views from graphic user interface developed to control the test system.



V: 50 V/div; I: 2A/div, 5ms

Voltage Profile	TV1	**THDV:**	3,02
Current Profile	INDI1	**THDI:**	18,40
Displacement Angle between voltage and current			39,20^{O}

(a)



V: 50 V/div; I: 2A/div, 5ms

Voltage Profile	BV2	**THDV:**	3,30
Current Profile	TRI1	**THDI:**	46,83
Displacement Angle between voltage and current			35,20^{O}
Unbalance Voltage Level :			5%
V_{AN}(t) RMS	127,00 V	**V_{CN}(t) RMS:**	108,26V

(b)

Figure 6 – Examples of Voltage and Current Profiles used in the experimental tests: (a) considering only harmonic distortion and (b) considering harmonic distortion and unbalance of voltage waveform.

The data acquisition system (WaveBook/516) acquires the voltage and current waveforms in order to calculate de power flow measured by the induction watt-hour meters and the output signal from photo-sensor.

In this context, control routines relating the data communication from devices to microcomputer and a friendly user interface to control all the tests procedures were developed, as is shown in Fig. 5.

The interface used for control the Measuring Yokogawa Standard was IEEE-488 bus (GPIB), and RS-232 for control WaveBook/516. The voltage transducers and current sensors are calibrated automatically by the software considering the reference voltage and current rms values in each phase provided by chosen profiles in the standard equipment at the start of experimental meter test.

III. CURRENT AND VOLTAGE PROFILES

There are database of current and voltage waveforms profiles where the harmonic content is regarding real cases acquired in consumers with different load characteristics (industrial, commercial, agricultural, and residential). Figure 6 shows examples of voltage and current profiles used in the experimental meter tests. In these examples the profiles providing situation with harmonic distortion only, and considering also unbalance of voltage waveforms.

Considering the two-phase induction type watt-hour meter, four profiles of current waveforms and five profiles of voltage waveform were selected to be used in the meters tests.

Thus considering the combinations of theses profiles, in order to compose arrangements of voltage and current waveforms pairs, and additionally the sinusoidal profile case, a twenty one pairs of profiles were available to be used in the experimental tests. It should be informed that the database can be increased with the insertion of additional cases.

In the same way, for three-phase induction type meters were selected five voltage waveform profiles and five current waveform profiles, totalizing a twenty six pairs of profiles available for tests (taking into a count a sinusoidal case). Moreover, the voltage profiles can be selected considering voltage unbalances of 3% or 5%.

Table 1 shows information regarding the harmonic distortion and the displacement angle of instantaneous crossover between voltage and current waveforms for some cases available in the system.

IV. EXPERIMENTAL TESTS

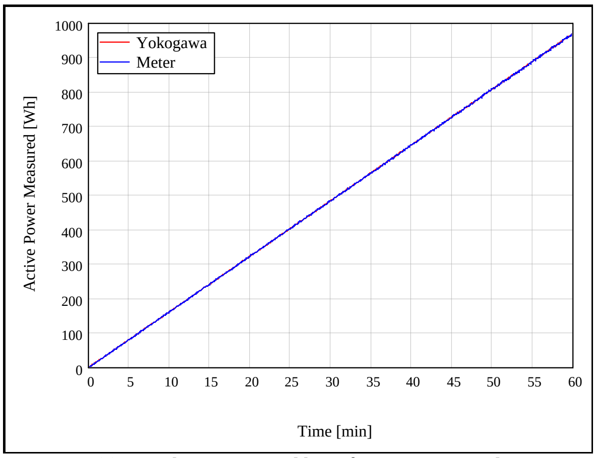
The experimental test considering one selected profile case demand one hour and thirty minutes (1h:30 min). The first thirty minutes stage is related with the thermal and mechanical stabilization time of induction meter and the remaining sixty minutes stage to accomplish the measurement test. In the second stage the system register the watt-hour measured by the meter under test at every complete lap of the disk, and register also the watt-hour measured by the reference meter at each five seconds.

Figure 7 shows results regarding one example of experimental test applied to a two-phase induction type watt-hour meter, 2% accuracy class, under low harmonic distortion conditions. Figure 7.(a) shows the registered watt-hour measurements, and Fig. 7.(b) shows instantaneous measured error presented by meter under test.

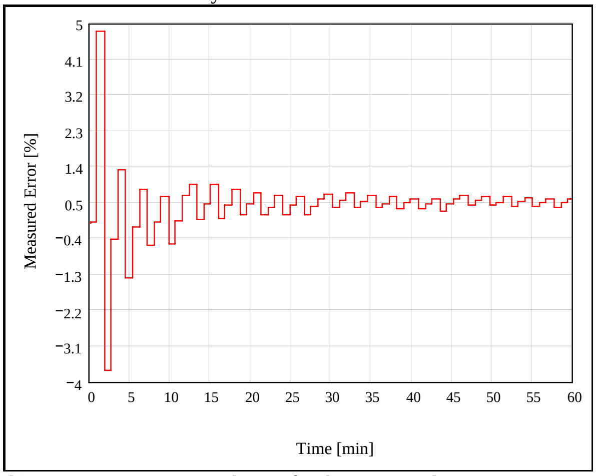
It should be noticed that an extensive number of experimental tests are performed, for each meter under analysis, employing all cases and situations available in the databases. After these experimental stages, generic models related with the standard meter, the meter under test, and the measurement error can be derived from these results through linear regression methods.

Table 1- Data of some profile cases.

V PROFILE	I PROFILE	THDV	THDI	Displacement Angle (θ)
v0	i0	0.80	0.25	0.00
tv1	tri1	3.02	46.80	34.99
tv1	indi2	3.02	4.46	34.99
indv1	tri1	4.76	46.80	18.40
indv1	indi1	4.76	18.40	18.40
indv1	rui3	4.76	7.54	18.40
indv2	tri1	1.89	46.80	53.56
ruv2	tri1	2.86	46.80	47.30
ruv3	tri1	2.49	46.80	23.54
ruv3	indi2	2.49	4.46	23.54



(a) Watt-hour measured by reference meter and by the meter under test



(b) Instantaneous measured error for the meter under test

Figure 7 – Experimental results, example for a two-phase induction type watt-hour meter under low harmonic distortion conditions.

In this way, using these models one can predict the expected measurement error presented by the meter tested under conditions not available in the system databases. Figure 8 shows a 3D behavior of derived models versus harmonic distortion of current and the cosine of displacement angle (θ) between voltage and current waveforms parameters, obtained from the experimental data, for a meter under test example.

V. CONCLUSIONS

A complete system to test measurement errors in active electrical energy meters of induction type, operating under harmonic distortions, and also considering balanced and unbalanced voltage waveforms conditions was presented. The analysis of measurement error is based on energy meter equipment with accuracy class of 0.1%, considered as a standard meter.

The main features of the proposed system include stable programmed profiles of voltage and current waveforms, with displacement control and harmonic distortions, database of current and voltage waveforms where the harmonic contents are regarding real cases acquired in different consumers (industrial, commercial, agricultural and residential), and control all procedures through an interactive manager software with a friendly graphic user interface.

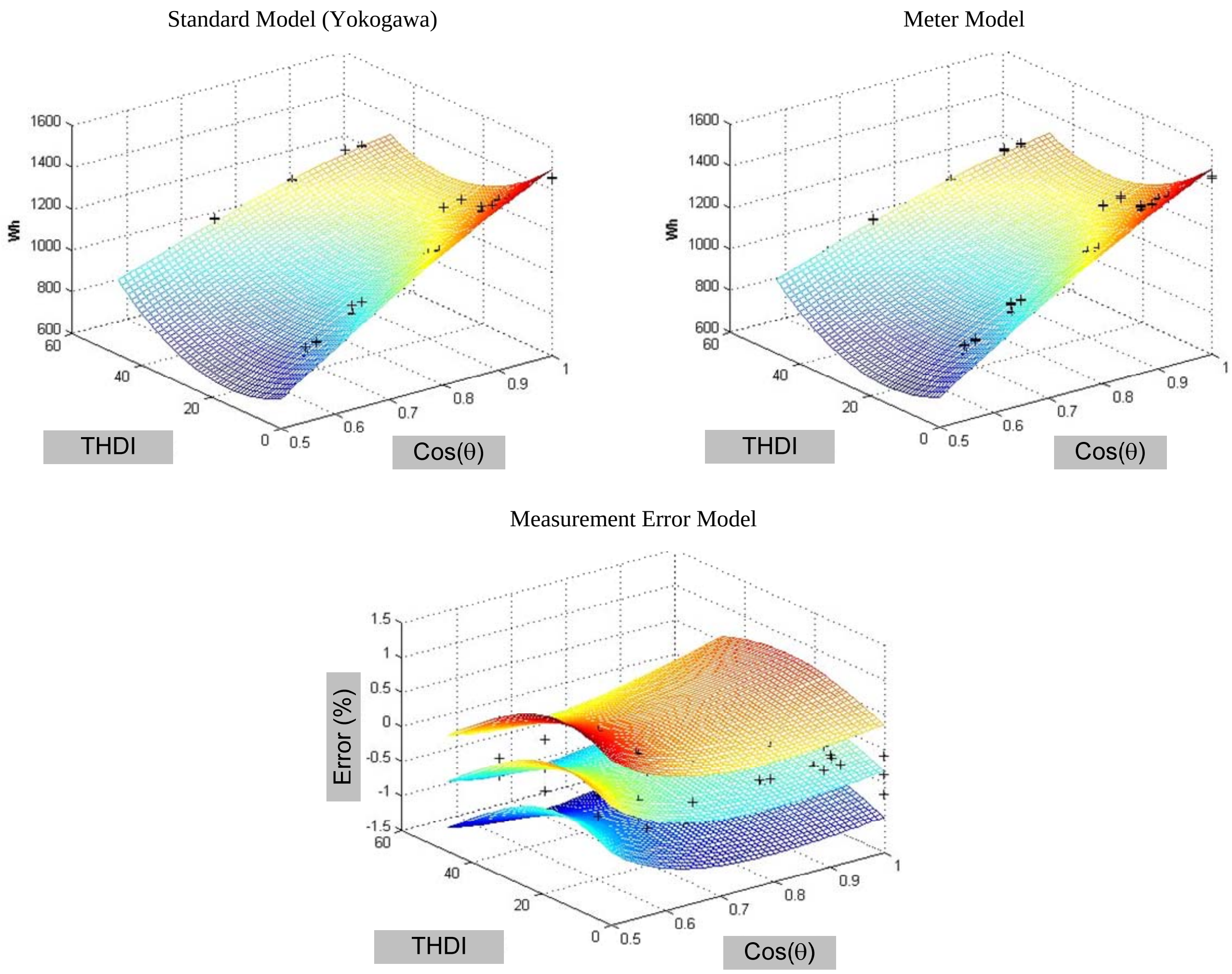


Figure 8 – Example of experimental derived models for the standard meter-Wh, the meter under test-Wh, and the measurement error, as a function of THDI and cos(θ).

A generic model related with the expected measurement error presented by the meter under test can be derived from experimental results provided by the proposed system through linear regression methods. These models can be used to predict the expected measurement error presented by the meter under conditions not available in the system databases.

REFERENCES

[1] A. Cavallini, G. Mazzanti, G.C Motanari " The Effect of Nonsinusoidal Supply on Life Performance of Electrical Insulating Systems" - International Conference on Harmonics and Quality of Power, 1996, CD-ROM;

[2] IEEE Task Force, -"Effects of Harmonics on Equipments" - IEEE Transaction on Power Delivery, Vol.8, N.2, pp. 672-680, April, 1993;

[3] K. Sangsun " Harmonic reference current generation for unbalanced nonlinear loads" - IEEE Power Electronics Specialists Conference, pp. 773-778, 2003;

[4] E. M. Makram e K. P. Thornton "Study of power system harmonics in an unbalanced system using the three-phase bus impedance matrix" - Proceedings of the Twentieth Southeastern Symposium on System Theory, pp. 30-34, 1998;

[5] A. A. Girgs et all "Testing the performance of three-phase induction watthour meters in the presence of harmonic distortion" - IEEE Transactions on Industry Applications, Vol. 26, N. 4, pp. 689-695, 1990;

[6] M. M. Saied " On the accuracy of watt-hour meters in nonsinusoidal environment" - IEEE Transaction on Industry Applications , pp. 2219-2225, 1995;

[7] E. Makram, C. Wright e A. Girgis " A harmonic analysis of the induction watthour meter's registration error" - IEEE Transaction on Power Delivery, Vol.7, N.3, pp.1080-1088, Jul, 1992;

[8] P. S. Filipski e R. Arseneau "Behavior of wattmeters and watthourmeters under distorted waveform conditions" IEEE Tutorial: Nonsinusoidal situations: effects on the performance of meters and definitions of power, IEEE Publications, 1990;

[9] R. Sasdelli et all "Revenue metering in the presence of distortion and unbalance: Myths and Reality" - International Conference on Harmonics and Quality of Power, pp. 42-47, 1998;

[10] C. W. Williams "Watthour meter accuracy under controlled unbalanced harmonic voltage and current conditions" - IEEE Transactions on Power Delivery, Vol. 11, N. 1, pp. 64-72, 1996.