# Performance Analysis of Electromechanical and Electronics Meters Under Current and Voltage Harmonics

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**Abstract** – *One of the important characteristics of energy meters is their accuracy. Due to the continuous increase of energy and especially electricity tariffs, consumers are looking for accurate meters that give the right measurement. However, the use of nonlinear loads leads to current and voltage harmonics production which presents the main cause of power losses, current and voltage distortion waveforms and measurement errors. In fact, this paper presents a comparative study of two types of energy meters which are Electromechanical and Smart Meter by giving the architecture and the accuracy of each meter and discussing the error sources coming from the meters itself. Moreover, it focuses on the effects of harmonics on the energy measurement and put attention on the importance of using an error function to estimate the error measurement value of the energy meter. Simulation results present the behavior of the two types of meters under harmonics, give an error function using System Identification Toolbox which is a linear ARX model and finally, prove that electronic meter gives less error and presents better performance under distorted current and voltage waveforms than the electromechanical meter.*

***Keywords***: *Single-phase Electromechanical Meter, Smart Meter, Accuracy, Measurement error, System Identification Toolbox*

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## I. Introduction

Energy is the basic necessity of life and exists in different forms in nature. We generally distinguish them into mechanical, nuclear, chemical and electrical energy. The last one is the most important as a result of its rising consumption day by day [1], and it is needed for different applications e.g. heat, lights and etc. In fact, what is important to consumers is to know how much power they consume and whether they are paying for the right amount of power consumption. That is why, electrical meter is used to measure the energy, and the essential characteristic of electrical meter is their accuracy which depends on many factors. In general, an electrical or energy meter is a device that measures the amount of electric energy consumed by a residence, a business or an electrically powered device.

In fact, energy meters are classified in accordance to several factors such as type of display i.e. analogue or digital electrical meter, end applications i.e. domestic, commercial and industrial and the technical aspect i.e. three phases, single-phase. For that, there are many types of energy meters, such as the standard meter which measures the number of energy unit used every hour, known as electromechanical meter which is a tool widely used to measure electricity at consumers, mostly households [2], then, then the digital meter or electronic meter which has a row of numbers displayed on an LCD screen and there is a button that must be pressed to get the reading displayed.

In earlier days, the function of energy meters were just to measure the power consumed by the user such as the case of classic energy meter, but now the meters are smarter enough not only to measure the energy consumption but also to give signal to the utility to cut or retain the supply by analyzing the data recorded by meters. These devices are known as Smart Meters.

As a matter of fact, a great deal of research proved that the measurement accuracy of the induction energy meter will drop when the voltage and the current waveforms deviate from the sine and distorted [3].

Furthermore, electronics meters can be affected by the presence of non-sinusoidal signals which lead to wrong measurement. According to the standard relevant for revenue energy meters such as EN50470-3:2006, the allowed measurement error is up to ±2.5 % [4].

The wrong and error measurement issue has been presented and discussed in the literature. Actually, [4] has proved that electromechanical meters have shown an acceptable performance compared to the electronics meters due to the complex architecture of the electronic types. However, according to [5], the measurement error is greater in electromechanical meters than the other types.

### *A. Contribution*

The present work originality lies in the estimation of an error function using System Identification Toolbox after analyzing experimentally the behaviour of energy meters (electromechanical and smart meter) under current and voltage harmonics.

Energy meters present the most important component of the electricity tariff measurement and the use of non-linear loads in the households or another placement presents the main problem of the wrong energy measurement.

The analysis of energy meters behaviour consists in using a square wave form as a voltage source to generate more harmonics in the circuit compared to sinusoidal wave form and also in using an RL load where the resistance $R$ is considered as the number of consumers used these electrical devices.

In fact, the aim of this analysis consists in explaining the behaviour of these meters under the presence of harmonics and whether they give the right measurement of power as calculated theoretically.

As a result, this paper proves and concludes that smart meter and especially electronic meter gives less errors than the analogue meter and presents an acceptable behavior under harmonics. Then, it aims to find an error function to calculate and estimate the measurement error of these meters.

### *B. Paper organisation*

This work is organized as follows: section two highlights the principle work as well as the architecture of each meter. Section three discusses the accuracy of these meters and the error sources that can affect the power measurement and focuses essentially on the effects of harmonics on the behaviour of these meters. The importance of using an error function to estimate the error of measurement is presented and detailed in section four. The simulation results are given and discussed in section five, and finally, the conclusion is given in the last sixth section.

## II. Electrical Energy Meters

### *A. Single-Phase Electromechanical Meter*

It was manufactured before 1970’s [6] and it is popularly known as a kilowatt-hour meter. The electromechanical meter has a rotating aluminium disk which turns even when very small amounts of electricity are being consumed. It essentially consists of the following components as is shown in the Fig.1 [7]:

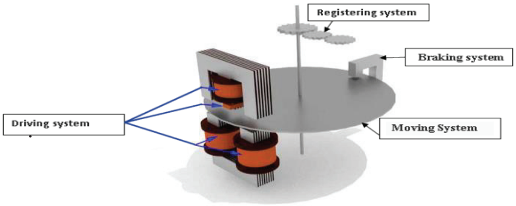

Fig. 1. Components of kilo-watt hour meter.

The operation principle of the Electromechanical Induction Meter has been widely described in the literature [4]. In fact, the driving system consists of two electromagnets made of silicon steel laminations which are shunt and series magnets, where the first one is composed of a fine wire of many turns, and is connected across the main supply. The current flows through it is proportional to the supply voltage [6], while the second magnet is composed of a heavy wire of a few turns and is connected in series with the load, carrying the load current.

The moving system contains a thin aluminum disc placed in the gap between the two electromagnets and mounted on a vertical shaft. Moreover, the braking system is required to control the speed of the moving system and to provide braking torque, and finally, the registration system also known as the counting system mainly consists of gear train which records a proportional number to the one of a disc revolution. The total torque of the moving disc is equal to the equation below [8],

$$\Gamma = k \times I \times V \times \cos(\varphi) \qquad (1)$$

where $k$ is a constant, $I$ is the load current, $V$ is the applied voltage and $\varphi$ is the load phase angle.

The total number of revolution made by the moving disc is a direct measure of the energy consumed by the load circuit.

### *B. Smart Meter*

Smart Meter or Solid State Electronic Meter is an electronic device that records consumption of electric energy in intervals of an hour or less and communicates that information at least daily back to the utility provider for monitoring and billing [6]. It was introduced in the late 1970's by the inventor Theodore Paraskevakos [6].

The smart meter architecture contains a microcontroller, analogue circuits and sensors which detect the current and voltage, converts the sensed values into digital form, and then sends them to the microcontroller, which processes the data, stores the reading in local memory, displays the information on a small LCD screen, and on a regular schedule, uploads the data to the utility provider via a communications interface.

The main section of the smart meter design is shown below in Fig.2.

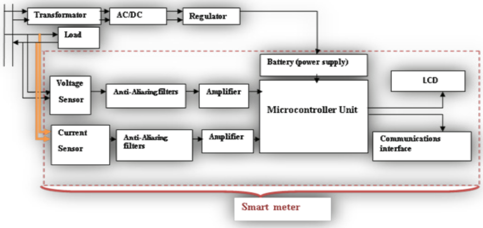

Fig. 2. Smart meter Architecture.

The main component of smart meter is the microcontroller unit since it contains the ADC converter which is responsible for converting the analogue signal to a discrete-time and amplitude signal and involves three functions namely sampling, quantizing and encoding.

In fact, the resolution of the ADC is defined by the number of bits in the signal processor, the more bits there are in the output, the closer the digital result will be to the analogue signal [9].

The equation of power given as shown below [9].

$$P = (1/n) \times \sum_{-\infty}^{+\infty} V_i \times I_i \qquad (2)$$

## III. Accuracy of Energy Meters

Consumers have noticed that their electricity consumption increases more and more without adding other electric equipment in the house or changing the number of loads, which means that there is a problem with energy meter accuracy. In other words, these meters do not give the exact energy consumption due to many causes which come from the meter itself or from the outside [10]. The expression of the measurement error is given by the following equation [11].

$$\varepsilon(\%) \frac{P_{th} - P_m}{P_{th}} \times 100 \qquad (3)$$

Where:

$P_{th}$: the power calculated theoretically

$P_m$: the measured power given by the energy meter

$\varepsilon$: the error

In fact, the electromechanical meter has a life span of at least twenty years, after which the disk could run slower and register up to 3% less electrical consumption [4]. However, [4] proved that electronic meters present an error up to 6%. Furthermore, a group of researchers in the University of Twente Enschede in the Netherlands has found that smart meters produced readings up to 583% higher than the actual energy used [12].

### *A. Errors due to the meter construction*

#### *a. Single-Phase Electromechanical Meter errors*

As previously stated, electromechanical energy meter is widely used for the measurement of energy consumed in domestic, as well as, in industrial installations. Since it is based on the induction phenomenon, it generates errors in energy reading.

As an explanation, it is necessary that the energy meter should give a correct reading on all power factors, which is only possible when the field set up by the shunt magnet lags behind the applied voltage by 90° [6]. So, phase errors are introduced because the shunt magnet flux does not leg behind the supply voltage by exactly 90° due to some resistance of the coil, iron losses and to the incorrect adjustment of the position of shading band.

Added to that, sometimes the disc of the energy meter makes a slow but continuous rotation at no load when the potential coil is excited but with no current flowing in the load. This is called creeping. This error may be caused by the overcompensation for friction, excessive supply voltage, vibrations, and stray magnetic fields. Moreover, the temperature variation can be considered as a source of measurement error when the resistance of the disc of the potential coil and characteristics of the magnetic circuit and the strength of break magnet are affected by the changes in temperature, which is insignificantly very small.

### b. Smart Meter errors

Smart meters are advanced devices that identify energy consumption more accurately than the conventional meters. They are designed to obtain information about when the energy was used, rather than just how much energy was used and communicate this information to the local utility provider for power monitoring and billing, On the other side, we cannot conclude that smart meters cannot give wrong measurement since its internal components could be affected by some errors such as the sampling and quantification error which comes due to sampling frequency. As an explanation, the sampling rate used to convert analogue signal to digital must be greater than twice the highest frequency of the input signal in order to be able to reconstruct the original perfectly from the sampled version. According to the Nyquist Shannon Sampling theorem [13], the condition for the sampling rate $f_s$ should fulfil the following equation (4).

$$\begin{gathered} f_s - f_{\max} \geq f_{\max} \\ f_s \geq 2 \times f_{\max} \end{gathered} \tag{4}$$

However, when the sampling rate $f_s$ is less than twice of the $f_{max}$ value, many information of the input signal will be lost. Therefore, an error during the power measurement will take place.

Besides, during quantization, an encoding error between the sampled signal and the value of corresponding code is produced. For the Linear Default, the power quantification error can be defined as [14],

$$P_\varepsilon = \prec \varepsilon^2(t) \succ = \frac{q^2}{3} \tag{5}$$

As for the Centered Linear Quantification, the power quantification error is given as [14],

$$P_\varepsilon = \prec \varepsilon^2(t) \succ = \frac{q^2}{12} \tag{6}$$

where $q$ is the quantum or LSB (Least Significant Bit) and is defined as the step of quantification

However, all these errors are negligible in front of those coming from outside the meter such as the presence of harmonics in the current and voltage input signal.

## B. Errors of energy reading due to the presence of harmonics

Harmonics which are coming from the use of non-linear loads become a very important issue to be learned and studied because if not treated correctly and immediately, then its impacts will be greater and adversely affect the performance of electrical equipment such as the accuracy of energy meters (electromechanical meter and smart meter) [15]. As a final point, harmonics are the external error of energy meter that causes the wrong measurement of energy consumption

In general, when a sinusoidal voltage is applied to a certain type of load, the current drawn by the load is proportional to the voltage and these loads are referred to as linear loads. In contrast, other loads make the current vary disproportionately with the voltage, and classified as nonlinear loads and the current and voltage have wave-forms that are non-sinusoidal, containing distortion as shown below in Fig. 3 [16].

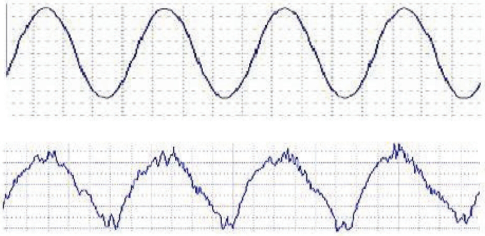

Fig. 3. *Distorted waveform.*

### a. Theoretical analysis of harmonics effects on induction meter

As it has been mentioned before, the Ferraris-based energy meters generate a torque on the rotating disk proportional to the active power.

This is done by generating a flux proportional to the voltage which interacts with a flux proportional to the current. These fluxes have the same frequency as the applied voltage and current. This mechanism causes the measurement error where it is designed and calibrated to operate correctly at the fundamental frequency.

Therefore, it may no longer performing correctly at the harmonic frequencies. Theoretically, the meter reflects the fundamental wave of the consumption power when the voltage and current supply are a sinusoidal wave. However it reflects the fundamental wave of the consumed power and that of the harmonics part when the supply power curve is distorted. As a result, when the current and voltage supply wave is deviated from sinusoidal or the frequency is changed, the electromechanical meter measurement accuracy will decline [17].

### *b. Theoretical analysis of harmonics effects on Smart Meter*

According to Fourier series, any periodic voltage waveform *v(t)* can be expressed as the sum of dc component $v_0$ which is equal to zero in general, and sinusoidal terms with fundamental frequency *f* [18] as shown below [18].

$$v(t) = V_0 + \sum_{h=1}^{N} V_{rms} \times \sin(hwt + \theta_h) \tag{7}$$

where,
$V_{rms}$: the effective value of harmonic $h$
$\theta$: Phase shift between the sine wave
$N$: harmonic number

Hence, the power measured by the meter will be the sum of the power of fundamental frequency and that of the harmonics, and this will cause wrong measurement.

## IV. Error Function

In order to estimate the error given by the meter, the best solution is to find a model that can help to calculate this error. For that, the main objective of this section is to identify a function that gives and estimates the power measurement error using the identification approach.

### *A. Modelling technique*

This approach deals with the building of a mathematical system based on the observed input and output. Therefore, the modelling technique used in this work is the system identification toolbox which gives model that describes the relationships between measured input and output data. The outputs are then partly determined by the inputs. Moreover, it is used for building a mathematical model of a dynamic based on the measured data and its principle is given in Fig. 4 [19]. The system principle will be explained more in the next section.

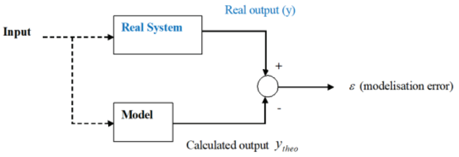

Fig.4. System identification principle

### *B. Models description*

In literature, various models have been proposed for system identification [20] such as ARX, ARMAX, and Transfer Function and etc [20].

### *a. ARX model*

The ARX model, known also as AutoRegressive with eXternal input, is a linear difference equation. The nature of this model is such that is particularly convenient to estimate the unknown parameters using linear regression [21] and its principle is given as in the following Fig. 5. It has a simple architecture and its polynomial representation are given respectively in equations (8) and (9) [21].

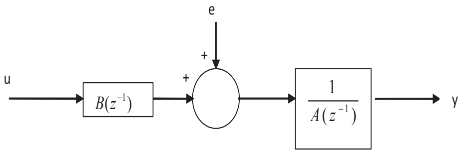

Fig. 5. ARX model principle.

$$\begin{aligned} y(t) = a_1 y(t-1) - \ldots - a_{na} y(t-na) + b_1 u(t-nk) + \\ \ldots + b_{nb} u(t-nb-nk+1) + e(t) \end{aligned} \tag{8}$$

$$A(z)y(t) = B(z)u(t) + e(t) \tag{9}$$

where $u$ and $y$ are the input and output of the system respectively and *e(t)* is the white noise which is in general converges to zero [21].

$$A(z) = 1 + a_1 z^{-1} + a_2 z^{-2} + \ldots a_{na} z^{-na} \tag{10}$$

$$B(z) = b_1 z^{-nk} + b_2 z^{-nk-1} + \ldots b_{nb} z^{-nk-nb+1} \tag{11}$$

where $na$ and $nb$ are the number of discrete output and input respectively, $nk$ is the time unit, and $a_k$ and $b_k$ are the parameters to be estimated.

### *b. ARMAX model*

An ARMAX model known also as AutoRegressive Moving Average with eXternal input, have been used extensively to represent the relationship of the system output and input in the presence of noise in many linear dynamic systems. Moreover, ARMAX model is essential and useful when dominating disturbances that have entered early in the process [22]. Its structure is similar to the ARX structure, adding a term, which represents the moving average error as shown in Fig. 6 [22].

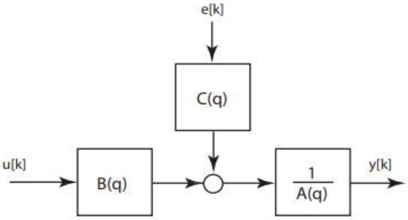

Fig. 6. ARMAX model principle.

*A(q)* and *B(q)* parameters are defined as in the ARX model while $C(q) = C(z^{-1})$ is defined as shown below.

$$C(z^{-1}) = 1 + c_1 z^{-1} + .... + c_{nc} z^{-1} \qquad (12)$$

As a result, the parameters to be estimated in this model are $a_k$, $b_k$ and $c_k$.

### *c. Transfer function*

The system identification of a transfer function consists of finding and identifying the parameters of the structure given in the following equation and Fig.7 [22].

$$y(t) = G(z^{-1})u(t) + H(z^{-1})e(t) \qquad (13)$$

where,

$$G(z^{-1}) = z^{-nk} \frac{1 + b_1 z^{-1} + \ldots + b_{nb} z^{-1}}{1 + f_1 z^{-1} + \ldots + f_{nf} z^{-1}} \qquad (14)$$

$$H(z^{-1}) = \frac{1 + c_1 z^{-1} + \ldots + c_{nc} z^{-1}}{1 + d_1 z^{-1} + \ldots + d_{nd} z^{-1}} \qquad (15)$$

As a result, the parameters vector estimated of this model contains [ $b_k$, $c_k$, $f_k$ and $d_k$].

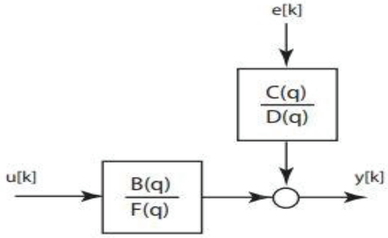

Fig.7. Principle of Transfer function model.

### *C. Parameters estimation*

The estimation of model parameters can be explained as a process which involves a mathematical optimization. In this paper the estimated model is chosen by using the prediction error method (PEM) [23] since the aim of this work is to minimize the measurement error given by the energy meters. The principle of this method is given below in Fig.8 [23].

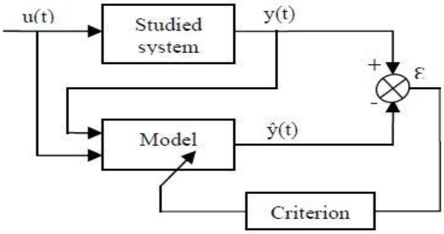

Fig. 8. Prediction error method (PEM) principle.

As a result, the prediction error is given as follow.

$$\varepsilon(k, \theta) = y(k) - \hat{y}(k / \theta) \qquad (16)$$

where $\varepsilon$ is the error, *y(k)* is the observed and the experimental output, $\hat{y}(k / \theta)$ is the predicted output while $\theta$ is the vector of the unknown parameters to be estimated given as follow.

$\theta = \left[ a_1 ......a_{n_a} b_1 ...b_{n_b} \right]$ : for ARX model

$\theta = \left[ a_1 ......a_{n_a} b_1 ...b_{n_b} c_1 ....c_{n_c} \right]$ : for ARMAX model

$\theta = \left[ a_1 ......a_{n_a} c_1 ....c_{n_c} d_1 ...d_{n_d} f_1 ...f_{n_f} \right]$: for the transfer function

It can be seen that according to the previous explanations, the ARX model structure has the simplest parametric structure and contains less parameter to be estimated compared to the other models.

## V. Simulation Results

The aim of this paper is to present the behaviour of the two types of energy meter under current and voltage harmonics, and whether it gives the right measurement of power consumption. It is also aim to find a function that helps to estimate the error measurement given by these meters. In order to reach this goal, a comparison between the power consumed by the meter and the theoretically calculated value is conducted in this section using MATLAB.

In these measurements, a shunt to protect the loads which is a coil of 66, 8 mH/5A, an inductance *L* and a rheostat *R* are used. *R* is similar in this work to the number of consumers, then, a differential probe known also as an active differential oscilloscope probe is used to permit the safe and accurate measurement of signals which are not referenced to ground. Moreover, it is used to see the waveform of the load current and voltage signal, and to take all the points in one period. After that, the power consumed by the load *P* is calculated in one period of time as is shown in the equation below.

$$P = \frac{1}{T} \times \sum v \times i \times dt \tag{17}$$

where $v$ is the voltage signal and $i$ the current signal consumed by the load, $dt$ is the difference between two successive values of time vector and $T$ is the signal period.

### A. Induction meter experimental measurement

The meter used in this section makes 375 turns which is equivalent to 1 kWh which means that one turn corresponds to 2.66 Wh. For that, the factor $Kh$ = 2.66 Wh is the factor used to convert rotations into unit of energy called watt-hours (Wh). Moreover, its accuracy class mentioned in its nameplate is 2, which means that the allowable error of this type of meter is ± 2%.

As mentioned previously, the value of rheostat *R* is similar to the number of consumers since this number is unknown. In other word, when *R* is higher it means that the number of consumers is higher as well, and it takes these values as shown below.

$R_1 = 8\Omega$, $R_2 = 21.74\Omega$, $R_3 = 43\Omega$, $R_4 = 56\Omega$

The selected values are just an example and can be changed and the voltage generated by the GBF is 1 $V_{p\text{-}p}$ with a square waveform to generate more harmonics.

The first step in this work is to use the first value of consumers $R_1$, then calculate the power at the fundamental frequency of 50 Hz), which means that the first period is 0.02 s. Then the frequency of the signal generated by the GBF is changed respectively as follows.

-100 Hz: the second harmonic
- 150 Hz: the third harmonic
- *h* x 50 Hz, where *h* is the harmonic number

Then, the number of consumers is changed accordingly. The setup used in this work is shown in Fig. 9.

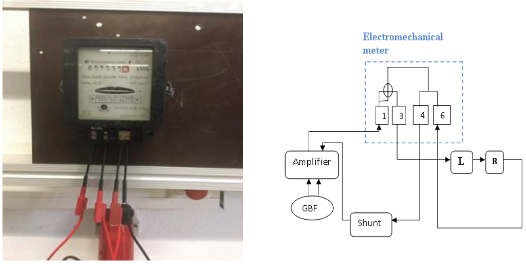

Fig. 9. Measurement montage with electromechanical meter.

After calculating the two powers using the frequencies from 50 Hz to 300 Hz, the results are given in the following Fig. 10, which shows the difference between the power given by the electromechanical meter (green curve) and the one calculated with the above equations (blue curve) for the four values of the rheostat.

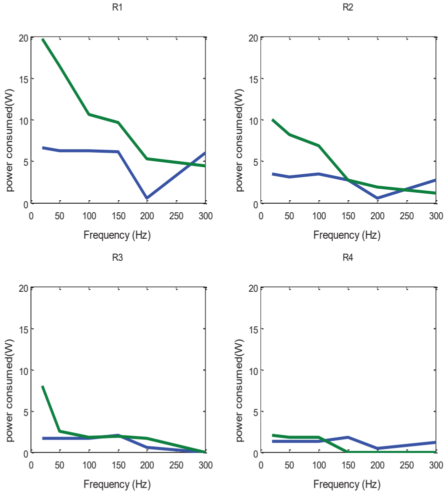

Fig. 10. Measured and theoretically calculated power of electromechanical meter.

The power measurement is limited at 300 Hz since it is found that the meter stops giving power reading from this value, which means that the sixth harmonic has affected the power measurement. The results are summarized in Table I.

TABLE I
SUMMARY OF RESULTS FOR INDUCTION METER

| $f$ (Hz) | 50 | 100 | 150 | 200 | 250 | 300 |
|---|---|---|---|---|---|---|
| $R_1$ $P_{th}$ (W) | 6.5 | 6.5 | 6.5 | 1 | 3 | 6 |
| $P_m$ (W) | 16 | 11 | 10 | 5.5 | 5 | 4.5 |
| $\varepsilon$ (%) | -1.53 | -0.0692 | -0.538 | -4.5 | -0.66 | 0.25 |
| $R_2$ $P_{th}$ (W) | 3 | 4 | 3 | 0.5 | 2.2 | 1.5 |
| $P_m$ (W) | 3 | 4 | 3 | 2 | 2 | 3 |
| $\varepsilon$ (%) | -1.66 | -0.75 | 0 | -0.3 | 0.1 | -1 |
| $R_3$ $P_{th}$ (W) | 2 | 2 | 2.2 | 0.5 | 0.2 | 0.01 |
| $P_m$ (W) | 2.5 | 2 | 2 | 2 | 1 | 0 |
| $\varepsilon$ (%) | -0.25 | 0 | 0.1 | -3 | -4 | 0.01 |
| $R_3$ $P_{th}$ (W) | 1 | 1 | 2 | 0.5 | 1 | 1.5 |
| $P_m$ (W) | 1.5 | 1.5 | 0 -0.5 | 0 | 0 | 0 |
| $\varepsilon$ (%) | -0.5 | 1 |  | 0.5 | 1 | 1.5 |

It is clear from the table that the electromechanical meter gives negative and positive power. In other words, it gives sometimes less power, or a higher power than the actual consumed by the load. Moreover, the error varies from -4% to 1.5 %, which is different from the allowable error given in its nameplate which is ±2 %.

Moreover, with the highest number of resistance $R_4$, the meter stops giving power from 150 Hz, which means that the third harmonic affects the measurement and makes the moving disc to slow down and eventually stops. In other words, the meter does not give measurement while there is a power consumed by the load.

### B. Smart Meter experimental results

Since the measurement principle of a smart meter is the same as of an electronics meter, the work is conducted using the same setup as previously as shown in Fi. 11 (no communication interface is necessary since the aim is to calculate the power).

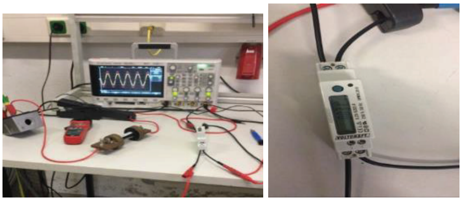

Fig. 11. Measurement montage with electronic meter.

Moreover, the accuracy class mentioned in the nameplate is class B which means the allowable error for this type of meter is ± 1%.

After number of measurements, the electronics meter does not support much higher frequency as the electromechanical meter. For that, the voltage generated by the GBF is changed to 4 $V_{p-p}$. Then the highest frequency supported by the electronic meter of 400 Hz is obtained. The following Fig. 12 shows the results which are summarized in Table II.

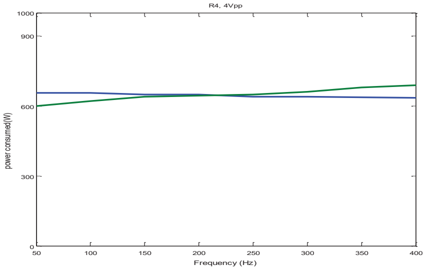

Fig. 12. Behavior of electronic meter under harmonics.

TABLE II
SUMMARY OF RESULTS FOR ELECTRONIC METERS

| $f$ (Hz) | $P_{TH}$ (W) | $P_M$ (W) | ε (%) |
|---|---|---|---|
| 50 | 680 | 600 | 0.117 |
| 100 | 680 | 650 | 0.0441 |
| 150 | 670 | 650 | 0.029 |
| 200 | 650 | 650 | 0 |
| 250 | 650 | 660 | -0.015 |
| 300 | 650 | 680 | -0.046 |
| 350 | 650 | 690 | -0.0615 |
| 400 | 650 | 700 | -0.0769 |

The electronic meter gives an error measurement from -0.07 % to 0.117 %, which is acceptable and does not affect the measurement because it is in the allowable error interval given in its nameplate which is ± 1%.

As a conclusion, the electromechanical meter gives a higher measurement error measurement than the solid state electronic meter. It also exceeds the allowable error limit given by the constructor. That is why it is recommended for consumers to use the electronics meter than the classical analogue device.

In order to easily calculate the error given by the meter, a model (function) called “error function” is needed, and this could be done by going through system identification.

### *C. Error function using System Identification Toolbox*

The aim of this section is to estimate an error function that helps to calculate the measurement error given by the energy meter and by using the System Identification Toolbox to estimate the unknown model as well as its parameters.

This simulation tool offers model that describes the relationship between measured input and output data which are partly determined by the inputs. Moreover, its field uses statistical methods to build the mathematical model of a dynamical system from measured data. Added to that, it includes the optimal design of experiments for efficiently generating informative data for fitting such model as well as model reduction [24].

In order to calculate the power consumption, the current and voltage waveform at the load need to be known. Therefore, the inputs are the harmonics amplitude in the frequency domain of the current, the voltage and the phase shift between them. Then, the output is the calculated power error. The model is described in Fig. 13.

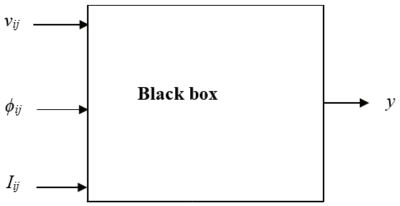

Fig.13. Model description.

$v_{ij}$: voltage amplitude of harmonic $j$
$I_{ij}$: current amplitude of harmonic $j$
$\phi_{ij}$: phase shift between and
$y$ : the power calculated by the difference of the power given by the meter and the measured one.
$j$ = number of harmonic
$i$ = the number of measurement.

Generally, for the LV network (public and industrial), the number of harmonics is limited at 25 [25], where after this number the harmonics begin to disappear. In this work, 8 is chosen as the harmonic number since the highest frequency supported by the meter is 400 Hz (8×50 Hz).

After calculating the input and the desired output, using the System Identification Toolbox, estimation is tried with various models such as the transfer function.

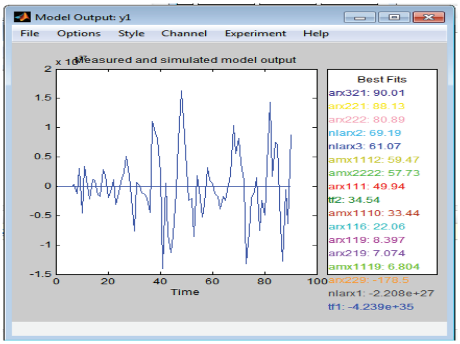

Fig. 14. Fitting of all the models.

The best model that should be near the experimental output is obtained after fitting all the models as shown in Fig. 14.

As shown in Fig.14, the blue curve has the best fitting and gives output near to the measured one and it has 90 as fitness value, which means that this model is near the experimental model with 90%. The results prove the efficiency of ARX model in term of speed convergence to the desired output. For that, it can be concluded that the best model is ARX321 as in the above equation (9).

As mentioned previously in section IV, after identifying the best model given by the System Identification Toolbox, the next step is to give the unknown parameters of this model which should be estimated. They are the parameters of *A(z)* and *B(z)* as well as the value of *na*, *nb* and *k*. First of all, the model is ARX321 with a result of

$$na = 3,\ \ nb = 2,\ k = 1$$

The estimated *A(z)* coefficients of the system output given by the identification tool are,

$$A(z) = 1 + 0.08405\ z\text{^-}1 - 0.01572\ z\text{^-}2 - 0.3433\ z\text{^-}3 \qquad (19)$$

The *u(t)* presents the system input and is defined as

$$u = [\, V_{ij} \ \ I_{ij} \ \ \varphi_{ij} \,]$$

As a result, the error function estimated in this work is the ARX model and its structure after defining its unknown parameters can be written as follow.

$$B_{20}(z) \qquad\qquad B_{21}(z) \qquad\qquad B_{24}(z) \qquad\qquad (20)$$

where $B_i(z)$ are given in the next Table III.

TABLE III
$B_i(z)$ COEFFICIENTS

| ***$B_i(z)$*** | |
|---|---|
| B1(z) = -0.7952z^-1 +0.4282z^-2 | B13(z) = -0.4858 z^-1 - 0.0549 z^-2 B14(z) = 0.3121 z^-1 + 0.4957 z^-2 |
| B2(z) =1.588z^-1-0.5681z^-2 | B15(z) = -0.8032z^-1 - 1.452 z^-B16(z)=0.01337z^-1- 0.9873z^-2 |
| B3(z) = 0.2345z-1+0.07136z^-2 | B17(z) = 0. 3934 z ^-1+3.134z^-2 |
| B4(z) = -1.128z^-1-0.3843z^-2 | B18(z) = -1.506 z^-1 + 0.133 z^-2 B19(z) = 2.364 z^-1 - 0. z^-2 |
| B5(z) = 3.821 z^-1 + 4.791 z^-2 | B20(z) = 0.674 z^-1 - 0.3928 z^-2 |
| B6(z) = -0.5677 z^-1 + 2 z^-2 | B21(z) = 5.325 z^-1 - 9.263 z^-2 |
| B7(z) = 0.6295 z^-1 - 8.545 z^-2 | B22(z) = -2.992z^-1 + 0.4694 z^-2 |
| B8(z) = 0.5349 z^-1 + 0.3828 z^-2 | B23(z) = -3.33 z^-1 + 1.396 z^-2 |
| B9(z) = -8.31 z^-1 + 3.731 z^-2 | B24(z) = 1.706 z^-1 - 1.329 z^-2 |
| B10(z) = -16.1 z^-1 - 7.348 z^-2 | |
| B11(z) = 0.1106 z^-1 - 0.05536 z^-2 | |
| B12(z) = -0.1116 z^-1 + 0.3234 z^-2 | |

System Identification Toolbox is a one of the techniques used to identify and to find the best model that presents and gives the best output which should be near and close to the reference and the desired output of the system. It aims to define and estimate the adequate unknown parameters which are the coefficient of *A(z)* and *B(z)* of the given model. It plays an important role in the error prediction method to make the predicted output as near as possible to the desired output.

## VI. Conclusion

In this paper, the accuracy of energy meters has been presented and discussed. The architecture of each meter (the electromechanical and smart meters) has been discussed in detail.

Furthermore, the effect of harmonics on these energy meters behavior has been discussed and the system identification used to estimate the function error as well as the different model that can be identified have been defined and explained.

Added to that, a comparison study of the performance of these meters under harmonics presence has been presented and shown. As a result, the analogue meter supports much more harmonics than the electronics type, nevertheless, it gives higher errors compared to the electronics type of meter.

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