A Study of Single Phase Static Energy Meter Behavior during Voltage Dips

Alshaimaa Mohamed Nasr\textsuperscript{1} Doaa Khalil Ibrahim\textsuperscript{2}, Member IEEE,
Soheir Fakhry\textsuperscript{1}, Mohamed Mamdouh Abdel Aziz\textsuperscript{2}, Senior Member IEEE,
\textsuperscript{1} Egyptian National Institute for Standard, Egypt
\textsuperscript{2} Cairo University, Faculty of Engineering, Egypt

Abstract- This paper discusses the impact of voltage dip (sag), with different dip levels and durations on single phase static meters accuracy. The paper also studies meter sensitivity to voltage dip by plotting its tolerance curve. The examined meters have different meter constants of same manufacture. Investigating harmonic content in addition to voltage dips effect on the tolerance curve for energy meter had been done. All the testes were executed at the power and energy lab of the NIS (Egyptian National Institute for Standard), using high accuracy devices.


I. INTRODUCTION

The measurement of electricity is a complex process. Achieving accuracy and equity in the trade of electricity requires an effective system for achieving metrological control, and a consistent application of the measured quantities. All of these require great awareness of: electricity delivery configurations, the measurement principles, the quantities being measured, the purpose of the measurements, and how accuracy and equity are achieved. Accurate measurement of electrical energy becomes more essential, as electrical energy is a vital ingredient in the economic development of any country. Obviously, customers are keen to ensure that they are getting what they pay for, and distributor is keen to ensure that power supplied does not adversely affect the integrity of the network [1].

NIS (Egyptian National Institute for Standard) is responsible for maintaining of the national measurement standard of AC power and energy traceable to SI through its power primary standard with power accuracy less than 30 ppm; it serves as the basis for dissemination of traceability in measurement through high level calibration and measurement services to various organizations in Egypt. It has the highest metrological qualities such as high stability, reproducibility and low drift. The power and energy lab of the NIS serves a wide area of Egyptian meter manufactures whose intend to get approval or verification certificate. As most of the energy meters manufactures export their production to Middle East and African countries, they strongly need to ensure the high quality and accuracy level of such exported meters.

As reliability and quality are the two most important factors of any power delivery system, a power distribution system is reliable if all its customers get interruption free power for 24 hours a day and 356 days a year. The term power quality is often referred to maintain a near sinusoidal voltage at the stipulated frequency of 50 or 60 Hz at the customer inlet points. It could be argued that maintaining voltage levels and frequency are the responsibility of generation. However, there is no guarantee that the customers get quality power, even if the generation quality levels are met.

The power quality problems of power distributions systems are not new, but customer awareness of these problems had increased. There are sets of conventional solutions to the power quality problems which have existed for a long time. Most of these conventional solutions do not always respond correctly as the nature of power system conditions changes [2]. Some customers are very worried of voltage dips (sags) [3]. Voltage dip is one of power quality problem which is a sudden reduction of the voltage at a particular point on an electricity supply system followed by its recovery after a brief interval [4]. In addition, there are some very sensitive loads such as hospitals (life support, operation theatre, and patients' database systems), processing plants (semiconductor, food, rayon and fabrics), air traffic control, financial institutions, and service providers which require uninterrupted clean power. In several processes, such as semiconductor manufacturing or food processing plants, a batch of product can be ruined by voltage dip of very short duration.

The primary source of voltage dips is the electrical short circuit occurring at any point on the electricity supply system. The short circuit causes a very large increase in current, and this, in turn, results in large voltage drops in the impedances of the supply system. Therefore, at almost every other point on the system the voltage is reduced, more generally, to a less extent. As any change of voltage, current or impedance at one point instantaneously brings a change at every other point on the system [5].

Most voltage dips and short interruptions are rectangular in shape and approximately only 10\% of the events are non-rectangular (not constant dip level) [6].

For domestic loads, first point of electricity customers starts with the energy meter which is the important subject settled to measure the amount of energy between the supplier and the customer [7]. So, it’s quite important to study the performance of the energy meter during dip phenomena, and the impact (effect) of the dip on its accuracy [8].
Type tests were carried out with reference power standard meter Com-303 with accuracy less than 100 ppm (part per million) (0.01%) at the power and energy lab of the NIS [9].

The paper presents extensive experimental results that demonstrate the sensitivity of single phase energy meters to voltage dip event, not only regarding to the device malfunction criterion, but also investigating the meter reading accuracy during the dip events. In addition, the single phase static energy meter sensitivity is tested at supply voltage with/without harmonics up to 20% THD [10].

The rest of the paper is organized as follows: Section II describes the experimental setup used. Section III explained the laboratory reference conditions required for tests. Section IV presents the meter acceptability curve. Sections V and VI demonstrate accuracy test description and results. Finally, Section VII concludes the work.

II. SET UP DESCRIPTION

Three single phase static energy meters which already passed NIS type test and fulfilled the requirements of tests mentioned in IEC standard 62053-21 had been tested in this study [8]. The three meters are: 220 volt, 50Hz, class 1. Table 1 annotates the error limits for the common meter class 1 for measuring active energy according to IEC 62053-21. Meters' nominal currents, maximum currents and meter constants are illustrated in Table 2.

<table>
<thead>
<tr>
<th>Test Current Value</th>
<th>Power factor</th>
<th>Percentage Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.05 Ib ≤ I &lt; 0.1 Ib</td>
<td>1</td>
<td>± 1.5</td>
</tr>
<tr>
<td>0.1 Ib ≤ I ≤ Imax</td>
<td>0.5 inductive</td>
<td>± 1.0</td>
</tr>
<tr>
<td>0.2 Ib ≤ I ≤ Imax</td>
<td>0.5 inductive</td>
<td>± 1.0</td>
</tr>
<tr>
<td>Specially requested by the user: 0.2 Ib ≤ I ≤ 1 Ib</td>
<td>0.25 inductive</td>
<td>± 3.5</td>
</tr>
</tbody>
</table>

Table 1: Maximum error limits for class 1 direct connected meter according to IEC 62053-21.

Table 2: Tested meters data.

<table>
<thead>
<tr>
<th>Meter</th>
<th>Nominal current</th>
<th>Max current</th>
<th>Meter constant</th>
</tr>
</thead>
<tbody>
<tr>
<td>First meter</td>
<td>10</td>
<td>80</td>
<td>1000 impulse/kWhr</td>
</tr>
<tr>
<td>Second meter</td>
<td>10</td>
<td>40</td>
<td>1600 impulse/kWhr</td>
</tr>
<tr>
<td>Third meter</td>
<td>10</td>
<td>50</td>
<td>3200 impulse/kWhr</td>
</tr>
</tbody>
</table>

The experimental set-up shown in "Fig. 1" had been used for the experimental tests carried out in this paper.

As static electricity meters, almost without exception, use a technique of generating pulses to indicate the amount of energy they have measured. Each pulse presents a specific quantity of watt-hours. Tests are typically carried out using a reference measurement technique. A known amount of energy is simultaneously supplied to a reference meter and to the unit under test (UUT). The reading from the reference meter is then compared to the reading from the UUT and the error is calculated.

Therefore, at least two separate pieces of equipment are typically required to complete this task:
1. An energy supply (a power supply).
2. A reference energy meter.

In this setup:
- The Fluke 6100A is simply used as the energy supply (supply current and voltage from two separated circuits). As Fluke 6100A sets a new benchmark for accuracy in power standards. Voltage and current are generated up to 6 digits resolution and accuracies approaching 100 ppm (0.01%).
- The reference energy meter is also a pulse comparator, MTE 2.3 plus, Portable Working Standard for testing electricity meters which allows checking of all meter installation parameters and associated circuits. Its accuracy class is 0.1 which is higher than meters under test accuracies [11].
- Qualistar C.A 8334 is used as monitoring equipment gives an instantaneous image of the main characteristics of the quality of the electrical network with high accuracy ± 0.5% that used to ensure and investigate the applied power waveforms during the test.

III. LABORATORY REFERENCE CONDITIONS

In order to minimize the impact of environmental parameters on study test results, the tests shall be carried out in the climatic and electromagnetic reference conditions as follows:
1- General test conditions: The tests shall be carried out only on a complete meter, with its cover, its terminal
screws being screwed down to the maximum applicable conductor fitted in the terminals (cable length between reference generator and meter is 1m).

2- Climatic conditions: These must be ensured within limits specified for the meter operation and test equipment as specified by their manufacturers. Tests shall not be preformed if the relative humidity is so high to avoid condensation on the meter or the test equipment. The allowable climatic conditions are specified below [8]:
- Ambient temperature: 15 °C to 25 °C;
- Relative humidity: 45 % to 75 %;
- Atmospheric pressure: 86 kPa to 106 kPa.

3- Electromagnetic conditions: These shall guarantee the correct operation of the meter in order to have no influence on the test results [4]. All the system set up is executed inside a faraday cage.

IV. METERS ACCEPTABILITY CURVE

The energy meter had been tested as a load connected to the network and suffers from same problems which any load met, moreover meter is the energy supply gate to loads [12]. Voltage dip doesn’t cause energy meters failure, the main problem is the effect on the meter error and its accuracy (as it will be discussed later). Although, some researches consider voltage dip as one of the electrical stresses that affect the semiconductors life time. Load acceptability (tolerance) curve is a way that describes the load sensitivity for the voltage dips; it’s used to determine how the supply voltage characteristics affect load operation. These curves are plots of bus voltage deviation versus time duration. In such plots, the bus voltage deviation - time duration plane are separated into two regions: an “acceptable” and “unacceptable”. Various power acceptability curves exist but the most widely publicized one, which could stand the test of time and could be relied on, is the “Computer Business Equipment Manufacturers Association” or CBEMA curve as shown in "Fig. 2." has been used as a measure of power quality indices for electric drives and solid-state loads [6], [13]. Although CBEMA was originally developed for the equipment connected to the 120-V/60-Hz AC supply, it has been widely used to evaluate the performance of various electrical and electronic equipment operates at different nominal voltages and/or frequencies. After the extensive research in computer power supplies in 1995, the CBEMA curve was revised and “renamed” (ITIC) or the Information Technology Industry Council curve. But, such curve should be strictly applied to single-phase “information technology” equipment with 120-V/60–Hz-rated conditions [6], [13].

The equipment sensitivity to voltage dips is usually expressed only in terms of the magnitude and duration of voltage sag. For this purpose, the rectangular voltage–tolerance curve shown in "Fig. 3" is used.

Rectangular voltage-tolerance curve indicates that deeper voltage dips than the specified voltage threshold (Vtr) and longer than the specified duration threshold (Tmax) will cause a malfunction (or trip) of the equipment [10],[14].

"Fig. 4" , "Fig. 5" and "Fig. 6" are the load acceptability curves for meters 1000, 1600 and 3200 imp/kWhr respectively considering energy meter as a load fed its energy from the utility network and compared it with CBEMA lower curve (under voltage conditions). These curves had been drawn according to real experimental time tests. Tests are performed with rectangular voltage dips and an ideal voltage supply 50Hz frequency at nominal rated current (10 A) and unity power factor. Malfunction here refers to turning off the indicator lamp (-p) (which indicates that the current is reversed) and pulse outing id delayed due to dip events.
The figures illustrate that meter tolerance curves are totally below the lower CBEMA curve, including part of the normal operation region as well. Moreover none of malfunction area for all meters out of the CBEMA curve undervoltage region.

The influence of harmonics on the load acceptability curve is also tested for the meter with constant 1600 imp/kWhr. Third and fifth harmonics orders of at 5%, 10% and 20% levels are examined. "Fig. 7." illustrates the acceptability curves for voltage with third harmonic content with 5%, 10% and 20% levels compared with meter curve of ideal voltage supply. As shown, the effect of the third harmonic is less than that effect of third harmonic, curves had moved little to left hand side and same for upper side, malfunction area increased, but with small increment.

V. ACCURACY TEST PROCEDURE

First, the under test meter is fed with a recovery 220V, 50Hz voltage and pure sine current 5A with PF 0.8 lagging.

Measuring meter error is achieved using reference meter which indicates the error per one meter pulse using its optical scanning head recording. The error readings are recorded for 10 readings.

Applying voltage with dip 0%, 0.2s duration, 0.0001s ramp in time and 0.0001s ramp out time. But for the first meter (1000 imp/kWhr), the dip time was 0.8 sec to realize the effect of dip since the pulse time is larger.

"Fig.9." illustrates acceptability curve for voltage with 5th harmonic content of 5%, 10% and 20% levels compared with meter curve of ideal voltage supply. As shown, the effect of the 5th harmonic is less than that effect of 3rd harmonic, curves had moved little to left hand side and same for upper side, malfunction area increased, but with small increment.
Recording again the ten times error per one pulse of the
meter, the pulse outing is a pulse had suffered the
voltage dip phenomena.

Voltage dips are again applied but with different levels
and durations: 10% dip for 0.2 sec, 40% dip for 0.2 sec
(except for 1000 imp/kWhr meter, time will be 0.8 sec), 70%
for 0.5 sec (except for 1000 imp/kWhr meter, time
will be 5 sec) and 80% for 5 sec duration [15].

Recording ten times error in every test to find out the
effect of both dip level and duration on error reading.

Same steps are repeated for currents: 10 A and 20 A.

After finishing all the tests for the three currents, the
meter is again tested for type tests.

VII. Test Results

After recording ten readings of energy percentage error for
each meter of the three tested meters, the average percentage
errors are calculated as follow:

Average percentage Error = \[ \frac{1}{10} \sum_{i=1}^{10} \% \text{Error} \]

- The average percentage errors for the three tested meters
  with pure voltage at three different current levels are
  illustrated in "Fig. 9."

- The average recorded ten times errors for 5A, are compared
  for the three meters due to 0%, 10%, 40%, 70%, 80% dips
  and shown in "Fig. 10." As illustrated, it is nearly the same
  for 70% and 80% dips but the error is extremely increased
  and drift in the negative direction for dips 0%, 10% and
  40%.

- The comparison between the three meter average errors at
dips 0%, 10%, 40%, 70% and 80% levels for 10A current
  is illustrated in "Fig. 11." Nearly 70% and 80% errors are
  the same, and the effect is less than the other levels. But the
  error of meter 1600 imp/kWhr is greater than the error of
  3200 imp/kWh.

- The comparison for the three meters at 20A is shown in
  "Fig. 12." In such case, the effect of current increasing is
  appearing for meter 1000 imp/kWhr. In addition, for 70% and
  80% dips, errors of the three meters are not the same as
  for 5 and 10 A cases, and the effect is less than the other
  levels. As shown, the error of 1600 imp/kWhr meter is
  greater than the 3200 imp/kWh.

- It is interesting to note that some standards related to the
testing of the equipment sensitivity to voltage dips and
short interruptions suggest that the tests should be
performed preferably at 0° point on voltage waveform, but
Standard IEC 61000-4-11 [15] concludes that testing of the
equipment “can start and stop at any phase angle”
(preferably at 0°) [10].
VIII. CONCLUSIONS

- The static energy meters are satisfying CBEMA standard, and each meter has its own malfunction area. Adding harmonics to the dip phenomena causes increasing in the malfunction area depending on the harmonic order and its amplitude.

- The error behavior for the three tested meters is nearly the same in positive direction and inside the acceptance limit of IEC (as mentioned in Table 1) for the three current levels with normal voltage without any dips.

- When the meters are tested under dip voltages, the error is totally changed:
  - The error is reversed in the negative direction for the three meters for deep dips.
  - Error value is raised when the current is raised especially for 1000 and 1600 meter constant, but in 3200 case it is drift, that maybe occurred as the pulse time is so small.
  - The dip level affects the percentage error. It’s raised in negative direction especially for 0%, 10% and 40%. The effect of the dip is decreased for 70% and 80% dip.
  - For 3200 and 1600 meters with dips 0%, 10% and 40%, all the average errors for all current are outside the limitation of the IEC requirements. However, for 70% and 80%, the average errors are around the limitation of the IEC.
  - For 1000 imp/kWhr meter, the average error is around the limitation of the IEC for all dips levels for 5A current only. For 10A and 20A, the average errors go outside the limitation of the IEC requirements (error also increased with the current) for 0%, 10% and 40% dip levels.
  - Increasing dip effect as the meter constant increases isn’t a fixed rule, as 1600 errors are greater than 1000 errors, while 3200 errors are greater than 1600 errors in some measurements and less than 1600 errors in some other measurements.
  - The type test had been repeated for the three meters after finishing all the study tests, and the meters give acceptable results in all the type tests especially in accuracy test.

REFERENCES


BIographies

Aishimaa Mohamed Nasr was born in Egypt in Oct 1981. She graduated from Cairo University, Faculty of Engineering in 2003. She joined the High Voltage Metrology in NIS from Oct. 2004. From Jan 2005, she works in reference laboratory for power and energy measurements. She joined the M.Sc. program in electrical engineering, Cairo University from 2005.

Doaa khalil Ibrahim (IEEE M’06) was born in Egypt in Dec. 1973. She graduated from Cairo University, Faculty of Engineering in 1996 and received the M.Sc. and Ph.D. in digital protection from Cairo University at 2001 and 2005, respectively. From 1996 till 2005 she was a demonstrator and research assistant in Cairo University. In September 2005, she became an assistant professor with Cairo University. From January 2009, she contributes in the Program of Continuous Improvement and Qualification for Accreditation in Higher Education in Egypt. Her research interests include digital protection of power system, utilization and generation of electric power and renewable energy.

Soheir Fakhry head of High Voltage Department in the NIS (National Institute of Standards in Egypt). She has B.Sc. in Electrical Power and Machines, Faculty of Engineering, Ain Shams Univ in 1967. She received her PhD in 1974 (Electrical Measurements) from Technical University Ilmenau – Germany. From 1997 till 2002 she was the head of Electrical and Electronic Metrology Division. From April 2002 till Dec. 2005, she was the vice president of NIS. She was the responsible of Establishment of the reference laboratory of high voltage measurements, reference laboratory for EMC, reference laboratory for power and energy measurements, Establishment of type test laboratory for Electricity Metering Equipment, and Establishment the National Primary Standard of power and energy.

Mohamed Mammadou Abdel Aziz (IEEE M’80-IEEE SM’05) is professor of Electrical Power and Machines. He has a B.Sc., M.Sc., Ph.D in Electrical Power and Machines, Cairo University, Egypt, 1970, 1972, and 1975 respectively. He is currently a professor in the Department of Electrical Power and Machines, at Cairo University. Dr. Abdel Aziz has been member of the Institute of Electrical and Electronics Engineers. On the technical side Dr. Abdel Aziz is author or co-author of many refereed journals and conference papers. Areas of research include cables, contact resistance, harmonics, power quality, photovoltaic systems, and wind energy systems.