RELIABILITY PREDICTION METHODS – THE PROCEDURE USED BY EDP

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ABSTRACT

Over the years, due to technological developments, the electrical meters became increasingly important to the power distribution system.
Until a few years ago all electrical meters were electro-mechanical and its only mission was for metering purposes. From the technological point of view, they were very mature and reliable devices.
With the smart grid development, the new electrical meters have a much wider range of functions in addition to metering.
Reliability prediction is a statistical process that aims to anticipate the future, based on known information from the past. So, these prediction methods are used to determine the probability of an equipment being in operating or non-operating state, in certain time interval.

EDP Distribuição collects information to predict the static meters reliability through the following steps:

- *Computations to predict the reliability of the meters;*
- *Information collected from the field;*
- *Laboratorial tests.*

This paper details EDP's procedure to predict the static meters reliability based on the steps mentioned above.

INTRODUCTION

The new generation of electrical static meters (namely smart meters) sets new goals but also concerns about their reliability regarding the following risks:

- It is expected an increase of failure rate, due the massive utilization of complex electronic components;
- Not all the used technologies are mature enough to ensure an acceptable failure rate;
- Potential financial and reputation losses, due to the premature meters substitution caused by higher failure rate.

EN 50470-3 [1] standard refers that the static meter should be designed to work on a reliable basis, reducing as much as possible failures that could result in measuring errors.
This standard indicates that the conformity of this requirement can be checked either by the execution of specific tests or by inspection of the documentation presented by the manufacturer.
CEI 62059-31-1 [5] describes the test methods to predict the equipment's reliability, by applying high temperature and humidity. However, this standard does not define any rejection or acceptance criteria.
This paper proposes and details a procedure in order to predict the static meters reliability.

COMPUTATIONS TO PREDICT THE RELIABILITY OF THE METERS

The IEC 62059-41 [7] provides guidance on how to predict the meter reliability based on the life time of each component. The basic assumption is based on simple series model, i.e. it is assumed that the failure of any component leads to a system failure. In addition, all failure rates are assumed to be constant for the time period considered. In order to compute the failure rate of the meter, it is necessary to sum the failure rates of each component under their respective operating conditions.

In case of life limited components it is also necessary to check if the component is in the constant failure rate period, in order to validate this method.

Static meters are composed of several functional systems (i.e. communications module, metering, memory, I/O, power supply and the enclosure) and the failure of any of them may result in a meter failure.

The instantaneous failures rates vs. time is modelled by the well-known bathtub curve. As can be seen in Figure 1, this curve can be divided into three time periods. First, at the beginning the failure rate is higher and corresponds to "infant mortality", then the failure rate decreases substantially and a constant failure rate is achieved. Finally, the end of life period corresponds to an increasing failure rate.

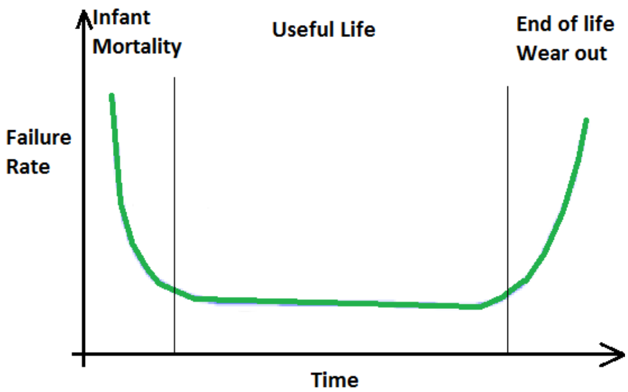

Figure 1 - The bath curve

This analysis considers that the failure rate of each functional system is constant with a well known value.
The meter failure rate is computed by the sum of the failure rate of each of its functional systems. The inverse of the failure rate corresponds to the *Mean Time To Failure –*

MTTF.
In order to know the failure rate of each component is necessary to check specialized manuals such as the Siemens standard SN 29500 [9], or by collecting information of its manufacture. The value achieved of failure rate of component *i* corresponds to a failure rate at reference conditions (temperature, humidity, voltage, current, and another other conditions) – λ_{ref_i}.
Accordingly the IEC 62059-41, to compute the failure rate at different conditions from the reference the following expression is used;

$$\lambda_i = \lambda_{ref\_i} \cdot \pi_U \cdot \pi_I \cdot \pi_T$$

Where,

π_U is the voltage factor;

π_I is the current factor;

π_T is the temperature factor.

If the π_x value is equal to 1, then the component is at reference condition regarding *x* condition. If the π_x value is higher than 1, then the component is in conditions more rigorous than at reference condition regarding *x* condition. If the π_x value is lower than 1, then the component is in conditions less rigorous than at reference condition regarding *x* condition.

As mentioned above the meter failure rate is the sum of each component, and the MTTF is its inverse value;

$$\lambda_s = \sum_{i=1}^{N} \lambda_i \text{ or } MTTF = \left(\sum_{i=1}^{N} \lambda_i \right)^{-1}$$

It is defined the reliability function as:

$$R(t) = e^{-\lambda_s \cdot t}$$

This function indicates the probability of the equipment be with right conditions to work properly after *t* time.
The IEC 61709 [2] defines expressions to compute the values of voltage, current and temperature factors in function of the operational, nominal and reference conditions.
The IEC 61709 [2] doesn't present the influence factors regarding humidity, pressure, or mechanical effects.

INFORMATION COLLECTED FROM THE FIELD

The IEC TR 62059-21 [4] describes methods to collect and analyze data from the failed meters in the field. This technical report classifies the meters based on its complexity, operating conditions, reasons for removing the metering equipment from service, criticality and cause of the failures. Sampling plans and information about the source of failure are also presented in this technical report.

LABORATORIAL TESTS

Two types of laboratorial tests can be done to assess the reliability of static meters: accelerated reliability tests and tests to check the metrological characteristics of static meters when submitted to high temperature rates.

Accelerated Reliability Tests

According to IEC 62059-31-1 accelerated reliability tests can be performed by applying stress conditions (such as temperature and humidity) in order to reduce the time to failure.
In this method the aging time of the meter is accelerated according to the factor computed by the following expression;

$$AF = \left(\frac{HR_s}{HR_u} \right)^n \cdot e^{\left(\frac{E_a}{k} \cdot \left(\frac{1}{T_u} - \frac{1}{T_s} \right) \right)}$$

Where,

HR_u is the relative humidity at normal operation conditions (70%);

HR_s is the relative humidity at stress operation conditions (85%);

T_u is the temperature at normal operation conditions (293 K);

T_s is the temperature at stress operation conditions (358 K);

E_a is the activation energy (0,9 eV);

n is a constant that is equal to 3;

k is the Boltzmann constant that is equal to 8,617 x 10^{-5} eV.

With this values the AF factor is equal to 1158, i.e, for each day period (24 h) the meter aging is approximately 38 months.

Variability of Meters Metrological Characteristics by Applying High Temperatures

High temperatures can also be applied to the meter to check the variability of its metrological characteristics.
In this test, first off all, it is necessary to measure the initial error of the meter. This can be done with the average value of three consecutive measures on several load points at reference conditions, for instance, power factor of 1, 0.5i and 0.8c for I_{max}, I_r and $I_r/10$.
Then, the meter is exposed for 1000 hours to the voltage of $1.1 \times U_{NOMINAL}$, the current of I_{max}, and the temperature

of maximum operational temperature (the manufacturer should specify this value, if not, then it should be used 55 ºC).
During the 1000 hours test at every 48h should be measured the meter error, which could not be higher than:

$$E_{\max} \leq 2 \times \sqrt{er^2 + eU^2 + eT^2}$$

Where,
er is the meter error at reference conditions;
eU is the maximum error variation due to the voltage;
eT is the maximum error variation due to the temperature.

At the end of this test the meter should be exposed again at reference conditions and the error measured at these conditions should not be higher than 50% of the initial error measure.

ACCELERATED RELIABILITY TESTS DESCRIPTION

Recently EDP Labelec has started performing the accelerated reliability tests. The duration of each test is 1000 hours. In this paper it is presented the preparation stage and it is exposed the first results.
In Figure 2 and Figure 3 it is shown the preparation stage of the test.

Figure 2 - Smart meters inside the temperature and humidity test chamber

Figure 3 - Temperature and humidity test chamber, FTP server, controller smart meters and DTC

In this stage, 5 smart meters of three different manufacturers (15 meters total) were prepared and installed inside a temperature and humidity chamber with temperature and humidity regulated for 85ºC and 85%, respectively.
All the smart meters are connected in series. For control purposes, two other smart meters have been installed outside the test chamber (one meter connected at the series circuit begin and another connected at the series circuit end).
The smart meters have been configured to have an active energy load profile with 15 minutes resolution. All the meters have been connected to the power supply (230 V AC) and to a 3 amps resistor load.
The load profile configured on the two smart meters installed outside the test chamber have been configured to collect not only the active energy but also the average voltage. With this information it is possible to see the voltage drop in the smart meter series.
A Distribution Transformer Controller (DTC) working as data concentrator has been connected to the power supply and all the smart meters are communicating with it through a PLC PRIME network, as shown in the Figure 4.

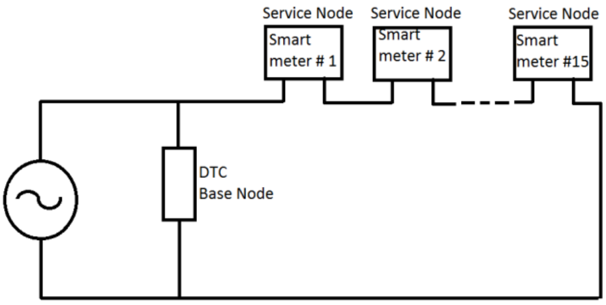

Figure 4 – Schematic of the circuit and the PLC PRIME network.

In Inovgrid project the DTC is an equipment that is installed in the secondary substations and its functions are not only to collect/configure information from all the smart meters connected to this secondary substation but also, to measure the electrical energy flowing in the MV/LV transformer and monitoring and control the LV network.
The DTC has a programmed task to request the load profile of each smart meter at every 6 hours, and then sends all the collected information to a FTP server.
As it is not possible to look inside the test chamber to verify the meters functionality, with this load profile request procedure it is possible to check with acceptable accuracy when the meters lose the communication functionality.
The main goal of this test is to define a criteria to accept or reject smart meters according to the results obtained from this common bases.

RESULTS

At the end of the 1000 hours test is expected that FTP server will have almost 3000 files with the load profile of each 17 smart meters (15 inside the temperature and humidity test chamber and 2 outside it).
In order to compute automatically the load profile of each smart meter it was developed a VBA routine to read all files and draw a line graph representing the load flow from the power supply to the resistor load side.
As referred above the test is still running and the results presented in this paper are only preliminary.
With nearly 500 hours left all the smart meters are communicating with DTC through PLC PRIME and it is possible to check that all meters are responding properly to the requests. In Figure 5 and Figure 6 can be seen either load profile collected at the beginning and the end of the circuit, respectively.

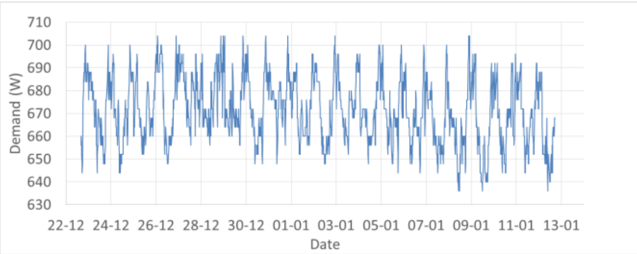

Figure 5 - Load profile of first smart meter in the temperature and humidity test chamber

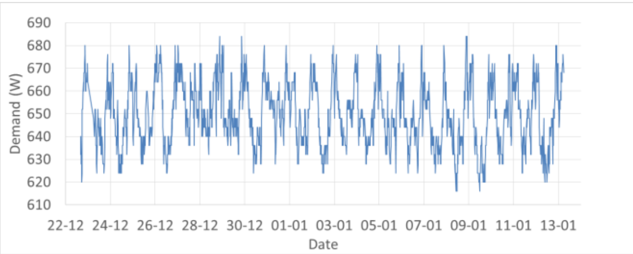

Figure 6 - Load profile of last smart meter in the temperature and humidity test chamber

The difference between values on both load profiles is due to the voltage drop in the meter series.
Collecting the load profile from the first and last meter of the circuit (average voltage values) it is possible to check that the voltage drop in all meter series circuit could be in several periods almost 4V.

CONCLUSIONS

This paper details the method proposed by EDP to predict the reliability of smart meters. This method comprises three steps: 1. Computations; 2. Laboratorial Tests; 3. Field collected information.

Moreover, it is described the adopted methodology to an accelerated reliability test to smart meters with a duration of 1000 hours. With 500 hours spent the preliminary results indicate that all smart meters are operational and communicating properly with the data concentrator. At the end of this test it will be possible to define a criteria to accept or reject the equipment under test.

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