TEM Journal. Volume 7, Issue 3, Pages 566-572, ISSN 2217-8309, DOI: 10.18421/TEM73-12, August 2018.

Test Bench for Functionality and Reliability of Power Protection Devices

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***Abstract* – This paper presents a test bench, designed for testing the functionality and reliability of a microcontroller based device meant to protect the consumers connected to the power grid. By means of this test system, the testing device is repeatedly applied to overvoltages, overloads, electric ground leakages and an electric arc. The test system checks up the load disconnection, as well as its automated reconnection, and in the end it generates a test report.**

***Keywords* – Power protection device, functional testing, reliability, test bench.**

1. Introduction

The need for testing the electronic devices before their serial production is a mandatory requirement. There are companies specialized in the manufacture of testing equipment, such as Qualmark [1], however the equipment made by this company is for general purposes. Dedicated test benches were designed and executed for many electronic devices. For instance, a test bench for induction devices is presented in [2]. Today, the integration of the various sources of renewable energy into the electrical power distribution system leads to further consideration for the protection systems and for the converters connected to the public network.

The paper [3] sets out a test bench for the converter from a wind energy source and the paper [4] presents a bench for testing the control stages of the converter. The problems that might come up upon the integration of the new energy sources began to be studied in specialized academic schools; in this respect, [5] presents a test bench developed at the University of Auckland. A test bench for the solar panels is presented in [6].

The safe and faultless operation of the electrical power supply system becomes increasingly important. A general overview on the reliability assessment issue is set out in paper [7], which includes a sub-chapter dedicated to the breaker failures. The book focuses on assessing the reliability of the electric equipment, saying that certain faults in the distribution systems can lead to inconveniences for a short period of time, but also to catastrophic failures in the electrical power supply.

The papers [8, 9] present a test bench for the protection electronic devices, departing from the remark that these ones can disconnect the voltage due to certain harmonic disturbances sent through the network. The paper suggests a simulation of the protection device and a follow-up of its behavior in various instances.

A test bench for the PC (Personal Computer) supply sources is presented in [10], where the supply source is tested in case of overvoltages, overloads and variations of temperature.

The paper [11] presents a complex study on the malfunctions of the energy distribution systems, as well as reliability and ageing considerations for the electric and electronic equipment. The paper [12] sets out a study of the supply system errors in Norway and Finland, which for 2000 to 2004 shows an average of 407 events in the network and an average ranged between 2.9 and 14.5 for the number of failures in the protection systems. The user is therefore expected to face dozens of events per year in the power grid.

DOI: 10.18421/TEM73-12
https://dx.doi.org/10.18421/TEM73-12

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Received: 20 June 2018.
Accepted: 30 July 2018.
Published: 27 August 2018.

For reliability estimation, accelerated tests for the equipments are necessary. The book [13] that presents an overview of the accelerated tests issues, divides the tests into reliability ones (accelerated reliability testing ART) and durability ones (accelerated durability testing ADT), while highlighting the tests difficulty and the complex process of setting up the acceleration factors.

Electrical power meters are very important to the supplier, as they serve as a basis for billing and cashing. Special attention is paid to the electronic devices [14] and methods of accelerated testing that could enable reliability forecasts are being looked for. The protection devices are as important as the meters. The paper [15] deals with the reliability of the supply systems after the installation of the protection electronic devices.

The paper [16] sets out solutions for assessing reliability, the justification being that "in case of Low Voltage Circuit Breakers (LVCB), in particular for critical applications, conservative approaches are usually applied. That implies a scheduled replacement of devices could occur with a significant Remaining-Useful-Life (RUL). This paper aims to test different approaches to Predictive Maintenance (PdM) in this class of devices, ..., suitable for the development of a prognostic system, in a real industrial application." The paper [17] presents aspects linked to the ageing of the protection devices because of the high short-circuit current.

Protection device testing has raised interest in education, too, as proven by the PhD thesis [18].

2. The test bench

The device for protecting consumers against overvoltage, overcurrent, ground current leakage and the electric arc was made according to an original design, within the 62PED/2017 research project.

In order to check the repeatability of load disconnection and reconnection in network events, one has created an automated test bench, which generates all the types of events, in turn, and checks the behavior of the protection device EUT (Equipment Under Test). The block scheme of the test bench is provided in Figure 1.

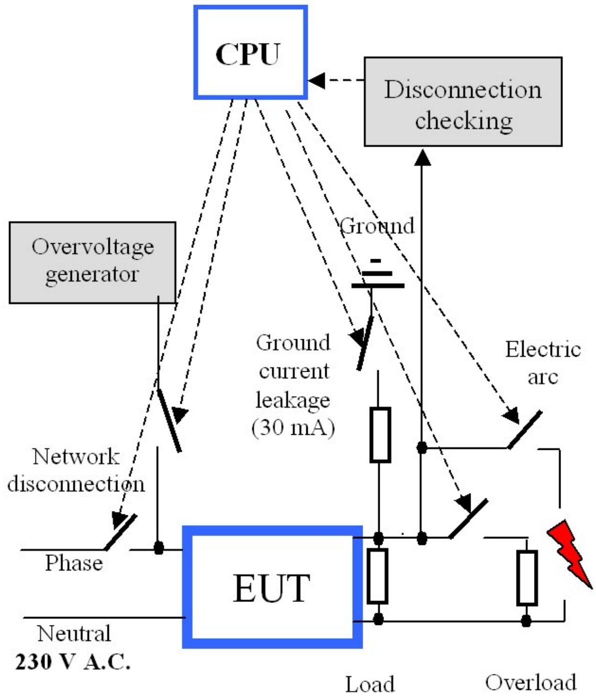

Figure 1. Test bench – Simplified block scheme

The bench complies with the EN 61439-1 and SR EN 61439-2 standards and the test methods with EN 62059-31-1 and EN 62606.

The bench carries out tests for the four types of protection adapted to the user's requirements. The selection of the tests, their duration and the test methods can thus be configured before beginning a cycle of tests. After one test cycle, two types of reports are generated – a detailed one and a totalizing one, in order to analyze the test results.

The technical features of the bench comply with the nominal parameters of the energy supplied within the low voltage electrical network of Romania, namely 230V A.C. voltage and 50Hz frequency. The supplied power is 6 kW and the network has a 32A classic fuse. Constructively, the bench is made of an 1800x800x600 -sized metal box, protection degree IP54 (against the touch of the active parts, as well as against the penetration of any foreign solid matters, of dust and water).

On the bench door are mounted the control panel, manual control elements (switches) and signaling elements (lamps) used for carrying out the tests. Inside, the bench has protection elements, a supply source, a central unit with a web interface, a control panel, a wireless router, power elements, measure and auxiliary elements. The bench is endowed with protection elements for the user and the equipment against overloads and short-circuit (protection functions), in case that the EUT fails the tests.

The CPU (Central Processing Unit) is the main element of the automation and it consists in a Siemens S7-1214 PLC (Programmable Logic Controller). The central unit is responsible for the automated run of the tests, controlled by the switches, according to the operator's settings, made with the control panel. This one (Siemens KTP400) is embedded into the test bench, it enables the configuration of the next cycle tests, it provides access to the reports generated upon the completion of the latest test and it helps the operator to follow the evolution of the main electric parameters during the tests. The web interface provides remote access to the settings and to the wireless router.

The power elements are used to ensure the conditions needed for the tests: load, overload, overvoltage, differential current and electric arc.

The operating condition is generated by the utilization of one or two consumers, the overload one by the utilization of three, four or more consumers and the differential current condition – by the utilization of a resistor connected between the phase and the grounding. As a measuring element, a digital measuring device is used, that can be integrated into the network control equipment introduced for the detecting of disconnection and reconnection, as well as for monitoring the electric parameters during the tests. The settings for the configuration of a test cycle are as follows: the test activation/deactivation, the load that gets connected, the testing duration (min.), the time till the disconnection and the number of repetitions. Upon the completion of a test cycle, the collected data are available within two reports – a detailed one and a totalizing one.

The detailed report includes the following information: test condition: passed/failure, test duration, voltage and current values during the test (minimum, maximum and average values).

The totalizing report displays the number of tests completed successfully and the number of tests ended in failure for each type of tests (load, overload, overvoltage, differential current and arc).

A simplified diagram of the testing process deployment is provided in Figure 2.

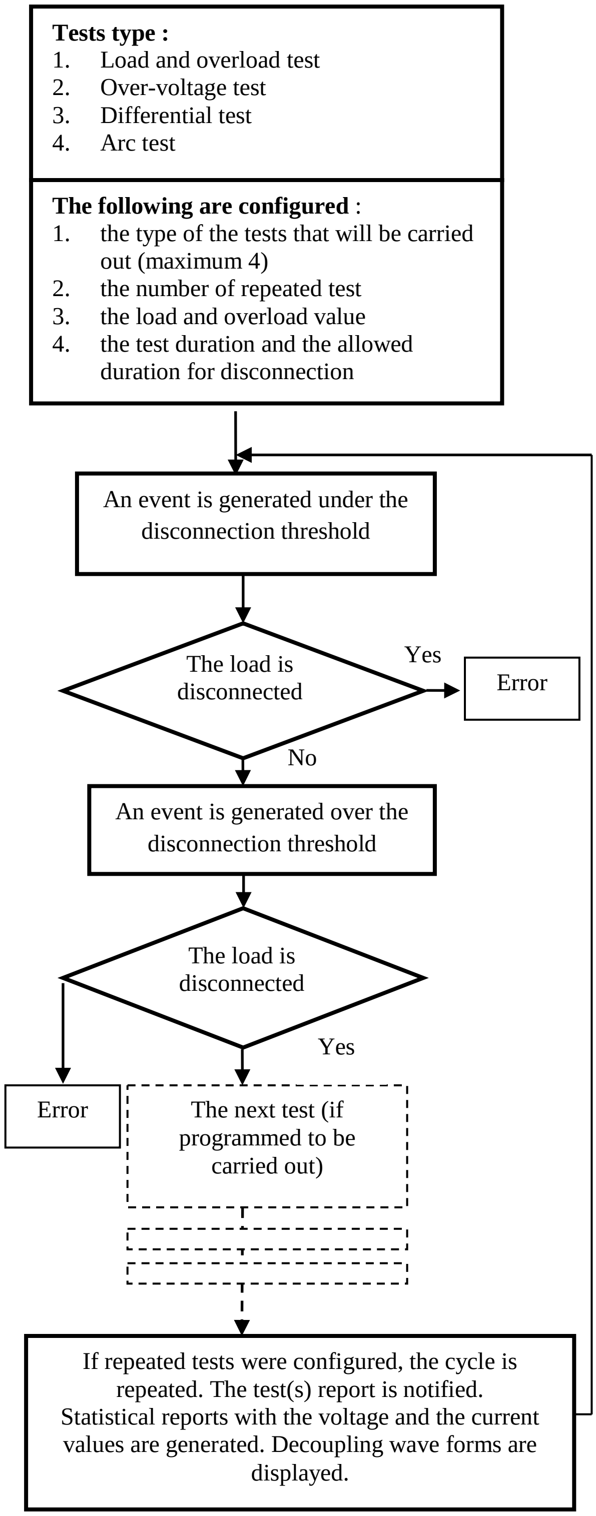

Figure 2. Test bench – Simplified operation diagram

At the beginning of the testing cycle, the control panel enables the access to the settings, reports, graphics, fanning and alarm sections thanks to the main menu, by pressing the specific button. All the operating panel pages displayed at the beginning or at the end or during the pause between the tests have the following joint elements:

1. Main menu – enable the access to the settings, reports, graphics, fanning and alarm sections;
2. The phase in which the bench is – viewable on the upper bar; the label informs on the current state of the automation installation test, such as damage, waiting, manual mode;
3. Date and time – on the lower bar of the screen; the field displays the current time, which gets recorded at the same time with the alarms.

The main menu is provided in Figure 3. and the test results in Figure 4. (screenshots).

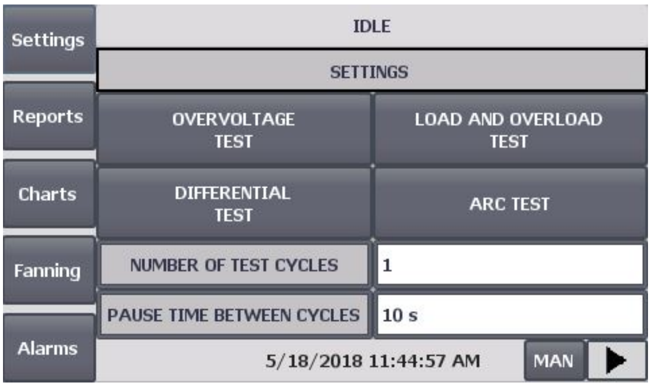

Figure 3. Screenshot of the main menu

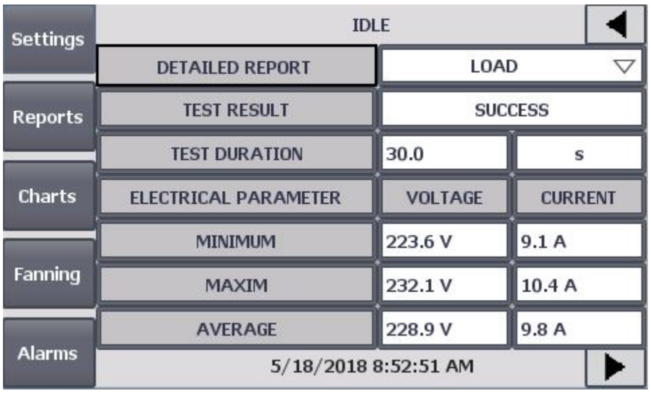

Figure 4. Screenshot of the test results

A picture of the bench is given in Figure 5.

The web interface helps the process to be viewed and controlled remotely, on PCs, tablets and smart phones. The structure of the web interface is similar to the one of the control panel.

The web interface consists in customized web pages provided by the web server of the central unit by the http protocol. The web server can be accessed from any device, by specifying a URL (default http://10.14.61.10). Due to the utilization of standard web technologies, the additional hardware and software components for viewing are not necessary.

Figure 5. Test bench – photo

A fragment from a screenshot of the web interface with the results of a test is shown in Figure 6.

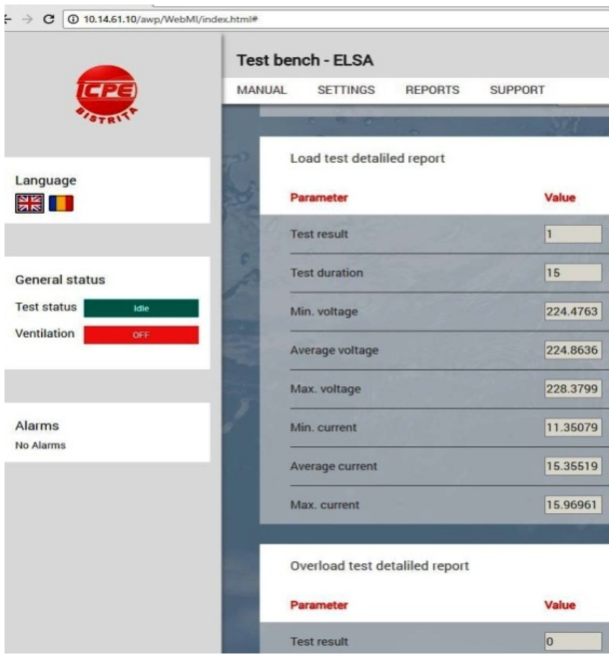

Figure 6. Screenshot with the test results obtained by the web interface

3. Reliability assessment

The reliability R(t) in quantitative terms is the probability that the system can correctly accomplish its functions for a certain period of time, under specified operating conditions.

$$R(t_i) = \frac{N_0 - n}{N_0} \quad , \qquad (1)$$

where N_0 – the statistical population and n – the number of defects.

The reliability indicators are used for comparing the reliability of the elements within a system.

The frequency function:

$$f(t_i) = \frac{\Delta n_i}{\Delta t_i \cdot N_0}, \qquad (2)$$

where Δn_i is the number of failures during Δt_i,

The failure rate:

$$z(t_i) = \frac{\Delta n_i}{\Delta t_i \cdot (N_0 - n)}. \qquad (3)$$

A relevant reliability indicator is the Mean Time Between Failures (MTBF), defined as:

$$MTBF = \frac{\sum_{i=1}^{No} t_i}{N_0}, \qquad (4)$$

where t_i is the duration for the operation of an element *i* from the N_0 statistical population.

Because of the long average time among the failures it is impossible to monitor the functionality of the electronic equipment. The first achievement of the authors was in 1996, namely the design and the execution of a test bench for the ATX supply sources for PCs, presented in [10]. The supply source is repeatedly tested to network events and an acquisition system monitors the output voltage and its compliance with the allowed limits.

The block diagram for the accelerated operation test is given in Figure 7.

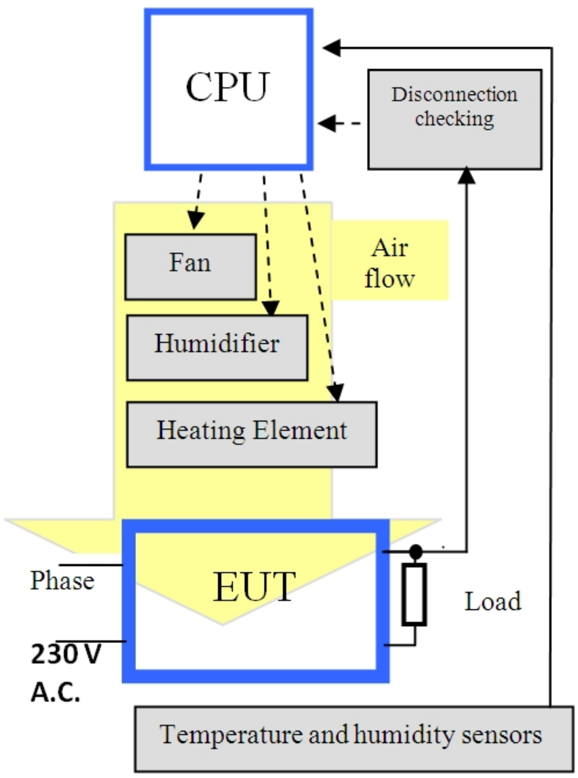

Figure 7. Test bench – Reliability assessment

A heating element provides the temperature increase for EUT and for the process to be quicker, the air has a forced circulation by using a fan. An air humidifier provides the humidity increase for EUT. The temperature and humidity increase/decrease cycles are successive. Their limits are detected by specific sensors. The operation of the bench is controlled by the central unit (CPU). The temperature and humidity variations were established according to EN 62059 (Electricity metering equipment – Dependability).

For the equipments that are operating only time to time, the accelerated tests can be made if continuous operation is forced upon. The most important part from the reliability point of view is the connection and disconnection of the load upon the appearance of an event. By using the statistical data from [12], 10 connections/reconnections are estimated as a yearly average. Using the test bench, which ensures 30 connections/disconnections per hour (26289/year) is obtained an average acceleration factor of 26280.

Another type of acceleration can be obtained by the generation of operating conditions under stress, with operating limits above the typical ones. For the presented bench, testing has also the stress component, because supply voltages are over the rated ones, in order to test the protection to overvoltage. Also the current is higher than the rated one, in order to test the protection to overload.

For the tests to be relevant, a large number of devices need to be tested. One test made on the prototype of the proposed protection device by setting up the following failure condition: the disconnection should take place at a threshold lower than the disconnection limit or there should be no reconnection in case of the tests performed by all four types of events within the network. After a fault connection / disconnection, the device can have a normal operation (meaning a temporary error) or remain blocked, thus displaying an error message (meaning a permanent error).

4. Experimental results

The time diagrams subsequent to the functionality and reliability tests show the variation of the voltage (in yellow) and of the current (in blue). These diagrams were used for adjusting the algorithm for detecting the events within the network and those linked to the load disconnection, which was an algorithm implemented in the microcontroller software.

The figures below show certain representative forms of wave.

In Figure 8. one notices the load disconnection because of the voltage increase over the limit value allowed.

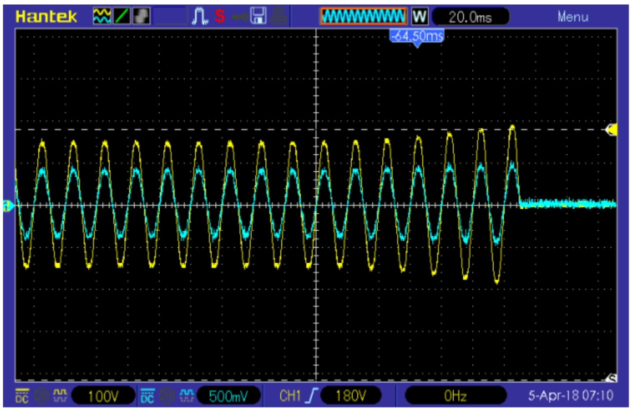

Figure 8. Load disconnection upon the appearance of an overvoltage

In Figure 9. the load is disconnected due to an overload. The rated current (the first 3 alternations) is increased by coupling an additional load (18 alternations) after which the decoupling occurs.

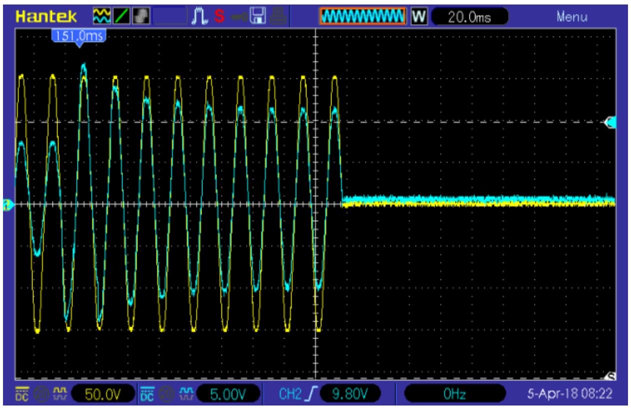

Figure 9. Load disconnection upon the appearance of overcurrent

In figure 10. the decoupling is due to an electric arc and occurs in the alternation in which the arc appeared. The variation of the current produced by the electric arc can be seen, that is the cause of the decoupling.

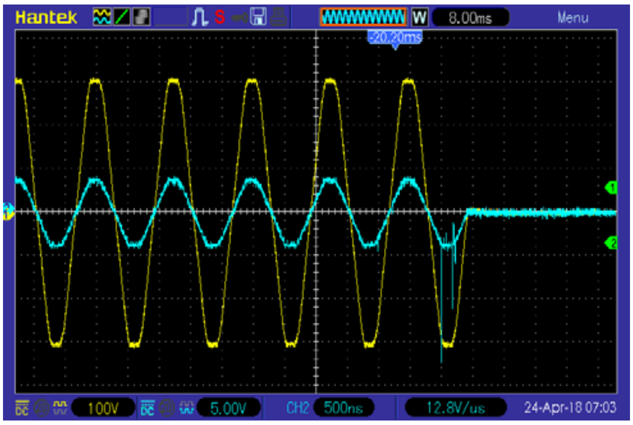

Figure 10. Load disconnection upon the appearance of an electric arc

Figure 11. shows a quick short-circuit decoupling that is performed at the end of the alternation of short-circuit. The load is resistor-coil (RL) type. the phase shift between current and voltage can be seen.

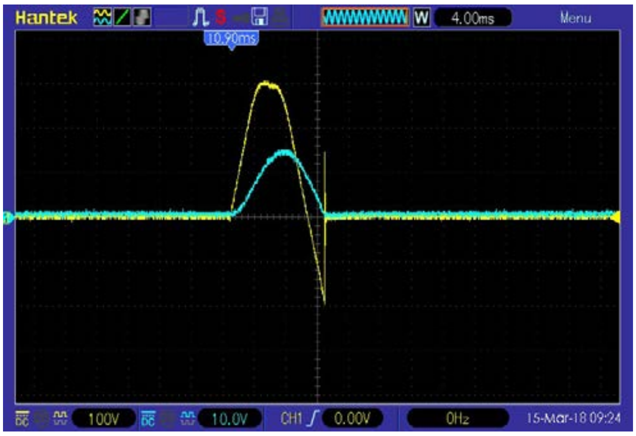

Figure 11. Load disconnection upon the appearance of a short-circuit

By repeated tests one noticed that the load disconnection to overvoltage, the ground current leakage and the electric arc did not take place always in a semi-period of the supply voltage, therefore the algorithm was corrected, in order to rectify this deficiency. Another remark was that upon reconnection the load current has a higher value at the beginning and in time it decreases to the rated value, therefore the initial value risks to produce a disconnection. The algorithm was improved in this case, too.

5. Conclusions

In order to test the device that protects consumers against overvoltage, overload, ground current leakages and electric arcs, one designed and developed a test bench that generates such events and monitors load disconnections and reconnections. The repeated testing of the connections and disconnections by various parameters of the network events enabled the correction and the improvement of the recognition algorithms. Connection and disconnection monitoring in case of the R, L and C combined loads enabled the optimization of the disconnection times and the reduction of the maximum disconnection time from 20ms to 10ms. Tests revealed conclusions regarding the heating of the device, the own consumption, the correctness and the relevance of the displayed messages etc.

The bench was also designed for assessing the reliability of the protection device by accelerated tests; however the results were not relevant, seeing that there was only the prototype. The accelerated tests to which the prototype was subjected proved the operation according to the expectations, including in the context of temperature and humidity variations.

Repeated testing showed that the recognition of the electric arc was not successful in all cases, which means the need of improvements in terms of the testing methods or of the recognition algorithm.

For the future, one aims at extending the types of electronic devices that can be tested by means of this bench. Methods of generalizing error detection for several types of equipment are in attention too.

Acknowledgements (If any)

This work was supported by a grant of the Romanian National Authority for Scientific Research and Innovation, CNCS/CCCDI – UEFISCDI, project number PN-III-P2-2.1-PED-2016-0570, within PNCDI III. We hereby acknowledge the structural founds project PRO-DD (POS-CCE, 0.2.2.1., ID 123, SMIS 2637, ctr. No. 11/2009) for providing the infrastructure used in this work.

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