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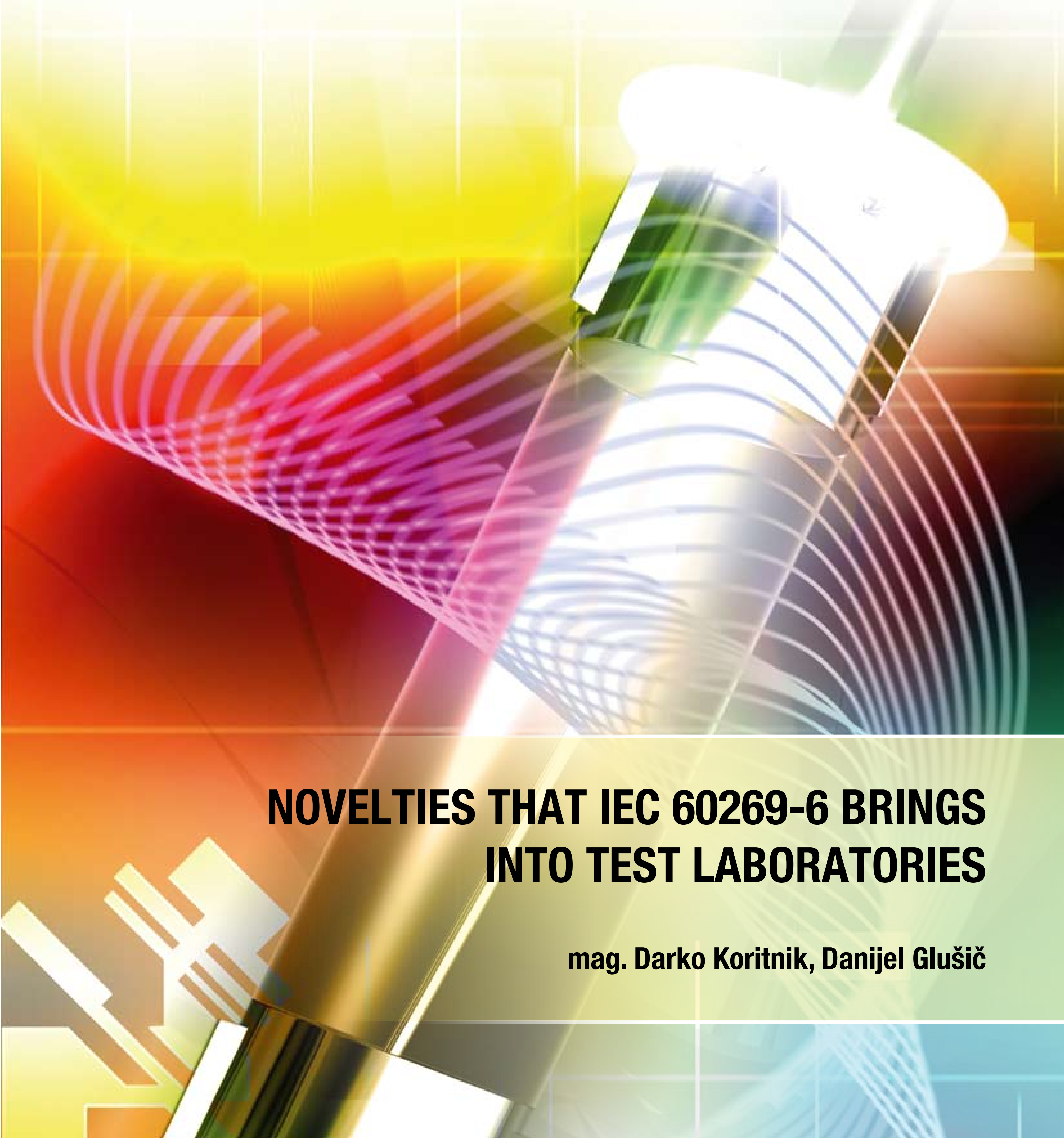

NOVELTIES THAT IEC 60269-6 BRINGS INTO TEST LABORATORIES

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Abstract

The IEC 60269-6 standard on Low-voltage fuses – Part 6 Supplementary requirements for fuse-links for the protection of solar photovoltaic energy system was published in September of 2010. With such, a period of uncertainty has ended when we did not know how to test fuses for photovoltaic systems. Before such standard was accepted, the manufacturers and test laboratories only had guessed how to test PV fuses. Through acceptance of new standard IEC 60269-6, there is a uniform document for serves as a guide for what we do.

Every new standard introduces some novelties and so it does IEC 60269-6, which requires some changes and completions of test laboratories. For past several years, we have been preparing for those changes in test laboratories. Equipment and measuring procedures have been further completed in relation to the information that has been received from clients and members of TC, who have prepared the standard. However, in ICEM-TC we did not go into large investments, until we were absolutely certain what would be final requirements of the standard. In our laboratory, such uncertain transitional period has been surmounting with improvised solutions that enable tests in accordance with standard requirements and did not require large financial investments. However, those solutions have been useful but time-consuming.

Presented in this paper, are solutions with which, in ICEM-TC, test laboratories have been adjusted for testing according to IEC 60269-6 standard. Temporary solutions, which are currently being used, are described as well as permanent solutions that are mostly still in the making.

Keywords: PV electric fuse, testing, laboratories.

1. Introduction

Testing laboratory in ICEM-TC is mainly intended for developmental tests. These tests are conducted on the basis of standards or in relation to the particular client requirements. Tests demands can be altered in regards to a type of test objects: Fuses, protective switches, overvoltage protection...and in relation to test parameters: AC, DC, current, voltage, cosϕ, time constant... All this is feasible rather quickly and simply if the required parameters are inside the boundaries of a test laboratory capabilities. With appearance of photovoltaics, those parameters have exceeded our capacities. Large inquiry and solutions that had looked simple at the first sight convinced us to reorganize and complete the test laboratory so all requirements of the IEC 60269-6 standard have been taken into consideration. Due to the already mentioned financial sources and time restrictions, we have utilized various improvizations and unusual approaches. We have reached our goal at its core and prepared the laboratory for realization of tests according to the IEC 60269-6, while on the other hand, a number of errors on the existing equipment has drastically increased.

2. History and the purpose of a test laboratory at ICEM-TC

For a long time, there has been a plan for a laboratory for high power tests in Slovenia (making and breaking capacity during normal and short circuit operating conditions). First attempts to build a laboratory have been at Dogoše transformer distribution station and afterwards in the central valley of Sava River, although everything has been left in the planning stage. In mid 90's, we have been preparing first devices and equipment high power tests. A huge step was made in 2001 when the ICEM-TC institute had been founded. Short after the founding, we have installed used equipment from the EPM München in one of the abandoned transformer station at the hydro power plant of Mariborski Otok. Later on, the equipment was completed, changed and renewed. We have replaced copper-wire controls with a programmable digital controller, which enables fast and easier adjustment to changes in the test laboratory. Majority of measuring converters are replaced with the newer ones (high-voltage differential probes, Hall probes...) and gathering of data is regulated with the help of a digital transient recorder. From older equipment, only the larger parts remained (transformers, loads, thyristor switch, and rectifier). Most of the mentioned equipment will be replaced soon with the new one. Loads are also restored and reorganized, so they entirely suit to our needs.

In ten years of work, we have learned something indeed. We notice that the initial arrangement of the equipment has not been optimal, gathering and transfer of measuring signals has not been the best, and we mainly must replace few key elements (transformer, thyristor switch, rectifier...). Because of such, in 2011 a complete renovation of the test laboratory is underway.

3. Testing according to IEC 60269-6:2010

IEC 60269-6 is based on IEC 60269-1:2006. From the aspect of testing, there are very little news and even those tests are seemed to be simplified. Test laboratories that covered requirements of the part one of the standard have simply adjusted to the new requirements. Theoretically, that is true, although there are a number of test laboratories that covered only a portion of tests from the part one of the standard. We have been in a similar situation at ICEM-TC, where we have been limited by test voltages, as in most of the test laboratories.

4. Test laboratory equipment

Standard Low voltage has already been limited before PV occurred to 1000V AC and 1500V DC, although tests with DC voltage above 600 V have been very rare. Majority of test laboratories have been adapted to those requirements. The test voltage has also been limited at ICEM-TC to 550V AC and 600V DC. With appearance of a PV program, the inquiry has raised up to 1000V DC and more. Due to such a number of problems have occurred:

4.1 Ensuring the correspondingly high AC voltage

To the existing transformer TR1, we have added two more transformers TR2 and TR3 (figure 2). Primary winding is connected parallelly and the secondary winding series or parallelly (figure 2). In such way, maximal voltage rate is expanded to 1000V AC with a step of around 10V. Then, the maximum prospective current decreases to app. 30kA, which is still enough for DC PV majority of tests.

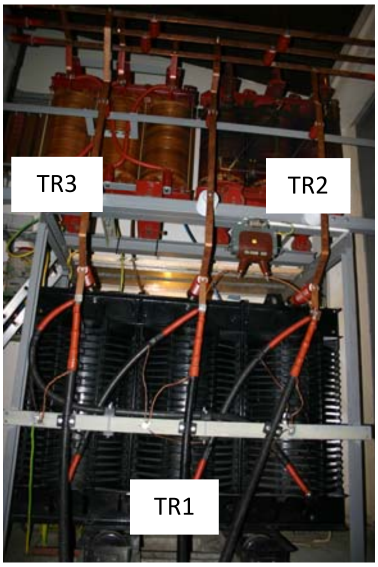

Fig 1: Setting of transformers

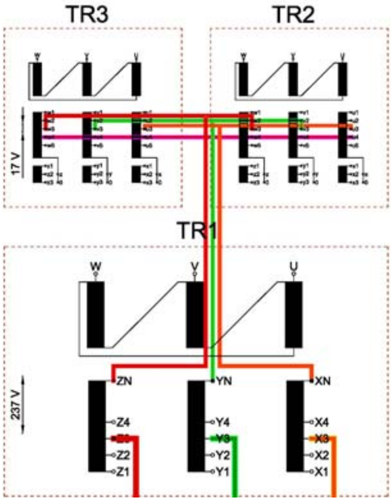

Fig 2: Example of transformers connection

4.2 The preparation of the corresponding rectifier

The existing rectifier (figure 3) is not designed for voltages over 600V DC and for the requirements of the PV tests, it is practically not applicable. The problem will be solved in two steps.

Short term provisional solution is a rectifier from aluminum factory TALUM. At TALUM, we have temporarily borrowed and partially reconstructed a diode rectifier (figure 4). That rectifier is originally intended for continuous operating at constant current of up to 10kA. During the tests, it is also often loaded with a current that is a few times the nominal, although only shortly. Because of such, the rectifier is not constructed optimally, although it serves its purpose. Turn on and turn off of the circuit is conducted with the existing thyristor switch on the alternating side. Long term solution will be a thyristor rectifier which would unite a rectifier and a switch in one device.

Fig 3: The existing rectifier

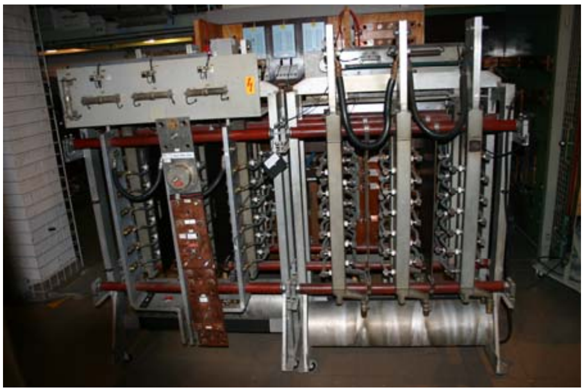

Fig 4: Temporary rectifier from TALUM

4.3 Checking and reconstruction of switches and other elements

Switches, busbars, insulators, loads and other elements in the circuit are checked and evaluated so the equipment could also withstand voltages of up to 1500V DC. Practically, smaller and larger faults (figure 5) have occurred, although they have been successfully resolved.

Fig 5: Examples of damages and faults on equipment

4.4 Measuring equipment

4.4.1 Measuring of voltage

Increase of test voltage and increased arc voltage has required a new voltage measuring converter. Among various possibilities, we have decided for high frequency differential probes. Their characteristics are not the best. However they are sufficient enough to meet the standards and the measuring procedure and they have a user-friendly concept, hence they galvanically separate measuring point from a transient recorder.

4.4.2 Gathering of data

Gathering, analysis and storing of data has already been conducted before with National instruments PXI measuring system. The system is based on flexibility and enables an easy adaptation to new requirements; however for testing of new PV fuse, we have had to introduce only a few software changes.

5. Measuring procedures and practical solutions

Most of the measuring procedures for tests, according to IEC 60269-6, can be thoughtfully assumed according to already fleeting procedures for other parts of IEC 60269 standard. Particular specifics do come up in relation to the characteristics of testing laboratory and physical phenomena.

5.1 Calibration with reduced voltage

Before the realization of short circuit tests as well as prior to other current tests it is necessary to calibrate the measuring circuit. With such key parameters are verified: Prospective current, power factor or a time constant and recovery voltage. Calibration, from the view point of a test laboratory is often more problematic than the test itself and because of such, the test laboratories use different procedures with the intention to decrease the number of calibration strikes and their negative effects. Computer application to determine necessary settings (figure 6) has already been used at ICEM-TC. On the basis of that calculation, the necessary settings are theoretically determined. It has been shown in practice that the calculated and measured values vary for app. 10% max. That application is not meant as a substitute for calibration but only as a guide for staff.

Calibration is always conducted with the measurements. We calibrate only up to 20kA under the full voltage because of mechanical and thermal limitations of equipment. In that example the effective current flows and parameters are determined with the help of a direct measurement (figure 7).

For current higher than 20kA, we have introduced calibration with reduced voltage. Primary winding of the test transformer is supplied with 400V only instead of 10 000V (figure 8). With such, both current and voltage theoretically decrease by the factor of 20. Practically, particular deviations appear which are dependent on the current. Due to such, we have conducted a series of calibration tests and prepared correctional diagrams.

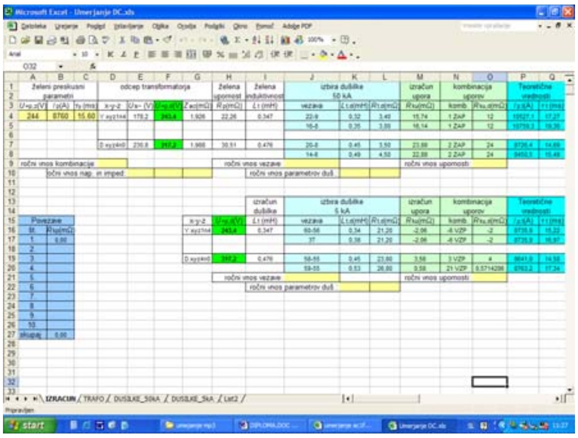

Fig 6: Computer application for calculation of necessary settings of transformers and loads

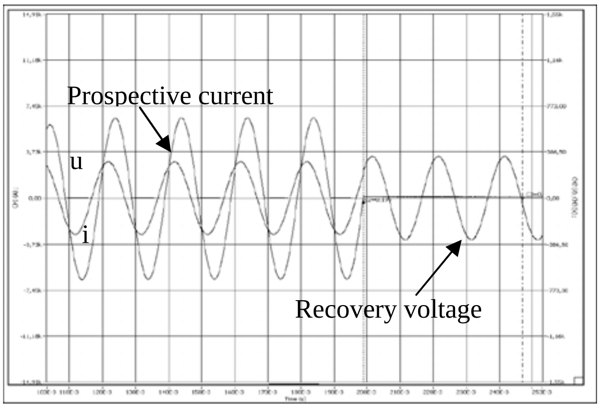

Fig 7: Example of calibration parameters

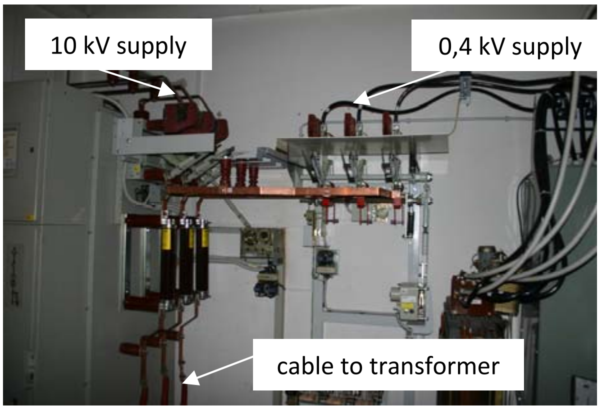

Fig 8: Arrangement for calibration with a reduced voltage

Calibration with reduced voltage provides us only basic values. Even tough, at the beginning, we have doubted the adequateness of the method, with the help of our own calibration measurements and inter-laboratory comparison we have determined that this method completely satisfies the requirements of developing tests.

5.2 Determining the time constant

Determining of the time constant is given in IEC 60269-1 standard (figure 9).

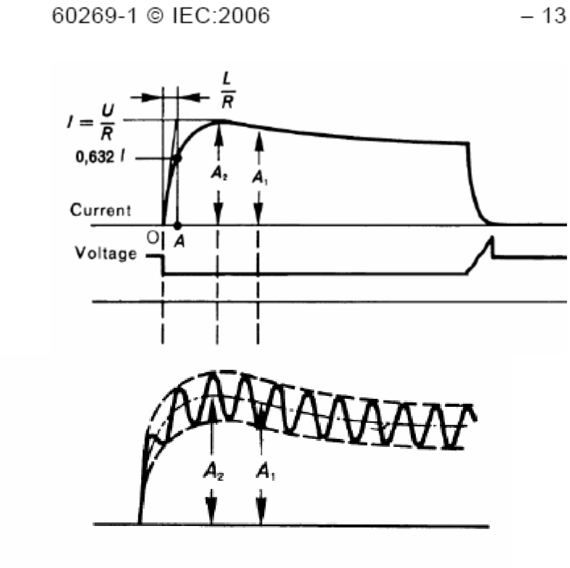

Fig 9: Instructions for determining the time constant in IEC 60269-1 standard

Theoretically it is clear how to determine time constant in cases of a completely smooth as well as ripple voltage. In case of the ripple voltage, practical problems appear which the consequence of voltage rectifying is. Standard IEC 60269-1 determines time constants between 15 and 20 ms. In that case, it is quite easier to determine effective value of maximal current I and time when that current reaches 0,632·I. The problem tough appears in IEC 60269-6 standard when the time constant is decreased from 1 up to 3 ms. In that case, the increase of the current is so fast that it is not possible to determine the course of the effective value. Under the identical settings of the circuit, the slope and the current waveform are mostly affected by the particular moment when the turn on is conducted respectively start angle on the alternating side of the rectifier.

We have searched for different possibilities of a more precise, simpler and faster determining of time constant, tough we have not found an appropriate solution. Because of such, we have analyzed the influence of start angle with the measured value of time constant.

Presented in Table 1 is a characteristic example (730V, 490A, 2ms). Parameters of the test circuit have been completely identical. We have only changed the moment, respectively the moment of start on the alternating side. We have observed one

3,33ms (60˚) ripple and divided it into 20 equal parts, each being 3˚.

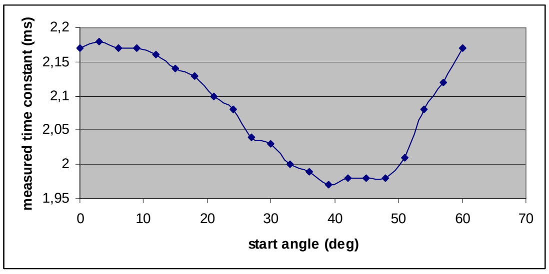

Fig 10: Comparison of measured values of time constant in relation to the start angle on AC side

Table 1: Comparison on measured values of time constant in relation to the start angle on AC side.

Start angle (˚)	Time constant (ms)		Start angle (˚)	Time constant (ms)
0	2,17			
3	2,18		33	2
6	2,17		36	1,99
9	2,17		39	1,97
12	2,16		42	1,98
15	2,14		45	1,98
18	2,13		48	1,98
21	2,1		51	2,01
24	2,08		54	2,08
27	2,04		57	2,12
30	2,03		60	2,17

The comparison of calculated values has shown expected deviations in the range of ± 0,10 ms. Required time constants are between 1 and 3 ms, and if we take into consideration reading errors, uncertainty of measuring instruments and even add some reserves, the boundaries can be narrowed to 1,5 – 2,5 ms. In such way, the corresponding values of time constants are reached without any complicated and time-consuming analyses of the current waveform. That approach is simple, fast and reliable, although it requires loads, which enable to set time constant within the narrowed range.

6. Standard tests and measurements

As we have previously stated, the biggest problem presents DC voltage of up to 1500V, which is nothing new from the viewpoint of the standard. IEC 60269-6 standard still introduces some novelties in the field of testing as well. For a better overview, we have created a comparison of test requirements between IEC 60269-6 and IEC 60269-1. We have followed chapter 8 and its subchapters.

Subchapter: 8.1 – General – Mentions some changes in organization, preparation of tests and set of required tests. From the viewpoint of tests themselves, there are not any significant changes except for few exceptions, which are described in the continuation.

8.2 – Verification of the insulation properties and of the suitability for isolation – without changes

8.3 – Verification of temperature rise and power dissipation

PV Fuses of lower nominal currents are often installed in fuse disconnectors, which disable access to a fuse during operation. We have encountered that very problem with other fuses in closed enclosures.

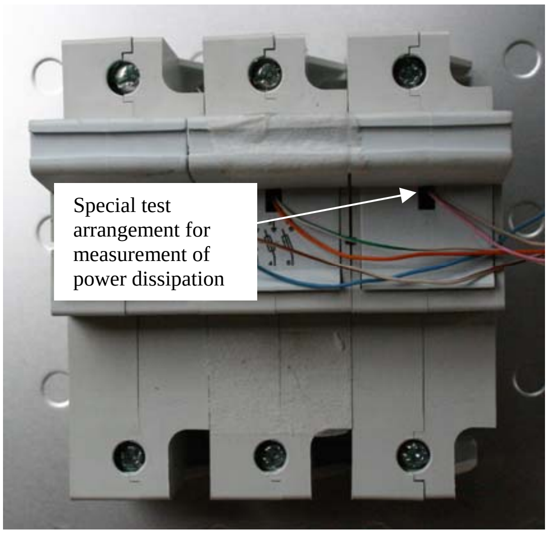
Special test arrangement for measurement of power dissipation

Fig 11: Example of reorganization of fuse-holder for the purpose of power dissipation measurements.

8.4 – Verification of operation

Verification of conventional non-fusing and fusing current

Test arrangement and measuring devices stay the same as before and small novelties are only in the fields for required test parameters.
Verification of rated current

New requirements that require additional preparations appeared in this field. Different approaches are possible. We have used switches that start or shut off loads for higher currents, and for lower currents the adjustable resistors. Operation of indicating devices and strikers, if any

Simplified method and evaluation that is possible to realize during the test of breaking capacity (I5), during the preparations and at lower voltage of 50V.

8.5 Verification of breaking capacity

This subchapter, from the viewpoint of test laboratories, is the most problematic, although in the sixth chapter of the standard, it is significantly simplified in regards to other chapters of IEC 60269.

I1 – 1500V, 30 kA, 1-3ms are uppermost required boundaries. With above described resolutions, we have almost reached those values at ICEM-TC. Upon the reconstruction of the test laboratory, all the required parameters will be attained.

I2 –If the laboratory is qualified to carry out I1, it also requires just the appropriate loads and with ease covers those tests as well.

I3 –crossed out

I4 –crossed out

I5 –Preparation of this test is significantly simplified and the inductance is determined and not the time constant. Inductance of a circuit is only limited to downwards (≥100µH), and there is not a limitation for the upwards direction. During the carrying out of tests, we have noticed that a significant increase of inductance (1000 µH and more) negatively affects the results. To conduct development tests, the missing uppermost boundary is rather distracting since we do not know which parameters would be used during certification.

8.6 Verification of the cut-off current characteristics

No changes

8.7 Verification of I^2t characteristics and overcurrent discrimination

No changes

8.8 Verification of the degree of protection of enclosures

No changes

8.9 Verification of resistance to heat

No changes

8.10 Verification of non-deterioration of contacts

No changes

8.11 Mechanical and miscellaneous tests

Added to an entire clause 8.11 is another clause that is simple at first look, although during practical tests some unclear details appear which quite powerfully impact on results.

8.11.2.5 Verification of functionality at temperature extremes

A simple concept: the test object is heated to a certain temperature (50˚C) with a tolerance ± 5˚C, which does not require any special temperature chambers. Further on those test objects are loaded with a particular current and the time of circuit break as well as an overall condition of a test object is observed. Basically, these tests are rather simple, although in practice a lot of unclear details emerge. In the standard itself, it is not defined what is the surrounding temperature during the current test. Are current tests carried out at room temperature (20˚C) or in a chamber at 50˚C or even at an increased temperature caused by the heating of a test object? Different ambient temperatures in some of the cases strongly impact on test results.

7. CONCLUSION

At ICEM-TC, we test for different manufacturers who all carry out test according to the same standards; however for the needs of development, they utilize different adjusted procedures. We are quite used to such deviations and individual wishes that our clients have. In spite of that, the period before the approval of IEC 60269-6 standard has been rather uncertain and difficult. Everyone tried to convince us that we have to adjust to test PV fuses although no one exactly knew what would be the final requirements. As standard has been developing, we have been receiving more reliable information. Upon the acceptance of the standard, we have already had a qualified laboratory for almost all key tests. The emphasis has been and is still on the Verification of breaking capacity, where we have from the pre-existing and upgraded equipment achieved practically impossible and reached almost all the standard requirements (1450V, 30 kA DC). The use of devices at the limits of their capabilities or even over their limits has caused a number of faults. Most of them have been quickly and effectively fixed, except for one related to the transformers and because of such faults, the available current decreased to a half (15kA). In relation to the condition of our devices, current and the arriving standards and experiences that we gained, we have decided to completely reconstruct and renovate overall test laboratory. At the beginning of next year, we expect to open the renovated test laboratory where it would be possible to carry out all high power tests on PV fuses (up to 30 kA) and other similar devices.

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