FUSE CYCLE TESTING UNDER REAL PV CONDITION

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***Abstract*— Cyclic loads are one of the main factors contributing to the aging of fuses in photovoltaic systems. This is a long and unpredictable process, so it is necessary to conduct testing in conditions that resemble actual circumstances as close as possible.**

In actual operation, the cycle lasts 24 hours, with the fuse reaching its maximum temperature in daytime and cooling to the environment temperature during the night. Simulating such cycles in laboratory could take years, which is useless in development, so shortened cycles with accurately set load curves are used to represent real operating conditions. Such approach is appropriate and necessary for the development, however there is still doubt whether such shortened cycles provide relevant results.

ICEM-tc set up a test arrangement for testing fuses with realistic photovoltaic cycles. The main advantage of our test arrangement are actual cycles, as they occur in the operation of a PV power station, with only the nights (cooling period) shortened to two hours. This allows us to conduct two realistic one-day cycles in 24 hours. The total testing time is still long, from a few months to over a year, so the test arrangement is designed to operate autonomously without constant oversight, and does not take up expensive test equipment.

It can be used to simultaneously test 10 identical fuses connected in a series. The value and timing of the current running through them can be adjusted. In our case, we adjusted the current based on the daily diagrams with the data from the PV system installed on the building of the Faculty of Electrical Engineering and Computer Science at the University of Maribor. We conducted a 7-day test with 14 realistic cycles, using seven daily diagrams from different seasons and with different weather conditions, and seven reference cycles. We scaled the current amplitude so that the maximum current was equal to the rated current of the fuses.

We continuously measured the drop in the voltage, and the ceramic housing temperature on every fuse. All the data, including the current values, were entered into a database. Data from the database can be analyzed in real time or retroactively. By correctly processing these data, we can monitor cold resistance, maximum temperature and over temperatures, temperature dependence of resistance, and other correlations between the measured data over a long period of time.

***Keywords*—Fuse, testing, cycle load, photovoltaic, ageing**

I. INTRODUCTION

The system for cyclically applying load to fuses that are used to protect DC circuits in PV power stations is designed in a way that allows us to expose a fuse or a group of fuses to operating conditions similar to those in DC circuits in PV power stations, and set desired daily cycles of loading the fuses, which can be repeated in 12-hour intervals, while continuously measuring the current, voltage drops and temperature on the fuses and their surroundings. Its robust design and autonomous operation allow us to conduct tests that continue over several months.

II. TEST ARRANGEMENT DESIGN

A. Main Circuit

The main circuit is designed as DC current generator. It is powered from the grid (230V, 50 Hz). We set alternating voltage by changing the transformer ratio of transformer (*Tr*). Regulated alternating voltage is transformed into full-wave DC through a transformer with a center tap (*T*) and diodes (*D1* and *D2*). The direct current running through the test fuses (*F1–F10*) is smoothed with an inductor (*L1*), connected serially. The value of the current is continually monitored and adjusted to the required value through a closed-loop feedback system.

B. Installing the test arrangement

The test arrangement is divided into two parts:

The power supply and controls are located in a metal cabinet indoor. This protects the system from the effects of the weather and electromagnetic radiation.

The second metal cabinet with test fuses is placed outdoors. Changes in the temperature of the environment, the wind, rain, and other environmental effects are monitored and recorded by measuring the air temperature in the cabinet.

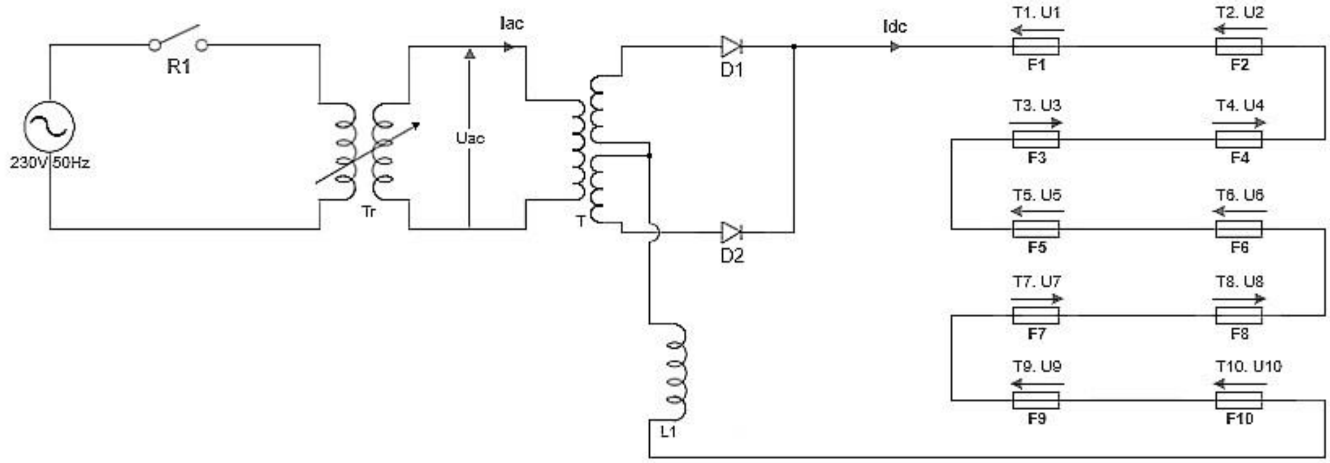

Figure 1: A circuit diagram of the test arrangement

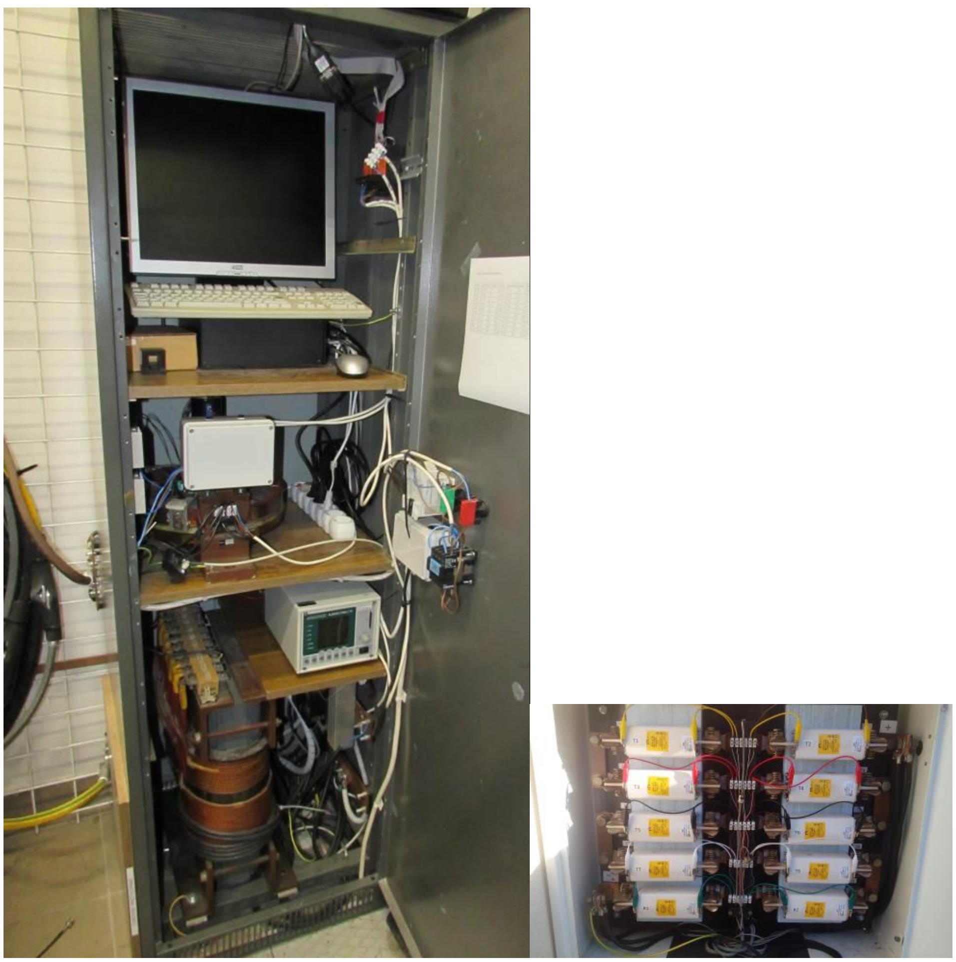

Figure 2: The test arrangement

C. Control and measuring system

The core of the control and measuring system is an application, running in the NI Labview environment, developed for this purpose.

Figure 3: Application’s user interface

The user interface of the control and measuring application is used to start and stop the cyclic testing. After selecting a unique name for the test, the user selects a test case setting the course of the DC current from the database, and can select a delayed start or resumption of a previous test after a pause. The application displays the course of the test, all the measured data and the state of the system.

All currents, voltages and temperatures are measured periodically with a 30-channel Almemo 5990-2 measuring instrument. The application receives the measured data in real time, controls the system accordingly, and saves the data into a database.

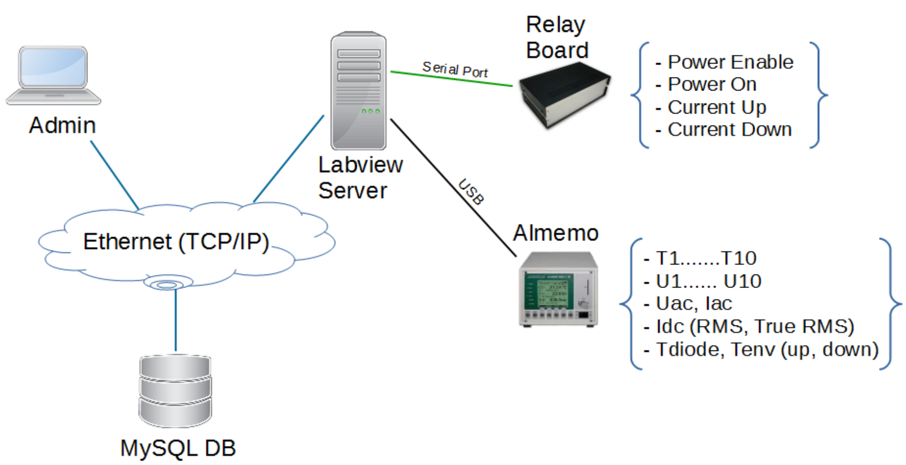

Figure 4: Control and measuring system

D. Current regulation

The test case sets the course of the current throughout the duration of the test. Test cases are saved as configuration files in the database containing test cases for the measuring system. The main configuration file sets the sequence of 14 half-day test cycles, while test cycle configuration files define the current at 0–200 A for every interval of 0–10 hours in 5-minute resolution.

E. Measuring and capturing data

After the test starts, system switches between three operating states in every 5-minute interval:

1) minutes 1 and 2: setting the current; when the current reaches the desired value, current regulation is blocked until the next 5-min. interval starts;

2) minute 3: sampling i.e. measurement; measurements of the temperature and voltage drops with constant current are conducted;

3) minute 4 and 5: constant load; constant current, set in the first two minutes, flows through the test specimens.

The system continuously conducts True RMS value measurements of the DC current flowing though the fuses in all phases of the operation, while other values of the current, voltage and temperature are only measured when sampling. When setting the current, the control system uses the transformer to adjust the current to the value from the configuration file.

If DC current in the state of sampling or standby considerably derogates from the desired current, the test is paused and an error is reported, and the system shuts down automatically.

Measurement results and test data are saved in the relational database.

III. RESULT ANALYSIS

Data from each 5-minute interval are saved in the database, and can be processed with a suitable software of choice. Microsoft Excel was used for the included analysis. The analysis structure allows us to monitor and analyze the results in real time and after the test is concluded. Any day can be included in the analysis. The results are presented in tables and charts.

The analysis is conducted in steps:

1) Downloading measurement results

A table with the results is downloaded directly from an SQL database. Every row in the table contains the results from one 5-minute interval. The data are divided into three groups:

- Serial number of the test, cycle number, number of the selected DC current course, time stamp and other tags that allow the system to function properly and enable the analysis. This data is irrelevant to the user and not displayed in the analysis.
- The desired DC value, actual AC and DC values, the AC voltage, diode temperature and other values required for correct system operation and equipment safety.
- Measured voltage drops for separate fuses (U1...U10), temperatures of fuse housing (T1...T10), and the air temperature in the cabinet, which are essential for analyzing the results.

2) Selecting days for the analysis

Generally, all days on which the test was conducted are included in the analysis. Certain days can also be excluded, which is especially useful when starting the test or when system operation was interrupted. This allows us to exclude the days that would introduce errors in the result analysis due to incomplete or incorrect data.

3) Calculating characteristic values

Any number of characteristic values can be calculated for every day.

For example: Cold resistance of the fuse; every test day starts with a cycle with an 2,5% of nominal current (5 A). For fuses with rated current of 250 A, such current does not represent a load that would heat the melting element. Cold resistance is calculated through the measured current and voltage drop. After repeating the calculation for every separate test day, we get the cold resistance timeline.

Test day	Maximal Voltage drop	Cold resistance	Maximal temperature and resistance at Tmax		
Day	dUmax(V)	Rhl(mΩ)	vrsta	Tmax(°C)	R Tmax(mΩ)
DAN0	0,0331	0,62753036	72	10,8	0,506832298
DAN1	0,0212	0,42990654	72	12,6	0,455734031
DAN2	0,0492	0,42279412	73	25,9	0,494855967
DAN3	0,0316	0,44061303	57	20,1	0,472630174
DAN4	0,0495	0,41749503	71	26,2	0,492850624
DAN5	0,0221	0,43875686	43	26,6	0,486787204
DAN6	0,0496	0,42671614	71	26,5	0,495632744
DAN7	0,0288	0,44230769	72	22,1	0,469361147
DAN8	0,0502	0,42596349	75	30,7	0,504055025
DAN9	0,0162	0,45620438	31	26	0,483680692
DAN10	0,0504	0,43650794	73	30,3	0,502770367

Figure 5: Example of calculated parameters

As shown in the figure, any independent parameters, such as maximum voltage drop and cold resistance of the fuse, can be calculated. Any related parameters, such as maximum temperature resistance, can also be calculated. Users can add or remove other independent or related parameters, and edit them for the charts and further analysis.

4) Presenting characteristic values

Characteristic values are saved in a table. A timeline diagram with the selected values is the basis for a quick analysis. Up to 12 different values can be presented in a single diagram. The diagram can contain same values measured on different test specimens (e.g. cold resistance of different fuses), or different characteristic values for the same test specimen (e.g. cold resistance and maximum temperature for one test specimen). Any combination of characteristic values and test specimens is possible.

Active	Fuse	parameter	Scale	
☑	T3	Tmax(°C)	5	°C/div
☑	T3	R Tmax(mΩ)	0,05	mΩ/div
☑	T3	dUmax(V)	0,01	V/div
☑	T4	Rhl(mΩ)	0,05	mΩ/div
☑	T3	Rhl(mΩ)	0,05	mΩ/div
☑	T6	Rhl(mΩ)	0,05	mΩ/div
☑	T7	Rhl(mΩ)	0,05	mΩ/div
☑	T8	Rhl(mΩ)	0,05	mΩ/div
☑	R1	Rhl(mΩ)	0,05	mΩ/div
☑	R2	Rhl(mΩ)	0,05	mΩ/div

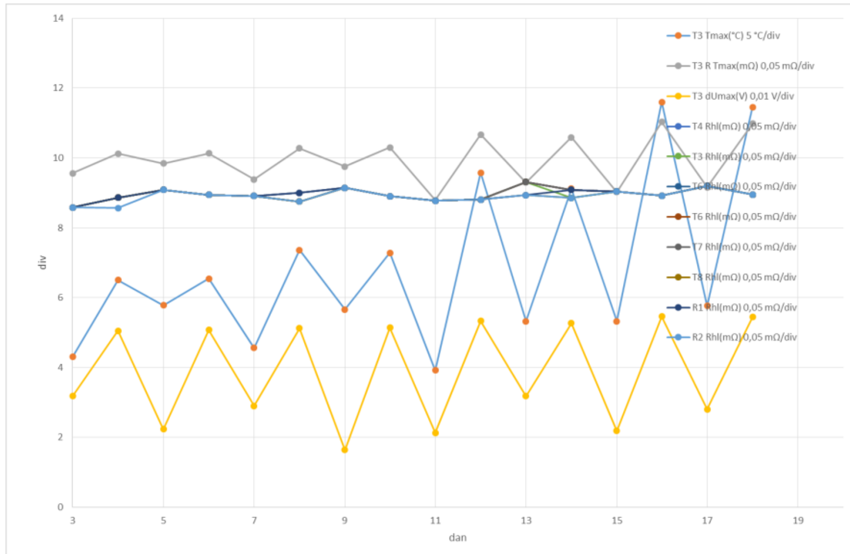

Figure 6: Example of a chart

IV. Conclusion

Testing fuses with an actual PV cycle is a compromise between creating realistic operating conditions and cutting the time required for testing. The test arrangement allows us to continuously load the tested fuses and measure key parameters. Real-time results and the flexibility of the test arrangement allow the user to adjust the test parameters during the test. Simple and flexible result analysis, and charts provide countless possibilities for comparing different parameters. All these possibilities are necessary, but not enough for studying the effect of cyclical loads. Making any final conclusions also requires correct interpretation of results, which is left to the knowledge and skills of development engineers.

Periodicals:

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