Multiple shots on SPDs –additional tests

Alain Rousseau

SEFTIM
Vincennes, France
alain.rousseau@seftim.fr

Xuyun Zang

Shanghai GrandTop Lightning
Shanghai, China
xuyun.zang@grandtop.cn

Ming Tao

Eurotect Electrical
Ecully, France
eurotect123@free.fr

***Abstract*—the lightning threat becomes more and more severe in low voltage power system especially in electronics and telecommunication system. The surge protective devices (SPDs) are used as common protective measures. Single pulse is the main test method described in standards such as IEC 61643-11. At last ICLP conference in 2012 a new 10-pulse generator was presented able to simulate the natural stroke with multiple pulses. This paper presents more test results with lower ratings. This will also contribute to show if multiple pulses has an effect on a coordinated system of SPDs and the protective efficiency of such a system under multiple pulse stress. In addition, a modification has been made to the generator to surimpose surges to continuous current to simulate a test regime that may be useful for wind turbines for examples. The paper introduces the purpose of the multiple pulses test, the test system and test results.**

Keywords-SPDs, tests, mutiple pulses

I. INTRODUCTION

There are many evidences [1], [2], [3] (see also tests performed by Matt Darveniza from one side and Rick Gumley from another side presented in previous IEC meetings) that multiple shots can create problem to varistors even with magnitude much lower than the maximum capability of the varistor. The time interval for multiple strokes is typically around 30 ms to 100 ms. Previous tests have shown that varistors that withstand many tens of kA can only handle a few kA when repetitive strokes are applied.

The measured lightning current shows that lightning is a continuous process with multiple pulses [1]. When lightning strikes a line or a lightning protection system, impulses are injected in the equipotential bonding SPD at the entrance of the installation. Same occurs for induced surges on the incoming line. Typical surge to considers are in the range of 1 kA to 15 kA with an 8/20 wave for induced events and a waveshape near 10/350 could also be used in case of direct strike.

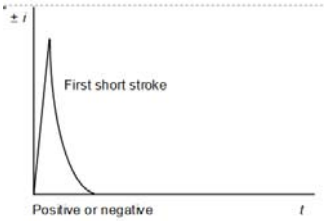

Figure 1. Typical single impulse as considered today by SPD standards

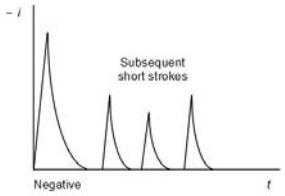

Figure 2. Possible multipe impulses for flat areas

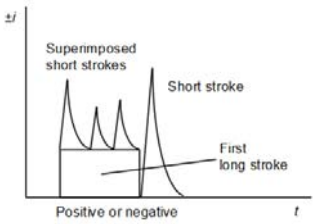

Figure 3. Possible multipe impulses for exposed areas or high structures

One of the purposes of the study is to check the behavior of various type of SPD that can be found in the market including combination type SPDs. For some SPDs the effect of multiple pulses could lead not only to degrade or age protective components (varistors, gas discharge tube …) but also other components included in the SPD design. They may not be directly connected to the main protective circuit but to a subsidiary function that may affect the long term behavior of the SPD and its characteristics.

A lightning generator, presented at ICLP 2012, able to generate multiple pulses to simulate the continuous flash will allow checking the SPDs failure modes for actual surge stresses. Such a stress may be of importance for sensitive systems such as safety equipment in industrial sites or for

wind turbines.

II. THE GENERATOR

A ten-pulse test system has been built in BJSTC (Beijing Surge Protection Device Test Center). It can simulate induced lightning impulse currents. The parameter of the waveform is 8/20 μs defined in IEC61643-11. The 8/20 μs peak current range is from several kA to 100 kA and the interval time of the pulse can be changed from 1ms to 999 ms. The maximum peak of the first and the tenth pulse is 100kA and the other pulses between them are 50kA. The generator has 10 independent discharge circuits which are triggered by ten time-controlled trigger channels. The computer and the trigger channels are connected by optical fiber. The discharge interval can be setup on the screen. The trigger unit diagram is shown in Fig. 4.

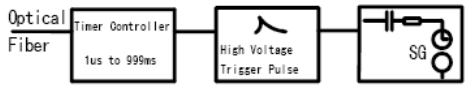

Figure 4. time-controller and the trigger unit

The design of the generator is open for other types of waveform such as 2/40μs and 10/350μs with crowbar circuit for future development.

Other impulse generator with output current from 3kA to 30kA is used for comparison tests. A Rogowski coil transfers the 50kA impulse current to 500V voltage and digitalize with a Tektronics oscilloscope DPO3012.

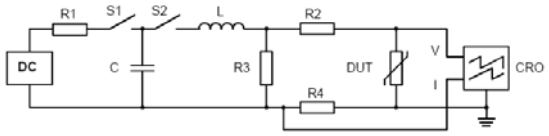

Figure 5. The diagram of the single-pulse current generator

Fig. 6 shows the diagram of the generator and Fig. 7 shows the generator itself.

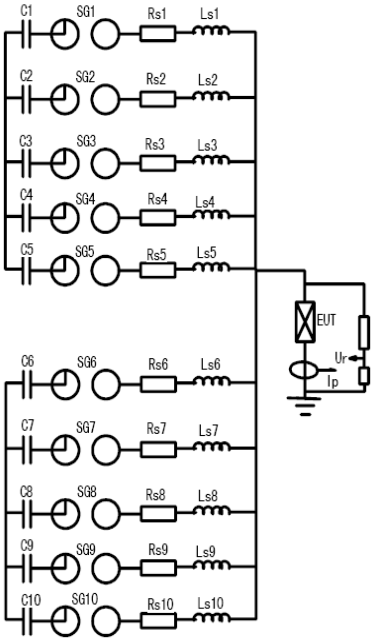

Figure 6. Diagram of the multiple pulses generator

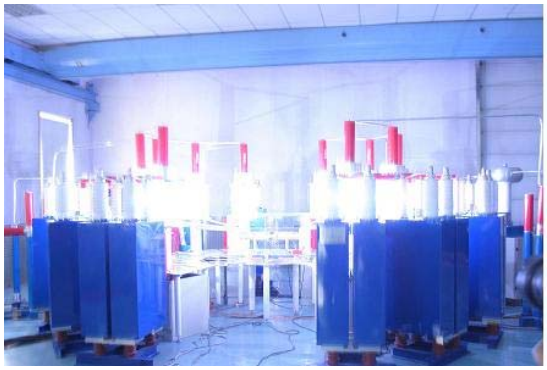

Figure 7. Ten flashes simulating the return stroke

III. TEST PARAMETERS

From the observations of lightning stroke, the last flash peak may havea large value [1], [2],[4] and [5]. The multiple pulsestest is then designed as a ten impulse sequence: the peak of the first one and the last one is two times of the other eight impulses. Originally the generator was developed for a peak value of 100 kA and preliminary tests have been performed at this level.

TABLE I. ORIGINAL PEAK VALUES OF THE PULSE QUENCE

Component	Peak kA	Waveform
First impulse	100	8/20μs
2^{nd}~9^{th} impulse	50	8/20μs
tenth impulse	100	8/20μs

The output current peak will change with the charging voltage changing. The radio of the 1st and 10th peak value to the middle eight peaks is always 2 times.

TABLE II. POSSIBLE PEAK VALUES OF THE PULSE SEQUENCE

Component	Peak kA				
First impulse	80	60	40	20	10
2nd~9th impulse	40	30	20	10	5
tenth impulse	80	60	40	20	10

The first part test (result B in section V) simulate multi-stroke with 10 lightning pulses with smaller peak value to check the withstand ability.

Other values of currents magnitudes are now used for testing SPDs.

TABLE III. PEAK VALUES OF THE PART-2 PULSE SEQUENCE

Component	Peak kA	
First impulse	In=20	In=10
2nd~5th impulse	In=20	In=10

The second part test (result C in section V) simulate multi-stroke with less lightning pulses. Only 5 pulse with peak value equal to nominal current of the varistors check the withstand ability.

Other wave shapes are possible and especially the 10/350 wave. It is also possible to surimpose the middle eight impulses to a continuous current.

IV. TESTED SPDS AND VARISTORS

The MOV typed is widely used in lightning protection system. One type In=20kA SPD is made of 34mm×34mm MOV. As we know In is the specific parameter of the 8/20μs waveform which expresses the impulse ability. A wide-used production in the market is chosen for the first part test.

The basic idea of the MOV quality is Uv (nominal varistor voltage of 1mA, hereby called Uv) and Is (leakage current, hereby called Is). In practice the two parameters will be measured before the impulse stroke and after the stroke. If the leakage current increases more than 50 μA, the varistor is considered as failed.

Two group samples are selected for comparison tests. The samples' nominal voltage and leakage current are measured for comparison.

TABLE II THE Uv AND Is DATA MEASURED OF THE SPDS

SN	*A1*	*B1*	*A2*	*B2*	*A3*	*B3*	*A4*	*B4*
Uv (V)	397	398	440	440	424	425	453	452
Is (μ A)	16.7	15.8	11.8	12.4	16.3	12.0	8.5	13.2

The test object of the second part uses the same type varistors (34mm*34mm). The varistors are chosen from the same production lot for balanced capability to be compared.

The maximum continuous power dissipation P_M is the average power dissipating continuously dissipated for a given life expectancy. It is always used in define the varistor test routine and used by the SPD producer in SPDs production design. The second part test is designed by 5 pulses with interval time 20ms, 50ms and 100ms between each pulse. The interval time of every group multi-pulse is 5 minutes and the test object is cooling with a fan for fast cooling down.

The total time duration of the three different type tests is 80ms, 200ms and 400ms, so during the test the procedure can be treated as an approximation adiabatic process. That means most of the heat is enclosed in the test object.

V. TEST RESULTS

A. *Single stroke tests*

The clamping voltage is measured with 8/20 μs waveform. The impulse current will apply to the samples with a single stroke of 20 kA. The tested sample is connected carefully to the output terminal of the generator for preventing insulation failure. The repetition of the impulse is 60s for the surface temperature of the samples is cooled enough near to the room temperature. Every three pulses the test sample is measured Uv and Is to check its variation.

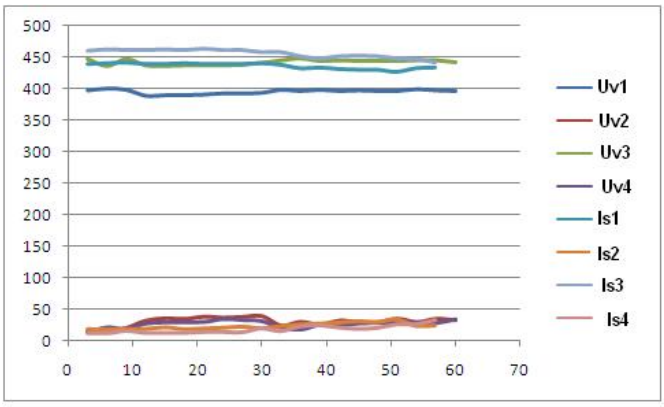

Figure 8. The Uv and Is Test Curve with 60 Single-stroke

A1 ~A4 Test Samples is stroke by 60 times and the leakage current changed small. It is obvious that the varistors are in normal situation.

B. *Multi-stroke tests*

Based on the observation of lightning stroke the waveform of the multi-stroke is different. There is long duration surge current or continuous current in the surge group. Tests are performed at In 8/20 with multi-stroke on the B1 and B2. The multi-stroke is simulating the continuous induced surge in the LV power system. The multi-stroke is performed with 10 pulses. And the time interval, according [1], is 40ms from one stroke to the next stroke. The total time duration of the 10 pulse surge group is 360 ms. The peak current of the impulse current is 20 kA, corresponding A1~A4 test.

Figure 9 is the waveform of the multi-stroke with 8 pulses applied on B1 and figure 10 is the waveform of 6 pulses applied on B2. The time interval of the fifth pulse and the sixth pulse is 160ms according [1] to simulate the last stroke.

After multi-stroke B1 failed. The leakage current overloads the meter. The varistor is nearly short-circuited.

After 6-stroke the leakage current of sample B2 changes from 12.4 μA to 439 μA. The sample failed.

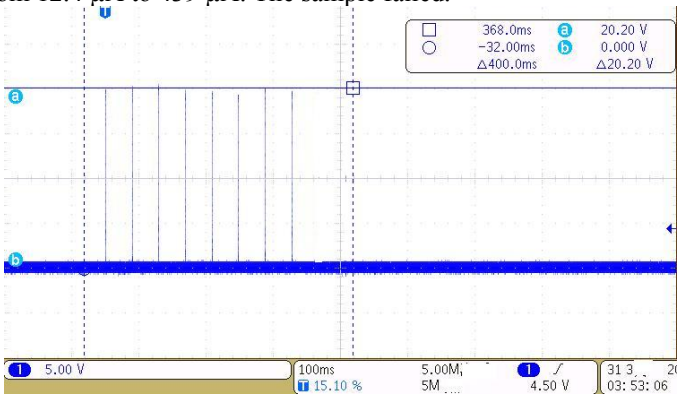

Figure 9. The waveform of the multi-stroke with 8 pulses on B1 sample

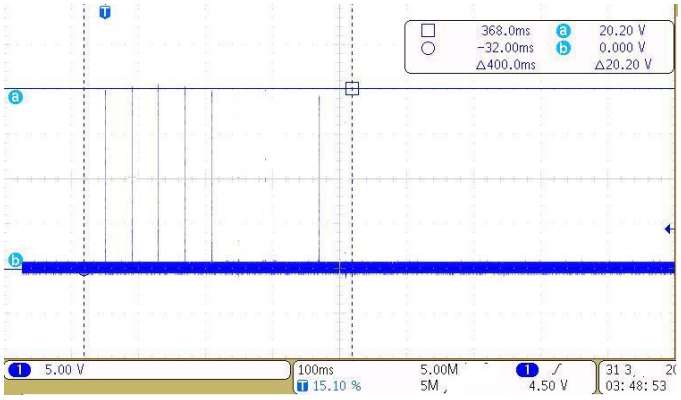

Figure 10. The waveform of the multi-stroke with 6 pulse with B2 smaple

C. *Multi-stroke with diferrent pulse interval*

The wave-shape of the 5 pulses is 8/20 μs and the peak of the current is 20 kA. The waveform is shown as followed:

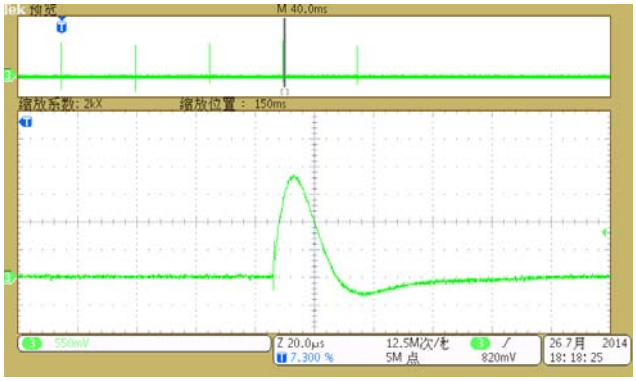

Figure 11. The waveform of the multi-stroke with 5 pulse with 50 ms interval

TABLE IV. THE TEST RESULTS WITH PULSE INTERVAL TIME 20ms

SN	Before Test		1st		2nd	
	Uv (V)	Is (μA)	Uv (V)	Is (μA)	Uv (V)	Is (μA)
1	607.7	1.12	545	4.44	Broken Failure	
	608.1	1	546	4.36		
2	625.3	8.36	Broken Failure			
	625	8.46				
3	560.8	3.47	Broken Failure			
	560.3	3.2				

Every sample is measured Uv and Is with positive and negative polarity. And the measurement is repeated after multi-pulse stroke. The test result shows that the samples are broken after one or two multi-pulse stroke. The varistor is almost physically damaged. More test results gave the same result.

Figure 12. The physical demagedof the samples

TABLE V. THE TEST RESULTS WITH PULSE INTERVAL TIME 50ms

SN	BeforeTest		1st		2nd		3rd		4th		5th	
	Uv	Is	Uv	Is	Uv	Is	Uv	Is	Uv	Is	Uv	Is
1	601	0.64	544	6.4	533	9.5	561	6.32	574	5	584	3.99
	602	0.85	542	6.13	536	8.86	563	6.55	576	5.15	587	4.01
2	622	1.03	612	1.54	591	3.81	609	3.87	MetalFailure			
	622	0.8	612	1.57	592	3.52	611	3.78				
3	625	1.46	606	4.49	MetalFailure							
	626	1.89	606	4.28								

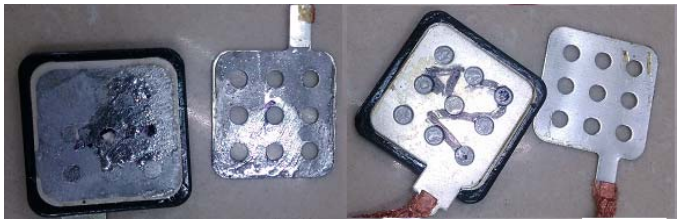

Figure 13. The metal demaged of the samples

After 5 multi-pulse tests two of the samples have broken between the varistor bodies to the conductor. The first sample is still in good condition.

TABLE V. THE TEST RESULTS WITH PULSE INTERVAL TIME 100ms

SN	BeforeTest		1st		4nd		5rd		8th		9th	
	Uv	Is	Uv	Is	Uv	Is	Uv	Is	Uv	Is	Uv	Is
1	591	5.41	599	4.67	603	5.2	609	5.26	601.6	6.07	601.8	5.56
	590	5.47	598	4.51	604	5.06	612	5.14	604.7	5.99	604.3	5.83
2	609	4.53	605	4.26	603	6.36	596	6.78	583.6	8.29	586.3	7.19
	610	4.66	608	4.26	604	6.73	597	6.84	587.6	8.2	590.5	6.96
3	579	5.82	583	5.49	611	4.51	590	5.8	582.3	7.91	583.9	8.55
	582	5.67	586	6.3	609	4.5	592	5.5	585.5	7.86	588.6	7.8

After 9 multi-pulse tests the three samples are considered in good condition.

VI. CONCLUSIONS

Previous tests have shown that multiple pulses may damage some SPDs at lower levels than the maximum discharge current. Such a way of testing has been proposed in the way of development of IEC SPD standards but has not originally being retained as a basic main test. However, measurement on natural lightning shows that such multiple pulses exist and a new generator has been developed in China to cover this need. Tests on various SPDs design are being performed in order to show how this stress can influence the SPD failure modes. Various configurations for multiple pulses have been tested with high and low current magnitude on different SPD designs. Test with impulses surimposed on continuous current have also been performed.

- With the new material and formula applied on the varistors manufacturing, the quality is more and more stable. The varistor can withstand tens of nominal impulse current with low leakage current variation.
- Multi-stroke on the SPDs is different from the single stroke. The varistor can't withstand 6-stroke impulse when the sample can withstand 60 single impulses.
- The pulse interval time is very important for the withstand capability in multi-stokes.
- The failure mechanism of the varistor and MOV type SPDs is not only with the dissipated power, but also with the design and the technology of the varistor production
- If the lightning stroke is multi-stroke in the LV power system the failure of the varistor can cause short-circuit and this failure mode needs to be considered in standards.
- It is necessary to pay more attention on the the research of the multi-stroke and the SPDs in the near future.

REFERENCES

[1] YANG Shao-jie, CHEN Shao-dong, ZHANG Yi-jun, et al. Characteristics analysis of the induced overcurrent generated by close triggered lightning on the overhead transmission power line [J]. Journal of Tropical Meteorology, 2010, 16(1): 59-65.

[2] Heidler F, Flisowski Z, Zischank W, et al. Parameters of lightningcurrent given on IEC62305-Backgroud, experimental outlook[C]//29th International Conference on Lightning Protect. Uppsala, Sweden, 2008:

[3] Berger K. Novel observation on lightning discharge: Results of research on Mount San Salvatore [J]. Journal of the Franklin Institute, 1967, 283(6): 478-525.

[4] MIL-STD-464A, electromagnetic environmental effects - Requirements for systems[S], 2002.

[5] Schroeder M, Cherchiglia A L, Souza V. Lightning current statistical analysis Measurements of Morro do Cachimbo Station- Brazil[C]//Proc. of the 26th International Conference on Ligh. Krakow, Poland, 2002

[6] Alain Rousseau, Xuyun Zang Lihua Zhang Ming Tao "Multiple shots on SPDs- Test Methods and Results", ICLP 2012