2015 International Symposium on Lightning Protection (XIII SIPDA), Balneário Camboriú, Brazil, 28th Sept. – 2nd Oct. 2015.

Degradation Analysis of MOV Type SPDs With Surge Superposing AC Operating Voltage

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***Abstract*—there are various kinds of surges in LV system superposing the AC operating voltage. This document presents the test on MOV type SPDs to discover the possible reasons for fire under operation that are observed in field. The tests are including the AC test, surge test, surge on AC voltage and multiple surges. The test results lead to the solutions on how to deal with the safety problem.**

Keywords— MOV; SPD; surge; impulse current, multiple surge, continous current

I. INTRODUCTION

The MOV type SPDs (called SPDs in this paper) are widely used in power systems for their excellent protective ability. They protect against any type of surges and can operate quickly. They are widely used in low voltage power systems for higher reliability of the system. But the SPDs can catch fire during operation condition, especially in lightning environment. The failure of the SPDs will then bring risk and danger to the power system and the equipment under protection. This becomes a significant point and should be addressed seriously.

The test standards in IEC 61643-11 to covers such problems with the end of life of MOV type SPDs includes the thermal stability test, the Temporary Overvoltage tests, the operating duty test, surge test and short-circuit test. The qualified SPDs have to pass these tests but sometimes failures still appear in working condition. There may be some other reasons to be investigated.

It is obvious that the SPDs failed because of the operating voltage (continuous operating voltage Uc), the surge currents or both of the two factors.

II. TEST METHODS

A. Samples under tests

The MOV, square type 34mm*34mm with reference DC voltage 621V, is chosen as test sample. This type MOV is usually used in SPDs. The samples under test are bought from different manufacturers for comparison.

Figure 1 : MOV samples

B. The tests are designed as followed:

1) Thermal stability test: the test is performed on SPDs and it is one of the type test according to the standards. Many SPDs have designed good ability thermal disconnectors for low fault current. In this paper these tests will not be performed again.

*2) High operating voltage Uc: Uc from Uref (reference voltage) up to the voltage that leads to MOV short-circuit.The reference test voltage in many 230/400V TT, TN and IT power system is 255 V. The Uc will be changed from 1.0*Uref, 1.25*Uref, 1.5*Uref, 1.75*Uref, 2.0*Uref , 2.25*Uref and higher. The power source should have enough short-circuit current capability greater than 100A.*

3) Surge Test with In and Imax: the waveform is 8/20 μs and nominal discharge current In=20kA. The maximum discharge current Imax (optionnel according to the standard) is 40kA.

4) Operating duty test: Surge (In) superimposing on the Uc (Uref): the test process is defined in item 8.3.4 in IEC61643-11 (2011).

*5) Operating duty test: Surge (In) superimposing on a higher Uc (1.5*Uref): During the lightning process, surges may be combined with overvotlages. The operating votlage Uc can be greater than Uref. The overvoltage maybe the main reason of the SPDs fire inccident observed in field.*

*6) Operating duty test: Multiple Surges (5*In) superimposing on a higher Uc (Uref): lightning observation and lightning detecting research has many datas that the lightning stroke is not one pulse, but multiple pulses. More than 80% of obervation in high towers show that 3~7 pulses are present in natual lightning. In this test the multiple pulse is*

*designed as 5*In and the time interval between the every pulse is 20 ms.*

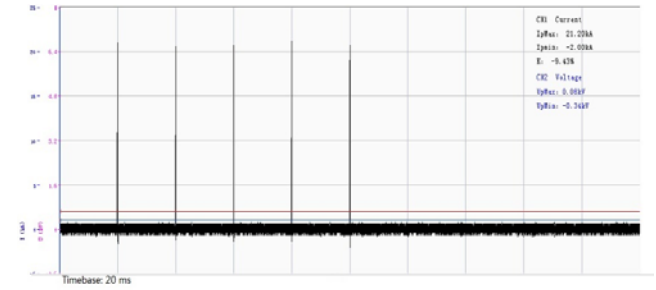


Figure 2 : Mutiple impulses

7) Operating duty test: surge with continous current superimposing on higher Uc (Uref): The lightning observation datas show that there is continous current between the surges. The test simulates one of the natural lightning event.

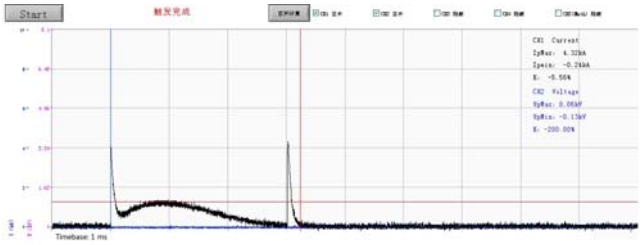


Figure 3 : mutiple surges and continuous current

C. Test Process

First, we will measure the reference voltage Uv and the leakage current Is before the test. After test if the sample looks normal, then we will repeat the measurement to check the quality of the MOV.

The current and voltage curve will be saved on a disk for further analysis. The videos of the samples are also saved.

The test equipment is a surge generator, an AC power source and the multiple pulse generators. The pictures of the equipment are shown below:

Figure 4 : test equipments

III. Test Results

A. Thermal stability test : as indicated above we don't discuss the test in this paper

B. High operating voltage Uc

It is obvious that MOV will fail and catch fire if the operating voltage is high enough.

TABLE I. HIGH UC TEST RESULTS

Number of SPD sample	Uc/ V	Time s	Pic. No.	Visual Check	Results
A-1	440	60		Normal	Ok
A-2	440	60		Normal	Ok
A-3	440	60		Normal	Ok
B-1	510	60		Normal	Ok
B-2	510	60		Normal	Ok
B-3	510	60		Normal	Ok
C-1	570	60	0035	Fire	
C-2	570	60	0036	Fire	
C-3	570	60	0037	Fire	
C-4	570	60	0038	Fire	
D-1	543	60	0039	Fire	

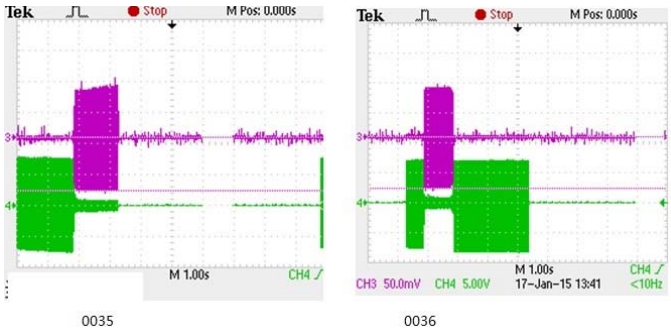


Figure 5 : high Uc test results (pictures N°35 left and N°36 right)

In figure above, the green curve is the AC voltage and the deep pink curve is the current of the MOV. The picture 0035 shows that the time for the MOV to become short-circuited from high impedance is about 1.4 second. The breaker opens the circuit of the power source. The picture 0036 shows the change of the voltage and the current. First under the voltage Uc the MOV goes to short-circuit in 0.6s and the current of the MOV lasts about 1.1s. At the same time the MOV catches fire and burned to create an open circuit. The voltage recovered after the MOV burnt.

The peak of Uc is 570*1.414=806 V. The higher voltage Uc on the MOV, the time is shorter to short-circuit. If the voltage is over 1000V, the test is close to the TOV caused by high voltage fault.

C. Surge Tests

The waveform of the test is 8/20 µs and the peak value is In and Imax. With the chosen samples the value are respectively 20kA and 40kA. Former tests showed that the samples can

withstand more than 50 impulses at In, or even 100 impulses with a time interval 60s.

With Imax = 40kA, the MOV samples will puncture but not catch fire.

Figure 6 : example of tests results (puncture) with the surge tests

D. *Surge current In/Imax with AC voltage*

The operating duty test is a routine test for SPDs. To pass the test is a basic requirement for SPDs.

The samples are designed using Uc=440V. Higher AC voltage will lead the MOV to failure.

TABLE II. SAMPLES USED FOR IN/IMAX WITH AC VOLTAGE TESTS

SN	Uv	Is	Uv'	Is'	Surge kA	Uc/V	Pic. SN	
A-4			644	1.4	10.68	440	G04761	
A-5			598	6.6	10.88	440	G04762	
A-6			602	4.2	10.79	440	G04763	
A-7			585	0.2	20.26	440	G04764	
A-8-2	604	0	594	0.1	20.34	440	G04767	
A-8-3	606	3.7	501	4.9	20.33	440	G04768	
A-8-4	607	3.2	607	3.2	20.34	440	G04769	
A-9			500	8.9	20.36	440	G04766	
A-10	601	3	580	5.1	38.86	440	G04781	
A-11	601	0	556	0.41	39.42	440	G04782	F
A-12	601	3	518	10.9	39.47	440	G04783	F

If the Uc voltage is increased to 510V (2 times Uref), the results show that most of the samples fail. But the failure mode is a puncture of MOV.

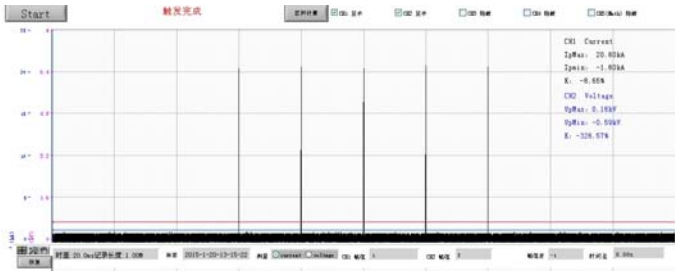
TABLE III. RESULTS OF SAMPLES USED FOR IN/IMAX WITH AC VOLTAGE TESTS

SN	Before Test		After Test		Ip(kA)	Uc（V）	
	Uv（V）	Is（uA）	Uv（V）	Is（uA			
B-4	599	4.5	594	4.6	10.77	511	
B-5	607	4.6	600	4.6	10.67	511	
B-6	595	3.8	588	3.9	10.86	511	
B-7	602	4.9	612	7	20.11	511	F
B-8	603	4.8	590	6	20.24	511	F
B-9	601	3.1	599	4.1	20.27	511	
B-10	608	3.2	596	6	39.62	511	F
B-11	595	3.6	Punc	Punc	39.50	511	F
B-12	597	4.6	585	5.4	39.62	511	F

E. *Multiple pulse test with Uc*

Uc here is Uref=255V. The short-circuit current of the power system is 38A.

The peak value is 20kA with 8/20 μs waveform, the number of the pulse is 5 and the time interval is 20 ms and 40ms.



The time interval is 20 ms and the peak of the 5 pulse is 20kA.

Figure 7 : test sample comparison before test and after test on sample H-21

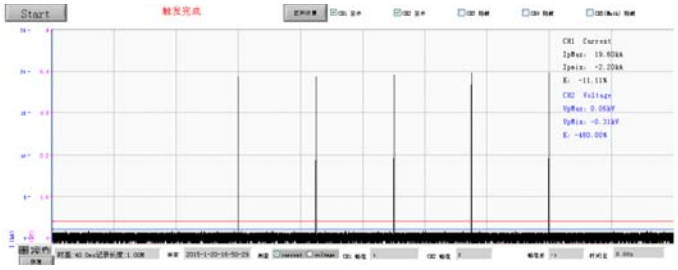


Figure 8 : multiple tests

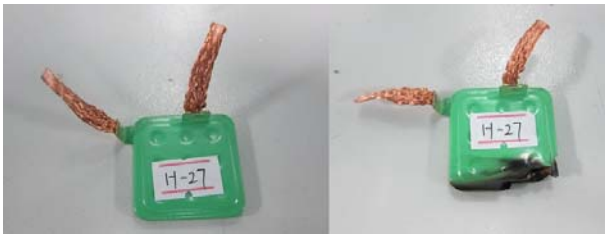


Figure 9 : test sample comparison before test and after test on sample H-27

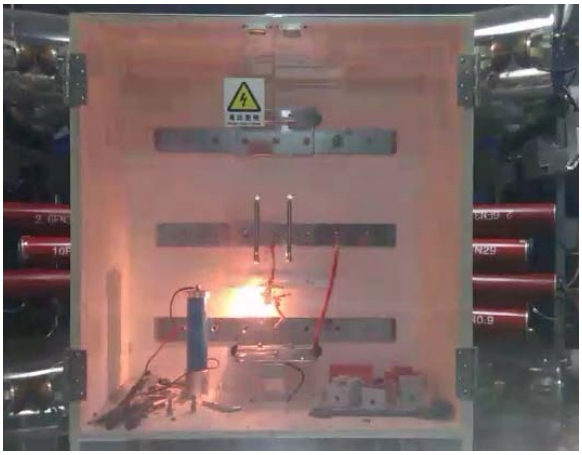


Figure 10 : picture of the MOV (H-27) sample with fire

With the multiple pulses the MOV will short-circuit with Uc and then catch fire. The test shows that with the natural lightning stroke the MOV type SPDs may fail and cause fire.

F. Surge with Continuous Current

There is continuous current between the pulses in the natural lightning stroke. This test is to simulate the continuous current and try to find the impact of the continuous current.

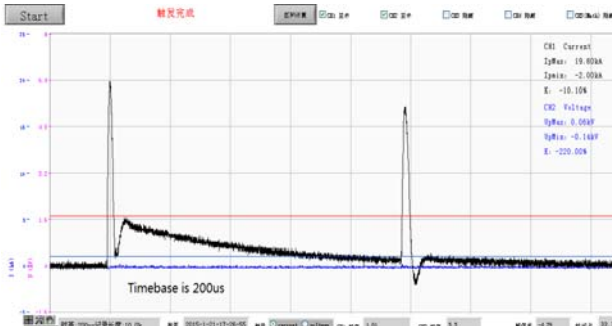


Figure 11 : continuous current and multiple imulse test

The first pulse and the second pulse is 20 kA 8/20 μs. The continuous current is simulated with a 30/300 μs surge current.

Figure 12 : sample H-47 is burned black after test

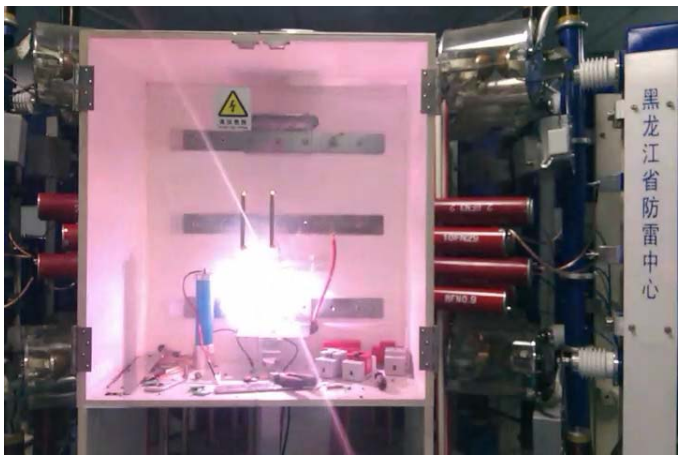


Figure 13 : picture of the sample in fire

We then changed the test settings by having a pulse peak value lower and the continuous current longer. The test shows that the fire will burn the SPDs.

Figure 14 : sample H-55 burnt after test

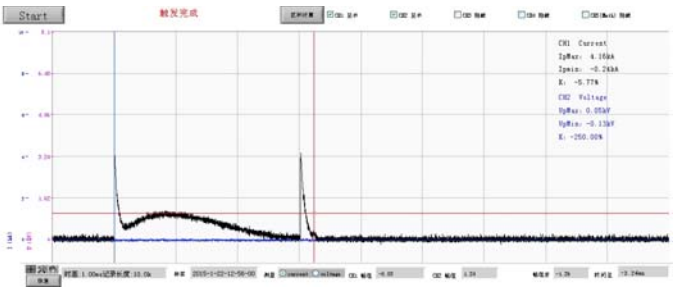


Figure 15 : continuous current and multiple imulse test

The time base of the current curve is 1 ms. Continuous current lasts 2.5 ms. The peak of the pulse is about 4.15 kA.

Figure 16 : picture shows that the SPDs is under fire

IV. DISCUSSION

Based on test results the discussion is as followed:

A. AC voltage is one of the reason that the SPDs catch fire.

Higher Uc will increase the fire occurence.

B. Single surge will not cause SPDs to cath fire. The MOV will be punctured.

C. The multiple pulses is another reason that cause SPDs to cathc fire

D. The continuous current between pulses can also lead the SPDs into fire.

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