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A Surge Suppressor Model for Increasing the Energy-Handling Capability in High Voltage Protection

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Abstract—**High voltage protection for low voltage AC power circuits is very important to minimize the damage of electrical equipment. Unfortunately, review of performance and safety features in commercially-available surge suppressors has shown that sometimes they cannot deliver the proper protection to withstand the high voltage surges. This paper will propose a model for higher capability of discharging high current and providing a constant safer voltage for class C protection system in AC power circuits. Metal oxide varistors (MOVs) are used as surge suppressors. Some configurations of MOVs have been tested to show the difference in protection capabilities. Experiments involving a wide range of high voltage surges revealed that the model provides increased in peak current and energy-handling capabilities for a given application.**

Keywords: surge suppressor, MOV, high voltage.

I. INTRODUCTION

ELECTRICAL surges generally can be divided into two categories, which are switching surges and lightning surges. Lightning is known to be one of the primary sources of most surges. It is a well-known fact that surge overvoltage is a significant contribution to equipment damage. Direct lightning strokes into high voltage transmission lines cause a severe stress on the electric equipment. The direct stroke in the conductor of an overhead line causes a voltage surge traveling in either direction of the line and to loads.

The switch-mode power supplies used for equipment such as fax machines, printers, elevators, escalators, electronic ballasts, and others, and a great percentage of other loads are becoming nonlinear. Such loads generate current harmonics, leading to distorted voltage. Voltage transients are very brief and unpredictable, making it very difficult in detecting and measuring them. Many works have been done by researchers to better understand these transients.

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The destruction potential of transients is defined by their peak voltage, the follow-on current and the time duration of the current flow, that is stated in [1]:

$$E = \int_0^T V_C(t) \bullet i(t)\, dt \quad (1)$$

where:

E = Transient energy
i = Peak transient current
V_C = Resulting clamping voltage
t = Time
T = Impulse duration of the transient

Working group of IEEE and IEC Standards have developed different surge waves for testing transient voltage surge suppressor (TVSS) devices meant for outdoor and indoor application locations to the low-voltage power distribution system, as stated in [2]:

1. Outdoor: Combo Wave – 1.2/50 μs voltage wave and 8/20 μs current wave are predominant at the service entrance outdoor location. However, lightning discharges induce oscillations, reflections that ultimately appear as decaying oscillations in a low-voltage power system.

2. Indoor: Ring Wave – A surge impinging on the system excites the natural resonant frequencies of the conductor system. As a result, not only are the surges typically oscillatory, but also may have different amplitudes and wave shapes at different places in the low-voltage power system. These oscillatory frequencies of surges range from 5 to more than 500 kHz. Based upon such conclusions, a ring wave, 0.5 μs with 100 kHz, which rises in 0.5 μs, then decays while oscillating at 100 kHz, each peak being 60% of the preceding peak. Such waves are depicted in figure 1.

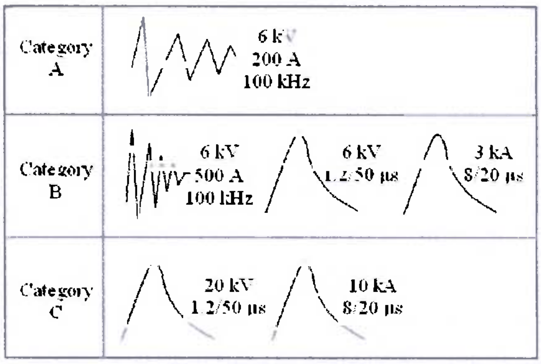

Figure 1 Test Waveforms as described by ANSI/IEEE C62.41-1991 according to [2]

II. METHODOLOGY

Before designing the protection system, some measurements were made to determine the exact components and the quantity of the components to be used in the design. The most important component was of course the varistor. For this project, the authors chose metal-oxide varistor 22.5 mm disc, manufactured by EPCOS, and the manufacturer's list number is S20K250. The properties of the varistor are as follows:

- Disc diameter = 22.5 mm
- Disc width = 5.9 mm – 6.6 mm
- Disc height = 27 mm
- Lead length = 30 mm
- Lead diameter = 1.0 mm
- Peak transient current = 8 kA
- Rated AC voltage = 250 V
- Rated DC voltage = 320 V
- Varistor voltage at 1 mA = 390 V
- Transient energy = 140 J
- Max. operating temperature = 85°C

The basic design of the protection system is as in Figure 2.

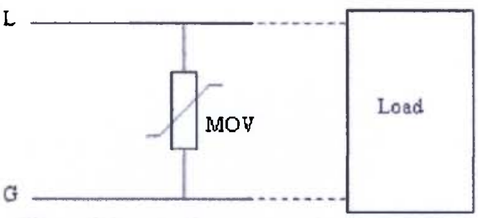

Figure 2 A protection system using single MOV

Tests were then carried out for S20K250 varistors. The tests were conducted in High Voltage and High Current Lab (IVAT) at Universiti Teknologi Malaysia (UTM) Skudai using an impulse generator made by HAEFELY and is known as PSURGE.

The first test was done by using a single MOV. The MOV was put in the PSURGE and connected between line and ground terminals. A surge impulse voltage was then applied to the varistor at a time, from the minimum voltage that can be generated by PSURGE, which is 2.7 kV onwards, with 500 V increment between steps, until the breakdown of the varistor was reached. The S20K250 varistor was blown into pieces at 17 kV, with discharge current of 8.18 kA. As the result, the varistor was said to be failed as an open circuit. The varistor was completely destroyed because the applied conditions exceeded the energy rating of the varistor.

For this project, the authors needed to design a class C protection system, but can withstand surges as much as 20 kV and 30 kA. Referring to figure 1, a TVSS device installed for class C protection system should be able to handle surges up to 20 kV and 10 kA. From the first test result, S20K250 varistor alone was not suitable for that particular protection system. The authors tried to make some modifications on the circuit and came out with a protection scheme which consisted of four parallel-connected MOVs. The paralleling of varistors provides increased peak current and energy-handling capabilities for a given application. With this for parallel-connected S20K250 varistors, the protection scheme should be able to withstand surge current of up to at least 30 kA, which will be tested. The proposed configuration is shown in figure 3.

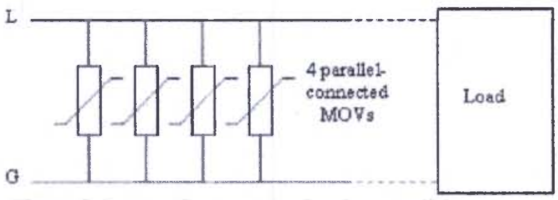

Figure 3 A protection system using four parallel-connected MOVs

The second test was carried out on the four parallel-connected MOVs circuit. Using the same method, the MOVs were connected between line-to-ground terminals in the PSURGE. A surge was then applied at a time, starting with minimum voltage which was 2.7 kV. This time, the voltage increment was set to 1 kV between tests. Until the maximum voltage surge which PSURGE can generate, which is 30 kV and discharge current of 14.8 kA, the four parallel-connected MOVs were not yet to be blown.

III. RESULTS

Table 1 and Table 2 show the result of the first test and the second test, respectively. Due to a quite number of data, the data were summarized to fit in this paper. The tables are showing data for surge voltage applied to the MOVs, residual voltage, discharge current and also voltage at peak current.

Table 1 Test Results for Single MOV

Surge Voltage (kV)	Residual Voltage (kV)	Discharge Current (kA)	Voltage at peak current (kV)
2.7	0.67	1.00	0.65
8.0	0.95	3.63	0.74
12.5	1.18	5.86	0.82
16.0	1.37	7.66	0.88
17.0	1.40	8.18	0.90

Table 2 Test Results for four parallel-connected MOVs

Surge Voltage (kV)	Residual Voltage (kV)	Discharge Current (kA)	Voltage at peak current (kV)
3	0.66	1.18	0.45
4	0.72	1.66	0.50
5	0.78	2.17	0.55
6	0.84	2.68	0.60
10	1.10	4.70	0.60
16	1.44	7.70	0.60
22	1.80	10.80	0.60
28	2.15	13.80	0.60
30	2.27	14.80	0.60

Some V-I curves were also plotted to show the graphical difference in terms of the characteristics for both MOV configurations, as shown in these figures

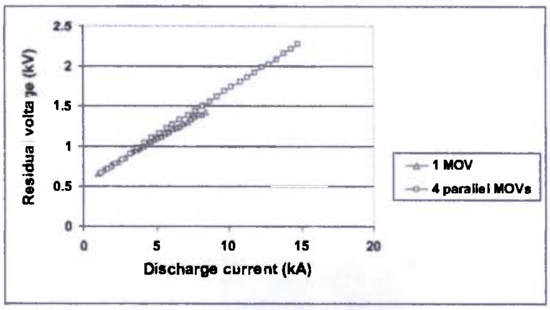

Figure 4 V-I Curve for Single MOV and Four Parallel-Connected MOVs

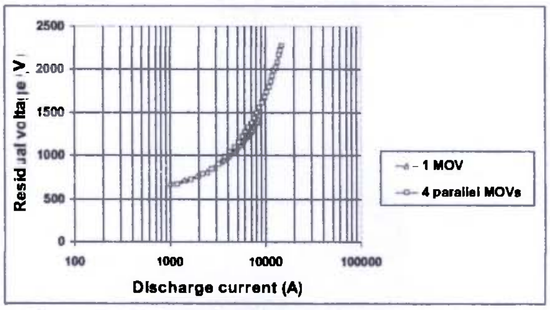

Figure 5 V-I Curve for Single MOV and Four Parallel-Connected MOVs (Log Scale)

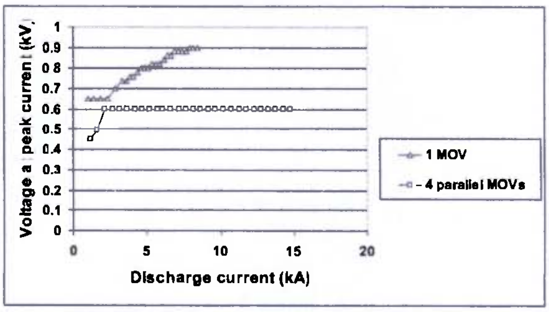

Figure 6 Voltage at peak current versus discharge current for Single MOV and Four Parallel-Connected MOVs

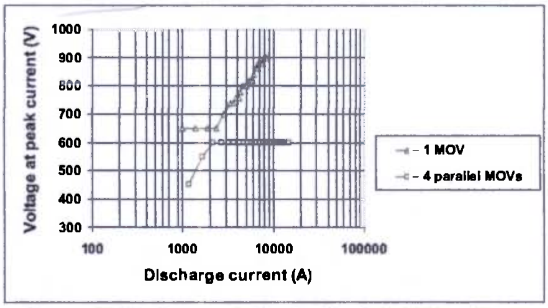

Figure 7 V-I Characteristics for Single MOV and Four Parallel-Connected MOVs (Log Scale)

As stated before, the first test ended up with the MOV blew at surge voltage of 17 kV and discharge current of 8.18 kA. That was a good indicator since the manufacturer claimed that the MOV should be able to withstand peak transient current of 8 kA.

As we can see from the above figures, there are not much different between single MOV and four parallel-connected MOVs in terms of residual voltage versus discharge current curves (figure 4 and figure 5), whether in log scale or in normal scale. Nevertheless, from the comparison between Table 1 and Table 2, test results for four parallel-connected MOVs showed a great improvement in the current discharging ability and higher strength in withstanding voltage surges. But due to limitation of PSURGE, the authors only did the second test to up to 30 kV, which is the maximum voltage surge that PSURGE can generate.

V-I characteristics curves in figure 6 and figure 7 clearly show the difference between single MOV and four parallel-connected MOVs. As we can see, four parallel-connected MOVs gave better results in terms of voltage at peak current, for a particular value of discharge current. While single MOV has a quite linear curve (higher value of voltage at peak current with increasing discharge current), the four parallel-connected MOVs gave a constant voltage at peak current, which is 600 V, starting from 3 kA of discharge current onwards. This fact is really important since calculation in energy handling capability as in "(1)" can include these values

IV. CONCLUSION

From this study, it is concluded that higher capability of discharging high current and providing a constant safer voltage for AC power circuits can be achieved by connecting MOVs in parallel. The differences of characteristics regarding the associate voltages and currents between those two connection configurations have been addressed. Experiment results showed that the parallel-connected model provided increased in total peak current and energy-handling capabilities for a given application. Tests can be carried out further to see the breakdown limit of the four parallel-connected MOVs.

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