DOES SIZE REALLY MATTER? – AN EXPLORATION OF THE UTILIZATION OF A SINGLE HIGHER ENERGY RATED MOV VS. PARALLELING MULTIPLE LOWER ENERGY MOVS

By

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ABSTRACT

This paper compares the merits of selecting either a single large MOV or the paralleling of smaller MOVs for AC line application. Recommended practices for the matching process of paralleled MOVs is presented through characterization testing examples and mathematical modeling. The paper also examines the effects of current, and therefore, energy sharing between parallel MOV arrays.

1. Introduction

The metal oxide varistor or MOV is commonly chosen as the first line of defense against transient over-voltages occurring on the AC mains. As a clamping device, much of the energy of the voltage transient itself is dissipated within the ceramic material of which the MOV is comprised. Thus the selection process of a MOV requires some knowledge of the expected transient in terms of available energy and surge current. Generally speaking, as available transient energy increases, a physically larger MOV would be required for higher rated energy. At the same time, designers of products such as TVSS devices, UPS systems or AC Panel protection devices may face physical space constraints or other dimensional form factor limitations. One route to solve this size issue is to compare the usage of a single, large MOV vs. that of using ganged (electrically paralleled) smaller MOVs to achieve equivalent ratings. This paper discusses trade-offs between these alternatives and presents a recommended procedure for the paralleling of MOVs should that choice be made.

2. Size Matters for Energy and Current Ratings

Essentially, the entire volume of material of an MOV is "active area" which accounts for its high energy rating. This is an appropriate characteristic for AC mains operation where available transient energy varies from a few joules to hundreds of joules. Likewise, the MOV's surge current rating increases with the surface area or diameter of the metalized surface of the MOV. AC Line lightning surge currents can reach 500A to 10kA depending upon the service, source, and location. Observations of higher currents have been cited, for example, to 40kA. Again, for this reason MOVs are chosen over other technologies.

Table 1 compares Energy and Surge Current parameters for typical 14, 20, 32 and 40mm diameter radial devices and a 34mm square device.

Table 1 – Surge Current and Energy Ratings of Various Size MOVs at Typical Voltage Ratings

Nominal Diameter	Voltage Rating (AC)	Maximum Surge Current (8x20 μSec, 1 pulse)	Maximum Energy (2 mSec)
14mm	130	6,000 A	50 J
20mm	130	1,0000 A	100 J
32mm	130	25,000 A	200 J
34mm	130	30,000 A	270 J
40mm	130	30,000 A	270 J
14mm	275	6,000 A	110 J
20mm	275	10,000 A	190 J
32mm	275	25,000 A	360 J
34mm	275	40,000 A	400 J
40mm	275	40,000 A	400 J

3. Physical Comparisons of Common Disc Size MOVs

While common disc sizes range from 5mm to 60mm, for the purpose of this discussion, a large MOV is defined as one incorporating a 32mm, 34mm square, or 40mm disc (Figure 1). A small varistor is defined as a 14 or 20mm disc since these are usually the smallest practical size for most commercial AC Mains equipment. A first-order comparison of these disc sizes is made in Table 2 for the 250VAC (RMS) working voltage types.

Figure 1 – Various MOV Packages available

TABLE 2 – Comparison of available 250 V_{AC} MOV packages

NOMINAL DIAMETER	MAXIMUM THICKNESS	MAXIMUM SEATING HEIGHT	MAXIMUM ENERGY	MAXIMUM SURGE CURRENT
14mm	5.6 mm	20 mm	100 J	6,000 A
20mm	5.6 mm	26.5 mm	170 J	10,000 A
32mm	9 mm	52 mm	330 J	25,000 A
40mm	9 mm	57 mm	370 J	40,000 A
34mm	6.1 mm	44.5 mm	370 J	40,000 A

4. Connecting MOVs in Parallel

MOVs with radial leads – the familiar "lollipop" device are generally available in diameters from 5mm to 20mm. These devices can handle up to 10kA peak surge current and dissipate up to 170 Joules of energy. For larger current and energy handling capability, larger diameter MOVs are available. These come in diameters from 32mm to 60mm and commonly have soldered tabs or are housed in plastic cases with screw terminals (see Figure 1). The physical size and the mounting arrangements make these larger components unsuitable for applications where space – especially headroom - is restricted. The only alternative in such cases is to gang or electrically parallel a number of smaller radial MOVs (Figure 2). The idea being that their energy capabilities like their capacitance will add, ($Energy_{Total} = Energy_{MOV1} + Energy_{MOV2}$, etc.). Another attraction of paralleling four 20mm MOVs – a commodity product - is that their cost is less than an equivalent 40mm device. Despite the attractions of paralleling, there are difficulties that must be addressed - current sharing is one such pitfall. For very high energy applications requiring more capability than even a 60mm device can deliver, then there is no option but to gang devices.

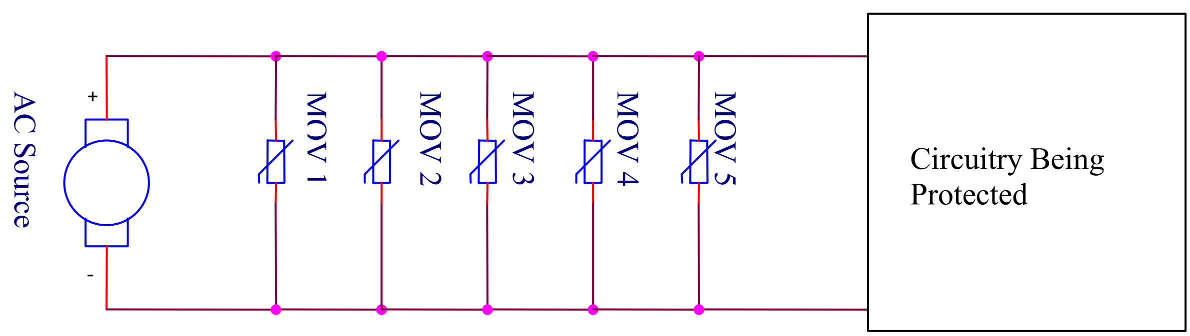


Figure 2 – Electrical arrangement of MOVs in parallel

The effects of sharing (mismatch) is not as dramatic under high level short circuit transients and it is possible to screen MOVs to a tighter V_{nom}[1] tolerance level. Still to obtain a 40 kA rating for the classic 8x20µSec lighting transient, 4 – 20mm discs would be required to perform the same job as a single 40mm

[1] Vnom (or Nominal Voltage) is the voltage drop of the MOV with 1mA DC forced current applied. It is the electrical characteristic region where the MOV transitions to the non-linear resistance (clamping) under higher applied currents.

disc. The importance of tolerance is increase significantly if a 120 kA transient rating is required (12 – 20mm discs vs. 3 – 40mm discs).

Some obvious tradeoffs are overall space required to place the larger component and available assembly methods. The height needed for the 20mm discs is 26.5mm vs. 57mm for the 40mm disc and the 20mm leaded product can be purchased on Tape and Reel for use with automated assembly equipment.

Unlike resistors, MOVs have highly non-linear voltage-current characteristics and the manufacturing process produces some variation from device to device even within the same batch. To account for this, MOV manufacturers traditionally quote a nominal voltage, $V_{N(DC)}$ with a ±10% tolerance. The problem this presents for paralleling MOVs is illustrated in Figure 3 which shows the upper and lower limit characteristic curves for a 150V-rated 20mm MOV. If two MOVs with characteristics represented by these respective limit curves were operated in parallel, then the degree of current sharing would vary with the operating point. For example with 300V applied, the respective currents would be 0.6A and 100A, a ratio of 1:167. At 600V the respective currents would be 4.5kA and 8kA, a ratio of 1:1.75. Although in practice such a gross mismatch would be unlikely, it does illustrate the problem. In general, sharing at low currents requires almost perfect matching, but is easier to achieve at high currents due to the more resistive nature of the device.

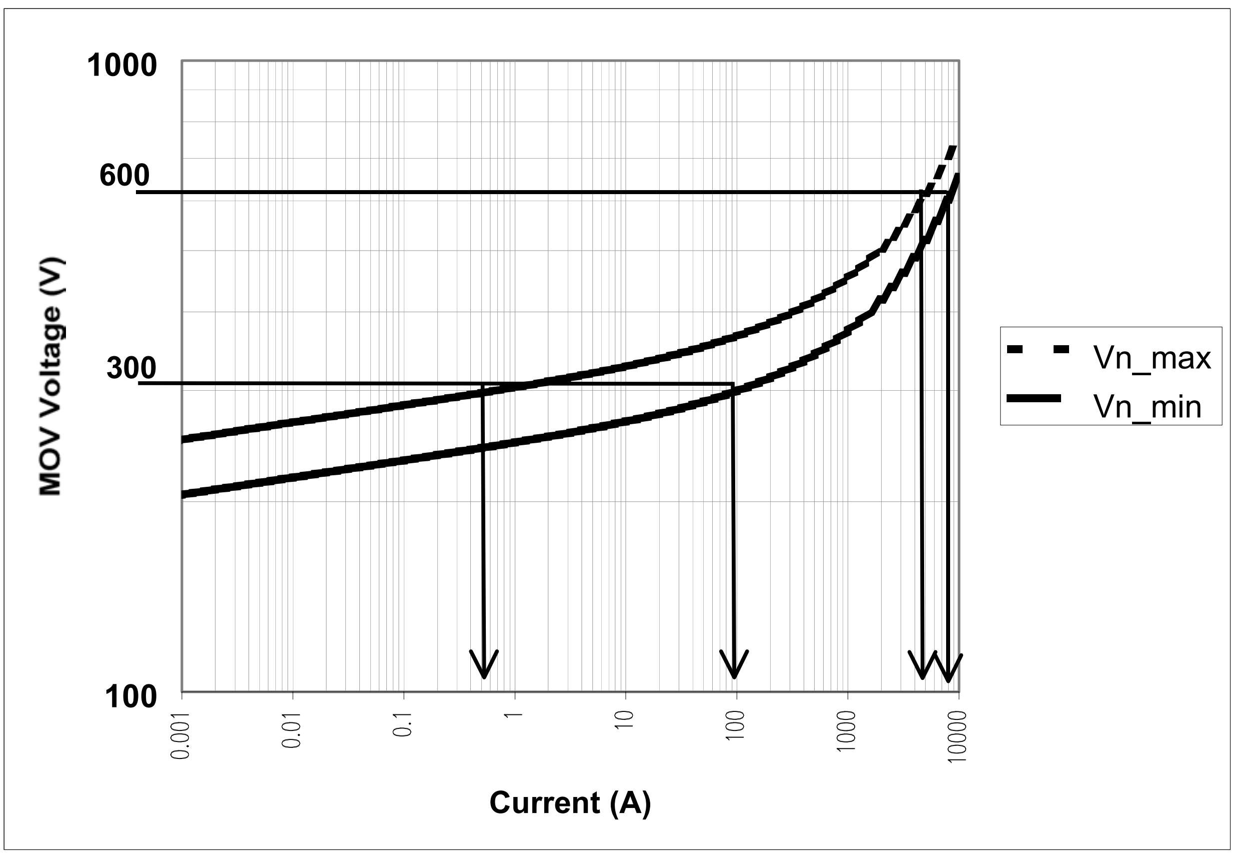


Figure 3 - Graph showing how mismatched MOVs share current at two different operating points.

5. How closely matched do MOVs need to be?

The application in certain cases defines how closely ganged MOVs need to be matched. For example where a given nameplate surge current rating is required, where the parallel combination need only share at or near the peak current rating, then a modest matching effort will suffice. On the other hand where a general increase in energy capability is required, to cope with the lower intensity, but more frequent disturbances, close matching over a broad range of currents is required.

The mismatch in Figure 3 is an extreme example and the normal distribution of MOV voltages within a batch is generally much tighter. Table 3 shows a summary of electrical measurement statistics for a sample of 25 pieces. As can be seen, the coefficient of variation (standard deviation divided by the mean) is greatest at low measurement currents. This suggests that sharing at high currents should be better than indicated at low currents where it is practical to measure. This trend is however statistical and does not necessarily hold for every device. Hence even perfect matching at low currents is no guarantee of perfect matching. To show the effect of different degrees of matching, the current sharing in three pairs of MOVs all from the same batch with different degrees of matching was both measured and simulated over a range of currents. The simulation was done using a PSpice model of the MOV. The model represents an average V-I characteristic and its nominal voltage can be adjusted to represent any actual device. However the adjustment is exactly proportional over the whole characteristic and thus the model does not exhibit the differing coefficient of variation at different currents shown in Table 3. The results are presented in Table 4. The measured and modeled values are in good agreement and show that for poorly matched sets (Table 4a) the sharing at the lower currents is particularly bad with the higher voltage part conducting only 43% of its partner. In poorly matched MOVs the burden is loaded on the lower voltage device. Table 4b represents data on devices matched to within one percent. Here the degree of sharing is good but is achieved only by close matching. In the case of the "perfectly" matched pair (Table 4c), measured sharing is very good but not perfect explained possibly by a combination of measurement error and imperfect matching on some parts of the characteristic curve. In each case the degree of matching improves with increasing current, as expected.

Table 3 - Sample summary statistics of MOV voltages

Statistic	Test Current		
	10µA	1mA	100A
Mean	191	225	324
Minimum	185	221	319
Maximum	199	231	331
Standard Deviation	4.3	3.3	3.9
Coefficient of Variation	2.2%	1.5%	1.2%

Table 4a - Current sharing in MOVs matched to within 4%

Measured			***Simulated***		
I_1 (A)	**I_2 (A)**	Match	**I_1 (A)**	**I_2 (A)**	Match
26	62	43%	27	61	45%
178	307	58%	185	300	62%
1732	2229	78%	1783	2178	82%

Table 4b - Current sharing in MOVs matched to within 1%

Measured			*Simulated*		
I_1 (A)	I_2 (A)	Match	I_1 (A)	I_2 (A)	Match
45	53	84%	46	56	82%
228	255	89%	236	264	89%
1916	2045	94%	2002	2098	95%

Table 4c - Current sharing in MOVs with near perfect matching

Measured			*Simulated*		
I_1 (A)	I_2 (A)	Match	I_1 (A)	I_2 (A)	Match
52	54	96.4%	54	55	99.1%
239	248	96.4%	251	253	99.5%
1796	1875	95.8%	1898	1902	99.8%

6. Recommendations for matching

1. Devices for paralleling should always be from the same manufacturer and have the same diameter.

2. Match sets by nominal voltage (at 1mA DC) to within 1% if possible. For more reliable sharing, measure at two points on the characteristic curve. If the peak surge current is known, for example where an MOV is used to protect the contacts of a circuit breaker for which the circuit inductance and maximum breaking current is known, then matching should be done as close to the operating point as possible.

3. Devices should be from the same production batch if at all possible. The main reason for this is that the distribution of nominal voltages within a production lot will be tighter than from lot to lot making matching easier. Also in general the overall characteristics of devices from the within a production batch will be better matched than from different batches.

4. Add some margin to allow for imperfect matching. A 20% minimum de-rating is recommended. For example where four 20mm parts could replace one 40mm device, five 20mm parts should be used in practice.

5. Arrange the layout of paralleled devices so that the track resistances and inductances are as near as possible the same.

7. Reasons to Use a Single Large MOV

Aside from the obvious ease of selecting and mounting a single package, and the resultant higher transient current and energy ratings, the larger MOV can provide significant pulse life margin. This can be seen by

comparing in Figures 4 and 5. For example, In comparing typical 250V_{AC} 20mm and 40mm MOVs, the single pulse surge current rating is 10kA vs. 40kA, respectively. Under close matching then, four 20mm MOVs would be required to equate to the 40mm in terms of surge current rating only. However, if for example a pulse life of 10 surges of 10kA is required for a product then five 20mm MOVs would technically be required as opposed to a single 40mm disc. Thus the space savings advantage is reduced and the board assembly process made more complex.

Figure 4 – Pulse Life Curve for 20mm MOV

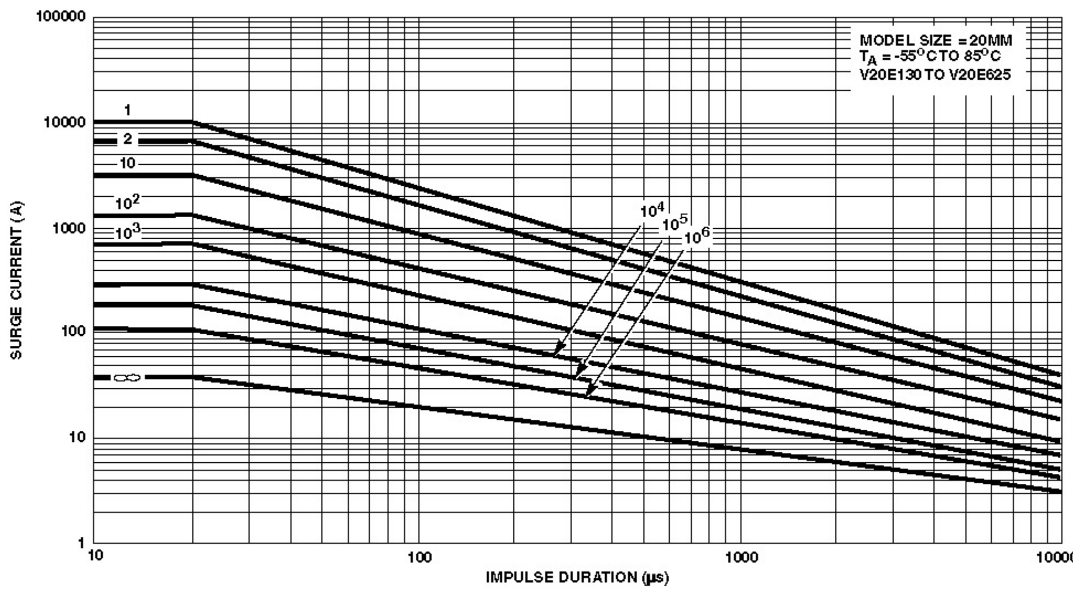
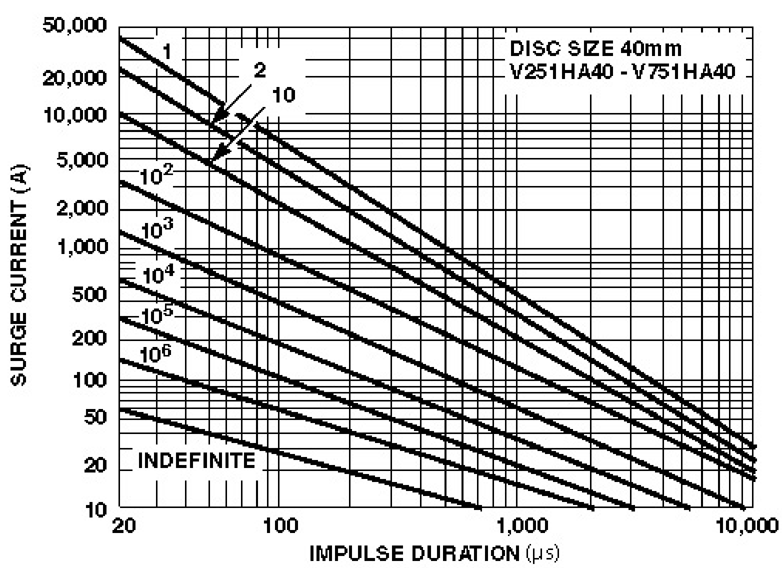


Figure 5 – Pulse Life for 40mm MOV



8. Conclusions

The following can be used as a guide for determining the proper protection scheme for the application:

- Devices can be paralleled to obtain an increased peak current and energy handling capability.
- Particular attention must be given to insure the combination will share current properly and not lead to a single device being operated beyond its rating.
- Based on the variability of the combination, the designer should de-rate the peak current and energy handling of the combination by 20%.
- The combination should be selected such that adequate Pulse Cycle Life in the application is achieved.
- For increased reliability a single device should be used, wherever possible.

Bibliography:

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