APPLICATION NOTES

Considerations for Selecting Littelfuse MOVs and Fuses for Industrial Motor Applications

Littelfuse offers specific Varistors and Classes of Fuses to address over-voltage and over-current transients in the Industrial environment. This application area is typically characterized as AC utility service entrance and distribution, and the associated high current inductive loads that can include medium and heavy motors.

Transient over-voltage suppression in these applications typically require Industrial Metal Oxide Varistors (MOVs) for induced lightning surges or for switching transients created by the motor itself. These situations demand that the MOV ratings match the surges found in these locations in terms of suitably high energy and surge current values.

Similarly, in selecting a load Fuse, it must obviously be of a value that will allow normal operation, including the allowance for certain fault conditions, but at the same time not open for the transient surges that the MOV is intended to suppress.

This Application Note discusses the first level considerations for applying both Littelfuse Industrial AC Line Metal Oxide Varistors and associated AC line Fuses with a motor protection example.

MOV Voltage and Connection

Whether single, split, or three-phase service, the operating voltage with suitable tolerance for high line operation is first in the selection process. Table 1 shows the typical AC Mains Service ratings for voltage in the US and the applicable standard MOV operating voltage rating.

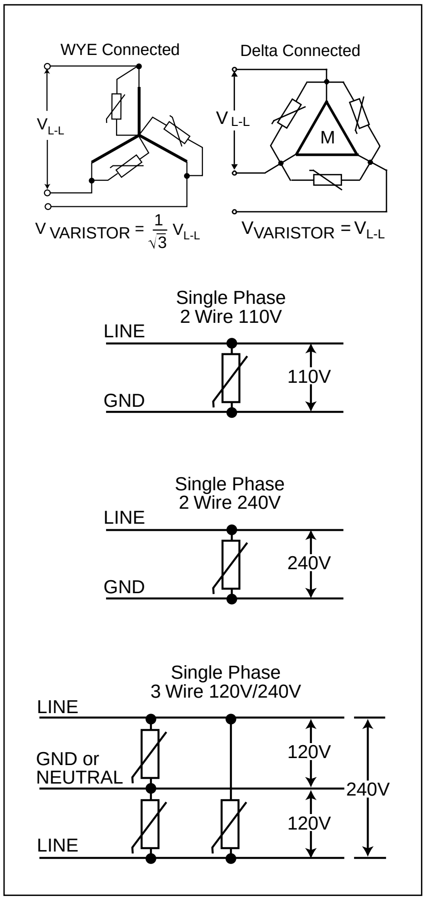


Figure 1.

Figure 1 illustrates the MOV placement in single-phase systems as well as the voltage ratings relationship for 3-phase delta and wye connection schemes. Here, the Neutral/Ground method must be known to determine the Line to Line or Line to Ground connection option and associated voltage amplitudes.

Table 1

Nominal System Voltage[1] (low voltage class)	Maximum Utilization Service Voltage[1]	Typical MOV Voltage Types (continuous RMS rating)
120 (two–wire)	127	130, 140,150
120 / 240 (three-wire)	127/254	130,140,150 / 250, 275
208Y / 120 (four-wire)	220Y / 127	L-L= 230,250,275
		L-G= 130, 140,150
240 / 120 (four-wire)	254 / 127	L-L= 250, 275 / 130,140,150
240 (three-wire)	254	250, 275
480Y / 277 (four-wire)	508 / 293	L-L= 510, 575
		L-G= 300,320,385
480 (three-wire)	508	510,550,575
600 (three-wire)	635	660

1 Per ANSI C84.1

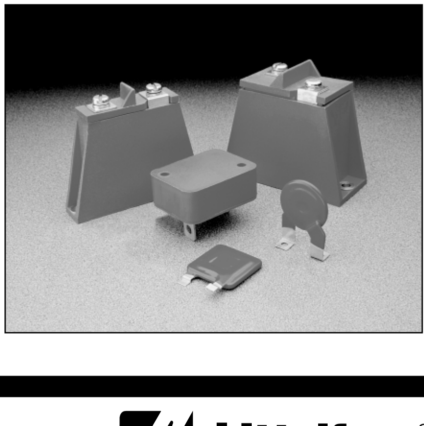
Surge Current, Energy and MOV Size

The Varistor peak surge current rating is primarily a function of the area of the disc itself. Likewise, since an MOV is a clamping device, it has an energy dissipation rating related to the MOV material volume. Available current in industrial applications often require that a physically larger MOV be utilized. Littelfuse Industrial Varistor disc diameters are 32, 40 and 60mm, and 34mm square as shown in table 2.

Selection of a specific size will require some knowledge of the expected peak surge current and waveform duration.

Table 2

MOV Series	Disc Diameter	Working Voltage Range (RMS)	Peak Surge Current (8x20uS)
BA	60mm	130 – 880 VAC	50 –70kA
DA	40mm	130 – 750 VAC	30 – 40kA
DB	40mm	130-750 VAC	30 – 40 kA
HA	40mm	130 –759 VAC	30 – 40kA
HB	34mm	130 –750 VAC	30 – 40kA



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Circuit modeling is preferred. A short-circuit analysis of the peak surge voltage divided by the circuit's impedance can provide a "worst case" value. However, short circuit analysis would yield a higher than actual peak current and therefore estimated clamping voltage from the MOV.

The respective surge current for each size type is also given in table 2 for the 8x20 lightning waveform. Most surges follow an exponential rise and decay waveform such as this.

In the industrial environment, the Varistor can be called upon to clamp or limit surges of tens of thousands amperes. As stated, the Varistor is a clamping device, a portion of the surge energy is dissipated as heat. The high temperature rise during high current surges requires that the MOV be derated for peak current when pulse duration is longer than 20 microseconds. The derating amount is type dependent. Figure 2 extends to pulses of 10 milliseconds and is an example of the lower voltage 40mm types.

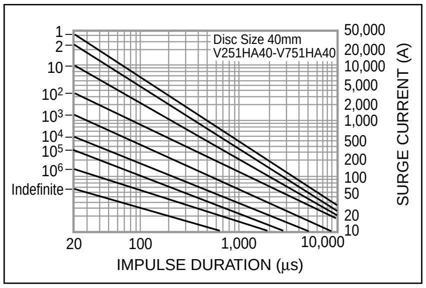


Figure 2. Surge current rating curves for V251HA40-V751HA40

For the same reasons, a limitation must be placed on the number of high current surges applied to an MOV. Littelfuse considers an MOV to be out of specification should its Vnominal voltage shift by 10% or more after a surge. These pulse life ratings are also provided in Figure 2.

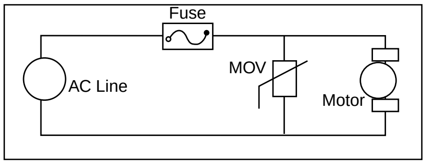
The level to which the MOV reduces the transient's peak voltage is termed "clamping" voltage and is a function of the current through the MOV. Figure 3 is a family of curves for the HB34 Series illustrating its maximum peak voltage. The designer should be aware of what component or product requires protection and its maximum safe peak voltage that it can safely withstand.

Design Example - Transient suppression considerations for an AC motor

One aspect of AC motor protection is the surge withstand capability of the motor itself. Paragraph 20.36.4 of the NEMA motor generator standard MG-1 defines a unit value of surge as: ü × V L-L (or, 0.816 × V L-L)

For transient rise times of 0.1 to 0.2 uS, twice the unit value of surge capability is required on stator windings. When rise times reach 1.2 uS or greater, 4.5 times the unit value is stipulated.

In the case of external transients such as lightning, this would equate to a surge voltage capability of 918V peak for a 230V motor (F.L.A. of 12A) on a 250 high line



condition. Since lightning surges can exceed these values, a suppression element would be required to protect the stator windings.

- Taking high line tolerance into account, a 275VAC rated MOV may be chosen for this example. A Littelfuse V271HB34 MOV is initially considered based upon desired form factor.
- Using a 2HP single phase, medium sized motor, the MOV's surge current rating would be determined by the peak current induced at the motor supply. Assuming a service location for the motor and line impedance of 2 Ohms, it is determined that a 3kA lightning surge is possible
- Maximum clamping voltage at 3kA is verified from the data sheet at 900V, below the 918 V suggested stator winding withstand capability.
- It is determined that the operational life of the motor is 20 years and that it be capable of 80 lightning transients during its service. The data sheet of the MOV is referenced for pulse rating curves which verifies a rating of more than 100 such surges.
- The ambient operating temperature for this application is 0° C to +70° C. This is within the MOV's –40 to +85° C rating. Likewise, it does not require derating of surge current or energy in this range.
- In addition to external transients, normal operation motor switching transients must be suppressed in order to reduce transients induced on the AC line and to protect adjacent electronic components. In the case of stored inductive energy, the locked rotor current rating of the motor is considered. The release of this energy either through a mechanical contact opening or fuse blowing can result in significant transient voltage. In this example, the locked rotor current is used as a worst case situation and is 65A from NEMA MG-1in this case. Assuming enough time prior to contactor opening or fuse clearing, the stored energy is $1/2LI^2$. Motor saturated inductance in millihenries must be determined. A portion of the resultant Joule energy would then be dissipated within the MOV.
- The selection of a local line Fuse for this motor application is determined by the rated line voltage, full load current rating of the motor, ambient temperature and other factors as described in the Littelfuse POWR-GARD Product Catalog. These include the points highlighted in the following section.

Additionally, exceeding the surge current or energy dissipation ratings of an MOV can result in damage to it. Since the failure mode is a short circuit, Littefuse recommends either source (line) or direct MOV over-current protection. Scenarios that could place the MOV at risk include abnormally high line voltage, such as through loss of Neutral connection, or unanticipated transient energy.

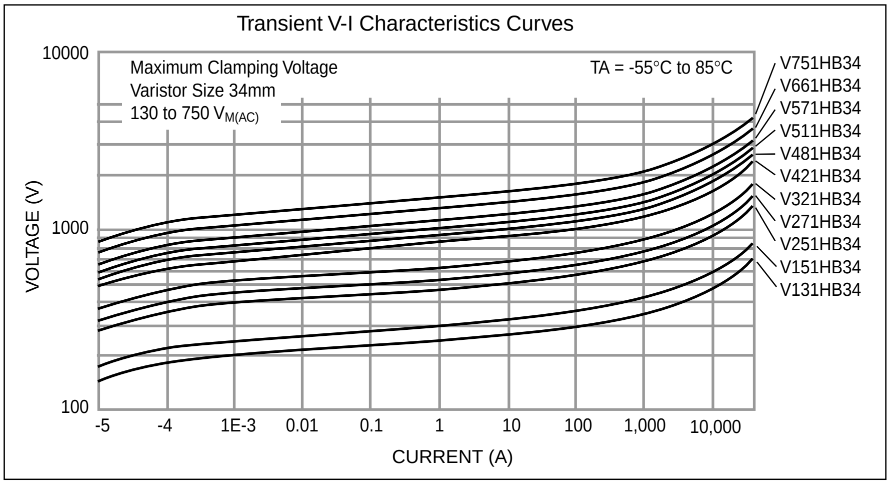


Figure 3. Clamping voltage for V131HB34-V751HB34

Fusing Considerations

Since certain Industrial applications may be capable of propagating 70kA under a short circuit condition, the sizing of fuses for these circuits are covered by the National Electrical Code for the U.S. The most common Fuse Classes were traditionally RK1 & RK5, but advances in the past decade has allowed these circuits to now be protected by Class J, Class CC & Class CD Fuses. The Littelfuse CCMR Series of Class CC & Class CD Fuses is capable of interrupting 200kA at 600Vac in a package size of 13/32" diameter by 1 1/2" long (ratings up to 30A).

The following lists the various methods to accomplish Fuse selection for Motor Protection.

- Using AC Motor Protection Tables to Select Fuse Ratings
- Selecting Fuses for Motor Running Protection Based on Motor Horsepower
- Selecting Fuses for Motor Running Protection Based on Motor Actual Full Load Currents

For the application example listed above, a 2HP 230V single-phase motor, the correct fuse rating would depend on the fuse class used in this case size. This is a concern, so we will focus on the UL Class J or Class CC. Motor Service Factor (S.F.) and Overload relays that are used. Since the F.L.A. of this motor is stated to be 12, we can use the tables listed below to select the appropriate Class J (table 3) or Class CC (table 4) fuse for this application. For this example we will assume an acceleration time of 2 seconds or less and select a 25A CCMR to protect the motor.

Verify the Transient Will Not Open the Fuse Under Normal Operations

A final selection criterion is to verify that the surges protected by the MOV will not result in the fuse being opened prematurely and limiting the effectiveness of the MOV. This can be accomplished by plotting the Surge Current and duration against the Time-Current (T-C) Curve of the selected fuse. If the resulting surge is to the left of the T-C Curve, the selected fuse will not open, if it falls to the right the fuse will open under that surge. As a rule the further to the right the T-C Curve falls from the surge the more repetitions that the fuse can be subjected to before it will open. An analysis would need to be conducted to determine the energy available in the pulse, a figure designated as I^2t, versus the melting I^2t of the fuse, calculated from the 10mSec point on the T-C Curve, to come to an approximation of the number of strikes that the fuse could accommodate without opening. A general rule would assume a 2 to 1 ratio of fuse I^2t to surge I^2t to obtain 100 strike of the pulse without opening. If this analysis is favorable, the fuse selected will serve as the motor protection and not effect the MOV operation. Since the MOV may fail in a shorted mode across the line and appear as a short circuit on the system, the fuse will clear the resultant short and prevent further damage.

Importantly, since the loads involved in Industrial Environments can be severe, one should always verify that the proper protection scheme is employed and if necessary review the requirements outlined by the NEC for clarification and compliance.

Selecting Fuses for Motor Running Protection Based on Motor Actual Full Load Currents

Protection is best achieved when fuse ratings are based on motor actual FLA as obtained from the motor nameplates. Locate motor FLA in the column appropriate for the type motor and type protection required. Read to the left to obtain the recommended amperage ratings.

Based on the information included in the MOV selection example, one can use the following chart to select the appropriate fuse to use in the application for Motor Protection.

Table 3

MOTOR F.L.A.	JTD_ID/JTD AMPERE RATING	MOTOR F.L.A.	JTD_ID/JTD AMPERE RATING	MOTOR F.L.A.	JTD AMPERE RATING
0.00 – 0.80	8/10	12.1 – 14.5	17 1/2	76.1 – 84.0	110
0.81 – 0.80	1	14.6 – 17.0	20	84.1 – 90.0	125
0.81 – 1.00	1 1/4	17.1 – 21.0	26	90.1 – 102	150
1.01 – 1.20	1 1/2	21.1 – 25.0	30	103 – 125	175
1.21 – 1.65	2	25.1 – 28.5	35	126 – 144	200
1.66 – 2.00	2 1/2	28.6 – 34.0	40	145 – 162	255
2.01 – 2.40	3	34.1 – 37.0	45	163 – 180	260
2.41 – 3.30	4	37.1 – 41.0	50	181 – 204	300
3.31 – 4.10	5	41.1 – 48.0	60	205 – 240	350
4.11 – 4.90	6	48.1 – 52.0	70	241 – 288	400
4.91 – 6.40	8	52.1 – 59.0	80	289 – 312	450
6.41 – 8.00	10	59.1 – 66.0	90	313 – 360	500
8.01 – 9.80	12	66.1 – 76.0	100	361 – 432	600
9.81 – 12.0	15				

NOTE: FOR SEVERE MOTOR STARTING CONDITIONS, FUSES MAY BE SIZED UP TO 225% MOTOR F.L.A. (See NEC Section 430 – 52 for exceptions.)

Selection of CCMR Time Delay Fuses Based on Motor Full Load Amps

Table 4

MOTOR FULL LOAD CURRENT (F.L.A.)						CCMR AMPERE RATING
For Motors With An Acceleration Time Of 2 Seconds Or Less		For Motors With An Acceleration Time Of 5 Seconds Or Less		For Motors With An Acceleration Time Of 8 Seconds Or Less		
Min F.L.A. (1)	Max F.L.A. (3)	MOin F.L.A. (1)	Max F.L.A. (3)	Min F.L.A. (2)	Max F.L.A. (3)	
0.2	0.2	0.2	0.2	0.2	0.2	3/10
0.3	0.4	0.3	0.4	0.3	0.3	1/2
0.4	0.6	0.4	0.5	0.4	0.5	8/10
0.5	0.7	0.5	0.6	0.5	0.6	1
0.6	1.0	0.6	0.9	0.6	0.8	1 1/4
0.8	1.1	0.8	1.0	0.7	0.9	1 1/2
0.9	1.3	0.9	1.1	0.8	1.0	1 8/10
1.1	1.4	1.1	1.2	0.9	1.1	2
1.2	2.1	1.2	2.1	1.2	1.8	2 1/2
1.5	2.6	1.5	2.6	1.4	2.3	3
1.8	3.0	1.8	3.0	1.6	2.6	3 1/2
2.1	3.4	2.1	3.2	1.8	2.8	4
2.3	3.8	2.3	3.3	2.0	2.8	4 1/2
2.6	4.3	2.6	3.4	2.3	2.8	5
2.9	4.8	2.9	3.7	2.5	3.1	5 6/10
3.3	5.2	3.3	4.0	2.7	3.4	6
3.5	5.4	3.5	4.1	2.8	3.5	6 1/4
3.6	5.7	3.6	4.2	3.2	3.7	7
4.1	5.8	4.1	4.3	3.4	3.8	7 1/2
4.3	6.2	4.3	4.6	3.6	4.2	8
4.6	6.9	4.6	5.2	4.0	4.5	9
5.2	7.7	5.2	5.8	4.5	4.9	10
5.8	8.9	5.8	6.6	5.4	5.5	12
6.8	10.0	6.9	7.7	6.7	6.7	15
8.9	13.5	8.9	10.0	6.8	9.0	20
11.5	15.8	11.2(2)	11.8	9.0	11.0	25
14.3	17.8	13.4(2)	13.4	10.0	15.0	30
20.7	23.3	16.1	17.9	15.6	15.9	35
23.7	26.7	18.4	20.5	17.8	18.2	40
28.8	30.0	20.7	23.1	20.0	20.4	45
30.0	33.3	23.0	25.6	22.3	22.7	50
35.5	40.0	27.8	30.1	26.7	27.3	60

1. Based on NEC requirement limiting the rating of time – delay fuses to 175% of motor F.L.A., or next higher rating.
2. Based on NEC exception permitting fuses rating to be increased, but not to exceed, 225% motor F.L.A., however per NEC section 430 – 152 Class CC (0 – 30) fuses can now be sized up to 300% of motor F.L.A.
3. Based on LITTLEFUSE CCMR time – delay characteristics.

Conclusion

Both transient over-voltage and over-current situations can be addressed to protect motors in medium and heavy Industrial applications. The selection process first involves the coordination of MOV and Fuse parametric ratings to that of the motor's nominal operation while following accepted industry recommended practices. Secondly, the determination of application conditions such as fault currents, transient voltage type, magnitude and frequency are required to identify matching ratings of the MOV and Fuse.

Bibliography:

1. Littelfuse TVS data book DB450
2. NEC – 1999
3. American Electrician's Handbook, 10th ed. Croft, Wait, and Summers
4. ANSI C84.1-1995
5. NEMA Standards Publication MG-1-1998
6. Littelfuse Powr-Gard Catalog PF101-8

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Littelfuse, Inc.
800 E. Northwest Highway
Des Plaines, IL 60016
(847) 824-1188
www.littelfuse.com