PROTECTION OF MOTOR CONTROLLERS USING NORTH AMERICAN TIME DELAY FUSES

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Summary

European or IEC motor controllers have experienced difficulty in gaining North American market acceptance even though complying with UL and CSA Standards. It is the author's belief that this is due in large part to philosophical differences between North American and European low voltage fuse standards. This paper therefore reviews North American low voltage, current-limiting fuse standards and explains their influence on equipment standards with particular reference to motor controlgear and the application of fuses for short circuit protection of motor circuits. Special reference is given to the North American Time Delay fuse.

1. Introduction

North American low voltage fuse, equipment and installation standards are co-ordinated to the extent that when short-circuit protection is provided by current-limiting fuses, it is common practice for the end-user, not the equipment manufacturer, to decide on the class and brand of fuse to be installed. This is contrary to European standards and practice where it is becoming more usual for the equipment manufacturer to have to assume responsibility for the installed fuses.

Introduction of the much smaller European designed IEC contactor into the North American market met with some resistance primarily because some controlgear manufacturers did not fully understand the concepts underlying the North American system of fuse protection and many North Americans did not realize that the IEC type of contactor needs a more current-limiting class of fuse than is commonly used for the protection of the larger dimensioned North American or NEMA type of contactor.

2. North American 600 Volt Fuses

For the purposes of this paper, we can say that North American general purpose current-limiting fuses are available in three basic classes - Class R, Class J and Class L.

The Class R fuse, ratings 0.1-600 amps, can be summarized as a large dimension fuse with current-limiting performance adequate for the traditional NEMA type motor controllers. The Class J fuse, ratings 1-600 amps, has overall dimensions similar to IEC 269 fuses and has much better current-limiting performance than the Class R fuse. The Class L fuse is the extension to the Class J range in ratings from 601 amps through 6000 amps.

A significant feature of the North American fuse system is that short-circuit performance limits are specified. That is to say, UL and CSA current-limiting fuse standards specify for each class of fuse the limits of cut-off current, or peak current as it is more commonly referred to in North America, and total operating I^2t that the fuse can let-through under short-circuit conditions, up to and including its maximum interrupting rating. Note that the normal interrupting rating for current-limiting fuses in North America is 200kA. The class of fuse also determines the dimensions to ensure that fuses of different classes are not readily interchangeable.

Table 1 compares peak current and total I^2t limits for Class J, R and L fuses at 200kA RMS Sym., 600V, single phase.

Table 1. Some Standard Limits of Ip and I^2t for Class J, R and L fuses

Fuse Class & rating (A)	Maximum Limits	
	Ip (kA)	I^2t (A^2s)
J-60	16	30,000
R-60	26	200,000
J-200	30	300,000
R-200	50	2,000,000
J-400	45	1,100,000
R-400	75	6,000,000
L-800	80	10,000,000
L-1600	150	30,000,000

The significance of the short-circuit peak current and I²t limits lies not so much in the actual values specified, but in the fact that equipment and controlgear standards can recognize permanent and standardized maximum short-circuit let-through limits which can be used to establish equipment short-circuit ratings when protected by fuses of a specified class. Brand testing of individual manufacturers' fuses is not required.

3. The Time Delay Fuse

First introduced in 1939, the North American Time Delay fuse was primarily designed to provide both overload and short-circuit protection in motor circuits. The Time Delay characteristic requires the fuse to carry 5.0 I_n for a minimum of 10 seconds. This delay permits the fuse to be sized close to motor full load current and yet still provide a good motor start characteristic.

A measure of the motor start capability of the Time Delay fuse is that it would require a Non-Time Delay fuse of twice the current rating of the Time Delay fuse to obtain a similar characteristic at 10 seconds.

The Time Delay fuse is normally sized for short-circuit protection at between 125% and 175% of motor full load current. It should be noted that this method of sizing the fuse only requires reference to the motor full load current. With the North American system, it is not normally considered necessary to check Time Delay fuse time-current characteristics for motor start capability or for co-ordination with the overload relay.

Both Class R and Class J fuses can be obtained with either a Non-Time Delay or a Time Delay characteristic. Note that both characteristics have to meet the same cut-off current and I²t limits specified for the class of fuse together with the conventional fusing current, I_f, which for North American general purpose fuses is 1.35 I_n. Figure 1 shows the basic difference between the time-current characteristic of a Non-Time Delay and a Time Delay Class J fuse.

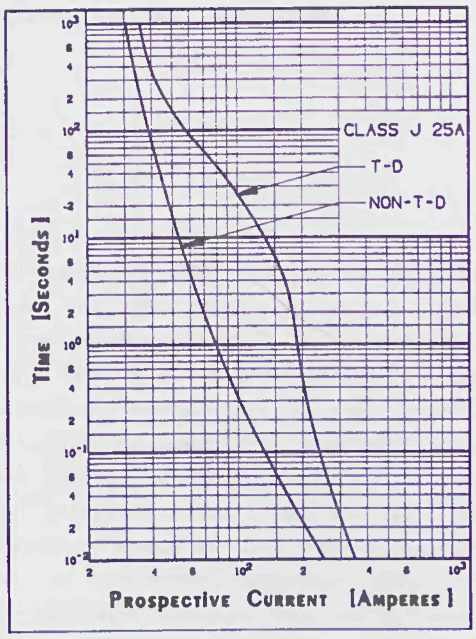

Fig. 1 Class J 25A. Time-current characteristics

4. North American Fuses and Equipment Standards

Equipment manufacturers can design and test to standardized fuse short-circuit characteristics. North American fusible equipment standards therefore specify that short-circuit tests must be conducted with test limiters or fuses that have peak current and I²t let-through characteristics not less than those specified in the fuse standards for the class and rating of a fuse to be used in the equipment. From the standpoint of short-circuit protection, this system allows for safe interchangeability of fuses of the same class but different manufacture, regardless of any design changes that fuse manufacturers can make from time to time. This in turn enables the end-user to exercise freedom of choice between fuse manufacturers. In North America, the equipment manufacturer is normally responsible only for the fuse class, not the fuse brand.

5. Motor Circuits and North American Installation Standards

Not only does the North American standards system recognize fuse peak current and I²t limits, but the wiring or installation standards (NEC in the U.S.A. and CEC in Canada) also provide guidance to the end-user by specifying maximum fuse ratings for the short-circuit protection of motor circuits.

These ratings are normally 300% of motor full load current for Non-Time Delay fuses and 175% of motor full load current for Time Delay fuses. If starting difficulties are encountered, they can be increased to a maximum of 400% and 225% respectively.
The installation standards therefore augment the system by identifying standardized fuse ratings to which motor controlgear can be short-circuit tested i.e. 400% motor full load current for Non-Time Delay and 225% motor full load current for Time Delay fuses. Lower test ratings can be used but the equipment must be specially marked to indicate the lower limit.
Again, note the end-user orientation in that the maximum rating of the SCPD is normally determined by the motor full-load current and not by the controller, unless specially marked.

6. Short-Circuit Protection of IEC Style Contactors

It is well known that the IEC contactor requires the SCPD to have relatively low cut-off current and I^2t let-through levels if "no damage" or Type 2 co-ordinated protection is required. In the North American system, the Class J fuse is the most current-limiting general purpose fuse and the Time Delay version is normally installed in motor circuits because it allows a lower current rating to be used and significantly reduces the cut-off current and I^2t let-through values.
Table 2 compares some typical 3 phase values of peak current and I^2t let-through at 200kA by Class J and Class R Time Delay fuses when selected for short-circuit protection of a 600V, 3 phase motor circuit having a full load current of 20 amps. To provide a reference point, typical values for a European type gG fuse are also shown.

Table 2. Typical let-through values of Ip and I^2t.

Fuse and % of motor full load current	Fuse I_n (A)	Ip (kA)	I^2t (A^2s.)
Time Delay:			
Class R at 125%	25	14.0	20,000
Class J at 175%	35	6.5	4,500
Class J at 150%	30	6.1	2,200
Class J at 125%	25	5.5	1,600
IEC269:			
Type gG at 200%	40	9.0	10,000

It can be seen from Table 2 that the higher damage levels would be obtained with Class R fuses and that the Class J fuse presents the end-user with the best prospect of obtaining "no damage" protection.

7. Motor Controlgear Co-ordination Tests

North American and IEC controlgear standards recognize two levels of short-circuit test currents - a lower level based on the contactor rating and a higher level to establish a higher short-circuit rating. These are known as test currents "r" and "q" respectively in IEC 947-4-1.
This standard also specifies two levels of short-circuit co-ordination for permitted damage levels - Type 1 and Type 2. While North American controlgear standards do not specify short-circuit co-ordination in terms of Type 1 and Type 2, they do not permit the overload relays to be damaged during the low level test when protected by fuses. Damage is however permitted when the SCPD is a circuit breaker.
IEC 947-4-1 also recognizes a third level of test current for verification of discrimination between the overload relay and the SCPD(s). This third level was specified in the old controlgear standard, IEC 292-1, as test currents "p", which were 0.75 I_c and 1.25 I_c, where I_c represented the cross-over point of the SCPD and overload time-current characteristics.
These test currents "p", contributed to the acceptance problems in North America, partly because discrimination between overload relays and fuses had never been regarded as a problem and partly because IEC292-1 specified that "The SCPD shall not operate in place of the starter for currents up to the maximum overload level in normal service (including stalled current of the motor)." This concept is contrary to that of the North American system which permits the end-user to size a Time Delay fuse close to motor full load running current.
IEC 947-4-1 has modified this part of the standard in that it classifies discrimination between the overload relay and the SCPD as a requirement which may be verified by a special test. Furthermore, it does not specifically require that the cross-over point of the overload relay and SCPD time-current characteristics shall prevent the SCPD from operating at currents up to the maximum overload level.
It should be noted here that limiting the fuse cut-off current and I^2t characteristics also limits the potential for variation in time-current characteristics among fuses of different manufacture.

A study undertaken by the North American NEMA and EEMAC fuse committees in 1985 for unification discussions with IEC/SC32B/WG8, showed that for operating times of 0.1 seconds or longer, the variation among North American fuse manufacturers' published time-current characteristics for Class J fuses was, for the most part, within ± 10% of the mean value. This relatively small variation among fuse time-current characteristics is obviously important to the concept of safe fuse interchangeability, particularly where equipment withstand limits are critical.

8. Conclusion

North American standardized fuse short-circuit characteristics have resulted in a high degree of uniformity among operating characteristics for fuses of the same Class and rating but different manufacture. They have permitted the development of a standards system based on the concept of safe interchangeability among fuses of the same class but different manufacture.

The Time Delay fuse has provided a simple method of rating fuses for use in motor circuits and the Class J Time Delay is recognized by many motor controlgear manufacturers as providing "no damage" protection for IEC type motor controllers in the North American market.

Under the European system, a controlgear manufacturer would have to test all available fuse brands, and hope their designs did not change, to achieve the level of fuse interchangeability expected in the North American market. It is the author's opinion, therefore, that fuse brand testing for proof of performance with equipment, particularly motor controlgear, is likely to remain the less preferred system in North America.

References

1. IEC Standards:

IEC 269 - Low voltage fuses.
IEC 947 - Low voltage switchgear and controlgear
IEC 292-1- Low voltage motor starters

2. UL Standards:

UL 198C - High interrupting capacity fuses, current-limiting types.
UL 198E - Class R fuses.
UL 508 - Industrial control equipment.

3. CSA Standards:

C22.2 No. 14-M1987 - Industrial control equipment.
C22.2 No. 106-M90 - HRC fuses.

4. Installation Standards:

National Electrical Code 1990.
Canadian Electrical Code 1990.

Notes:

1. U.S. and Canadian standards are not identical. However, many of the differences tend to be minor in nature and should be eliminated in the standards harmonization process now taking place in North America.

2. A proposal by IEC/SC32B/WG8 to include Class J and Class L fuses in the IEC 269 standard is currently being processed