EXTENDING THE LIFE OF LOW VOLTAGE ADJUSTABLE SPEED DRIVES

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Abstract – A fundamental aspect of Low Voltage Adjustable Speed Drives' (LV ASD) overcurrent protection is the elimination of harmful input power anomalies which could significantly damage the sensitive electronics in and around the Adjustable Speed Drive (ASD).

This paper will provide an overview of the newest Low Voltage Solid-State Circuit Breaker technology (SSCB) and how Petroleum and Chemical industry users can take advantage of its ability in eliminating almost all the electro-mechanical stresses applied at the input to any LV ASD when protected with traditional circuit breakers or high-speed protective fuses. This higher level of protection comes through the use of SSCB technologies which provide the lowest let through energy level of any overcurrent protective device available today. At the same time, these devices eliminate risk by reducing harmful arc flash incident energy to near negligible levels while requiring no maintenance.

Index Terms — Solid State Circuit Breaker, IGBT, Arc Flash, Let Through Energy, Personnel Protection, Molded Case Circuit Breaker, ASD, High-Speed Fuse, Semiconductor Fuse.

I. INTRODUCTION

In the past, Low Voltage Molded Case Circuit Breakers, (LV MCCB) or high speed ('semiconductor') fuses have been used as the input overcurrent protection for low voltage ASDs. Each ASD supplier will typically recommend specific overcurrent protection devices for the input protection of their ASD units. Superior ASD protection can be achieved using the newest and very rapidly growing Low Voltage Solid-State Circuit Breaker (SSCB) technology. To tackle this quickly evolving technology, UL issued the UL489I [1] standard to cover the specific nuances of these new switching devices.

Using silicon carbide (SiC) semiconductor modules, the unique power element sensing methodologies, used in the SSCB, can outperform any LV MCCB or fuse protection techniques, interrupting the highest short circuit currents faster than either of these previous overcurrent methods. An example is shown in Figure 1.

The SSCB provides extremely rapid and non-arcing switching operation. Since the current interruption is performed without any electro-mechanical contacts, these devices can provide almost an unlimited number of switching operations because there is no mechanical wear associated with the interruption of current. At the same time, the SSCB releases virtually no arc flash incident energy with peak let through currents as low as only 1500A - even when applied to system short circuit current levels of 200kA.

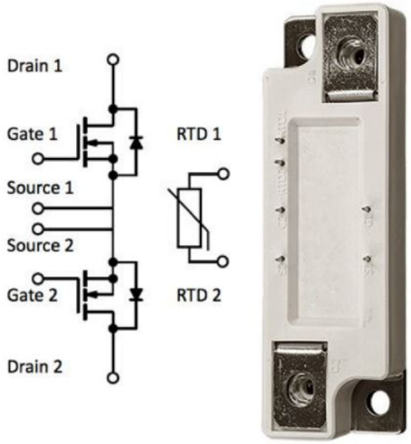

Fig. 1 Example of a typical bi-direction MOSFET module with embedded thermal Sensing [10]

A block diagram of the typical basic internal aspects of an SSCB is illustrated in Figure 2. Note the position of an air gap disconnect that provides full isolation. This air gap isolator is opened after any fault is interrupted by the semiconductor modules or if a local trip is initiated. This also provides a means for a local Lock Out Tag Out (LOTO) function.

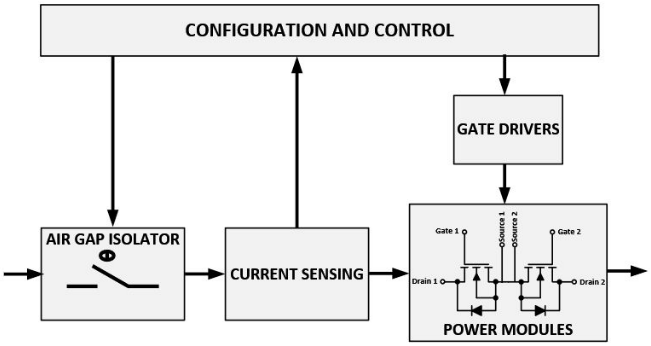

Fig. 2 SSCB Functional Block Diagram (Single line shown for simplicity)

ASD PROTECTION REQUIREMENTS

Each ASD requires source side (ac line) protection to minimize potential damage inside the ASD and any collateral damage associated with internal component failures. The requirements for this line side protection are defined by various governing bodies and their standards: Underwriters Laboratories (UL), typically 508A [2] and the former UL 508C replaced by UL 61800-5-1 [3], the National Electrical Code (NEC) [4] and the Canadian Electrical Code C22.2 No. 107.1 [5].

Previously, UL 508C did not provide a clear enough definition as to what testing was required as part of the "breakdown of components" test to determine the Short Circuit Current Rating (SCCR) of the ASD. With the introduction and adoption of UL 61800-5-1 [3], specific requirements for the "breakdown of components" test were clearly defined. UL 61800-5-1 [3] now provides clear definitions and clarity of all internal components of the ASD that must be properly protected, see Table I. The appropriate selection and coordination effort for these required protective devices necessitates that ASD manufacturers perform specific type testing.

TABLE I
TYPE TEST REQUIREMENTS FROM UL 61800-5-1[a]
Table 17 – Test overview [3] -Condensed

Test	Requirements Sections	Specification Section
Visual inspection	-	5.2.1
Clearance & creepage	4.3.6.1, 4.3.6.4, 4.3.6.5	5.2.2.1
Distances	4.3.6.7	5.2.2.2
PWB short-circuit	4.3.3.3	5.2.2.3
Non-accessibility	4.3.7.1	5.2.2.4
Enclosure integrity	4.3.6.4.3	5.2.2.5
Impact	4.3.7.1	5.2.2.5.3
Electrical tests	4.3.4.1, 4.3.6.8.2	5.2.3
Impulse voltage	4.3.3.2, 4.3.4.3, 4.3.6.1, 4.3.6.8.2.1, 4.3.6.8.2.2, 4.3.6.8.3	5.2.3.1
ac or dc voltage	4.3.3.2, 4.3.4.3, 4.3.6.1, 4.3.6.8.2.1, 4.3.6.8.2.2, 4.3.6.8.4.2	5.2.3.2
Partial discharge	4.3.6.1, 4.3.6.8.2.2, 4.3.6.8.3	5.2.3.3
Protective Impedance	4.3.4.3,	5.2.3.4
Touch Current measurement	4.3.5.5.2	5.2.3.5

[a] UL 61800-5-1, Table 17 – Test overview[3] -Condensed

The National Electrical Code states that the motor-branch-circuit-protective device shall comply with section 430.52, and the maximum ratings provided in Table 430.52.

However, section 4.3.8.1DV.2.1.1.3 of UL61800-5-1 states that overcurrent protective devices that are provided within the equipment or that are types that set the requirements for branch-circuit protection in accordance with the NEC, shall be provided and devices included as integral parts of the control equipment or, when rated in accordance with section 4.3.8.1DV.2.1.1.4. This section states that the ratings of an overcurrent device in series with connecting wiring shall not exceed the following:

a) For motor loads alone – 300 percent of the motor full-load current observed during the maximum normal operation of the system.
b) For resistive loads, and for combination resistive and reactive loads, with or without motor loads – 250 percent of the full-load current of the circuit under evaluation.

The NEC, using practical industry and commercial experience as its guide, requires a minimum fuse current rating equivalent to 125% of the ASD rated current. Even with an appropriately sized fuse that minimizes the amount of energy passing through it under short circuit conditions and still being capable of handling normal load characteristics, there is a high likelihood that component damage may result in the ASD.

Most ASDs, used on motor loads of less than 200HP, will not have main internal fusing. As such, each vendor must type test each ASD frame size with approved branch circuit protective devices for each of their devices. The NEC requires that branch circuit protection is provided using either UL 248 [6] listed fuses or UL 489 [7] listed circuit breakers. As a part of the type testing, any damaged internal components cannot produce a fire, shock, or induce impact (flying debris) hazards. To protect the ASD from any of these catastrophic failures, traditionally a coordinated current-limiting overcurrent device was placed on the line side of the ASD. The most used overcurrent devices were high-speed fuses or molded case circuit breakers, (MCCB) with a selectable trip element. With a wide spectrum of circuit protection devices and associated features, along with various manufacturers being able to provide a wide variety of products, the ASD vendors are required to perform a series of these type tests on all of their ASD platforms, in compliance with the protection standards. This typically results in multiple, specific, protection device selections by each ASD vendor providing very precise circuit protection characteristics.

This line side protection for an ASD can be accomplished in many ways. Each ASD manufacturer will provide detailed recommendations of the protection methods approved for the ASD. These are typically either circuit breakers or fuses which can be standard class/style or high-speed (semiconductor) fuses such as Class RK1, Class RK5 Class T, Class J, etc..

The current limiting ability of the overcurrent device is the key consideration in the protection of an ASD. Standard Class defined fuses have current-limiting capabilities that can, in most situations, isolate the ASD and minimize the damage level to a few failed internal components inside the ASD.

A standard class fuse or class circuit breaker typically cannot adequately protect all electronic components within an ASD. If faster clearing times are required, high speed (semiconductor) fuses can be used. These types of high-speed fuses are designed for the protection of sensitive power electronic devices (semiconductors) that require protection against overcurrent and overvoltage conditions. However, these too have limitations on their abilities to prevent component damage in an ASD.

Most present generation low voltage ASD topologies use insulated gate bipolar transistor (IGBT) switching devices. An IGBT generally has a much lower energy absorption capacity compared to older generation topologies where SCR or GTO semiconductors styles where used. One of the advantages of an IGBT is their ability to handle considerable quantities of power in a very small physical size. Due to their relatively small mass, their capacity to withstand overloads and over voltages is quite limited and thus requires special protection considerations.

The IGBT topologies are very susceptible to faults induced by overvoltage conditions. If not properly protected, the failure mode of most IGBTs is a case rupture event which can expel gases and particulates that can propagate additional damage to other internal ASD components.

To prevent this cascading failure mode, the overcurrent protective devices need to be selected according to performance requirements of the ASD and the required motor load performance characteristics. However, in many cases, compromises in protection occur if only the requirements of UL 248 [6] and UL 489 [7] are not considered.

A condensed version of the Type Test requirements for an ASD, from the 61800-5-1 standard, are shown in Table I. This table outlines the specific focal areas of the type tests and references the specific areas of the standard outlining pass/fail criteria.

II. PROTECTION PITFALLS WITH FUSES AND MCCBs

As a point of reference, the primary goals of the associated overcurrent protection standards for an ASD, are to ensure that the ASD does not catch fire and that internal device level faults do not cascade into larger events where internal ASD components become projectiles. Effectively, the goal is to prevent other collateral damage around the ASD. The overcurrent requirements in the various standards provide no expectations that the ASD will remain functional after a high overcurrent fault. The effects at various fault current levels and with varying ASD designs will provide varying levels of internal damage to any given ASD.[11]

Another aspect of the analysis is the dynamic current capabilities provided by various product sizes offered by some ASD vendors. Some ASD manufacturers will permit users to temporarily or cyclically subject the products to overloads such that the nameplate current rating of the equipment can be exceeded for short durations of time.

These types of operation modes places additional constraint on fuse selection or breaker sizing, usually resulting in the increasing of the minimum acceptable fuse or breaker size.

A simple example would be where the logic was to permit a 150% current overload because the ASD product was capable of operating in this mode for a specified period of time. However, the overcurrent protective device was sized at the required 125% of the motor's nameplate current.

Vendors of present day ASDs have added user capabilities allowing easy modification to their dynamic current capabilities. ASD manufacturers permit users to overload their products, as defined by their product specifications, such that the nameplate current rating of the equipment can be exceeded for short durations of time. Such operations place additional constraint on the overcurrent device sizing, increasing the minimum acceptable fuse or breaker size.

Differing fuse vendors, types or classes may be specified for similar load characteristics depending on the ASD topology and switching methodology. One vendor's selection of circuit protection devices may well differ from another vendor even though the ASD rating is of the same horsepower.

Presently, ASD users need to understand that the ASD power structure components with the ASD may be defined as consumable, or the ASD may be defined as factory/field repairable depending on the ASD size (HP rating) or frame style. Below certain capability levels, the ASD may be considered a consumable and it may not be economically repaired.

However, an ASD above a certain power level (varies by vendor), will be more economical to repair. In these cases, the least amount of individual device or internal component collateral damage, resulting from a fault, would be highly sought after.

When evaluating the level of protection for an ASD provided by an upstream switching device, a broader evaluation is required beyond its simple current and voltage ratings. Some of the most important aspects are the interrupt rating, along with the instantaneous trip and current let-through ratings. Another significant performance difference, between the traditional MCCB versus the newer SSCB technologies, centers around the method in which each devices measures the fundamental elements within the power flow as well as how each device determines and responds to fault conditions.

A. Interrupting Current Level

The interrupting current rating is the highest current, at rated voltage, that the circuit breaker or fuse has been tested and validated to interrupt. In the case of UL489 [7] listed breakers, the type testing to gain certification to this standard requires a very low number of fault interruptions.

In the case of an MCCB, this rating is determined by the method by which the breaker manages the extinguishing of the arcing between the parting mechanical contacts, as well as the absorption of the arc energy generated as a part of this action. As pointed out above, the testing requirements of UL489 only require a very small number of fault current interruptions to achieve a UL listing. Meaning that in actual use, if the device is subjected to interrupting fault currents more times than those defined by the UL 489 type testing, the device has a high probability of malfunctioning and causing peripheral damage to equipment around it.

In the case of the MCCB, the requirements for higher interrupt ratings results in a breaker with a larger physical size and an associated higher cost. The most common interrupting ratings, for the most available MCCBs used in industrial applications, are 65kA and 100kA [12].

This is an area where the SSCB provide superior capabilities. Because of the semiconductor switches used in the SSCB, the devices can very rapidly interrupt current, and their abilities support the achievement of 100kA, 150kA and even 200kA interrupting ratings with very minimal additional cost and design effort.

B. Instantaneous trip performance of an MCCB

The typical instantaneous overcurrent clearing time, that can be achieved by an MCCB, is generally around 2-3 cycles (30-50 milliseconds) [12]. In comparison, an SSCB is generally programmed to open a high short circuit fault between .03 and .045 milliseconds or faster. Because of the signal processing capabilities within the SSCB, even faster fault switching performance is possible. These high-speed capabilities are expropriated to provide redundant fault checking and validation abilities. This extends this time to the 0.030 and 0.045ms range which still provides a huge time improvement over the performance of and MCCB.

The load characteristics have the most significant impact on the range of response. The more inductive the load the more time is required to interrupt due to the stored energy within the load's characteristic.

Therefore, in most cases an SSCB can open and clear a fault significantly faster than an MCCB or high-speed fuse. This provides significant positive advantages regarding the protection of any downstream equipment. Besides having an ultra-fast clearing time and low let through current, there are several other areas where the SSCB provides significant advantages over the use of an MCCB or high-speed fuses. The SSCB includes significant digital intelligence in its decision-making algorithms and processes required to determine the differences between where and when fault protection is required compared to analog data/information more representative of a transient or start up event.

With its high-speed digital sampling of the analog voltage and current waveforms, the SSCB's on-device computational elements can analytically determine various fault characteristics and then protect accordingly.

C. Energy Let-through Ratings

An important aspect of performance of a switching and over current device is the associated peak let through energies (I^2t) between the MCCB and the SSCB.

Any device, that uses mechanically parting contacts to discontinue current flow, will create arcing as a part of breaking that current flow. This is because current continues to flow in the arc even as the contacts are separated. Current will continue to flow within the arc until the distance between the contacts is wide enough that the arc voltage can no longer be sustained, and the arc begins to extinguish. In the case of an MCCB, this collapse of the arc is aided by using various mechanical techniques which break up the arc and cool it.

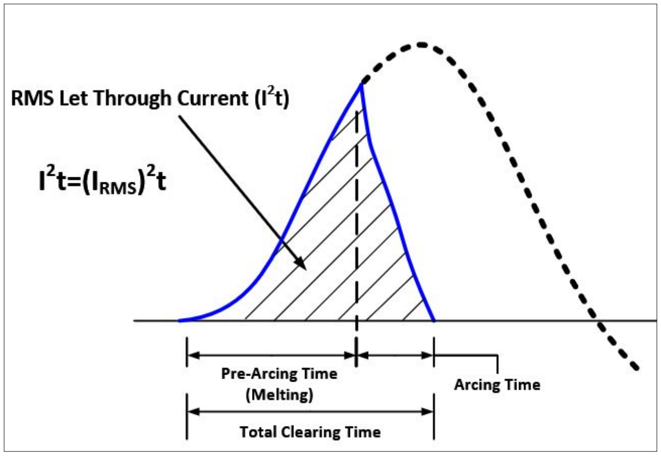

Fig. 3 Typical Fuse Interrupting Characteristic

In the case of protective fuses, different techniques are used within the fuse element designs to break the arc in many smaller portions. These smaller arcing points reduce the arc voltage across each break in the fuse elements and decreases the total clearing time. The total clearing time is made up of the fuse melting and fuse clearing time, refer to Fig. 3. Some aspects of this method or breaking up the arc into smaller arcing points is outlined in this reference [8]. In the case of circuit breaker interruption, the amount of energy that is 'let through' as the contacts part or as the individual points on the fuse elements melt, arc and ultimately clear the fault, is total let through I^2t energy. Refer to Figure 4This energy will be transferred to any attached load downstream of the protective device, whether circuit breaker or fuse.

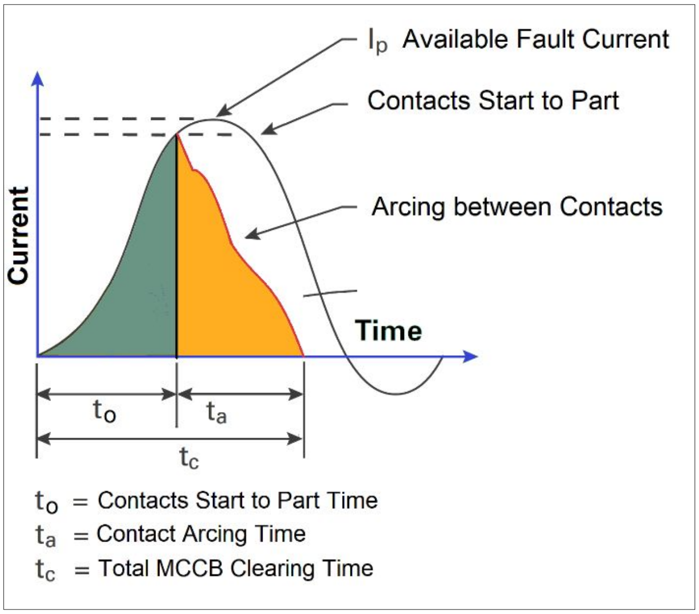

Fig. 4 Typical Circuit Breaker Interrupting Characteristic

When an SSCB is applied, the scenario of current disconnection is radically different. And SSCB is effectively an non-arcing device with no arcing duration. The SSCB does not rely on the breaking of current through the collapsing of an arcing event, as it does in a fuse or circuit breaker. The physical removal of current flow can be achieved in only a few microseconds and does not include any arcing activities.

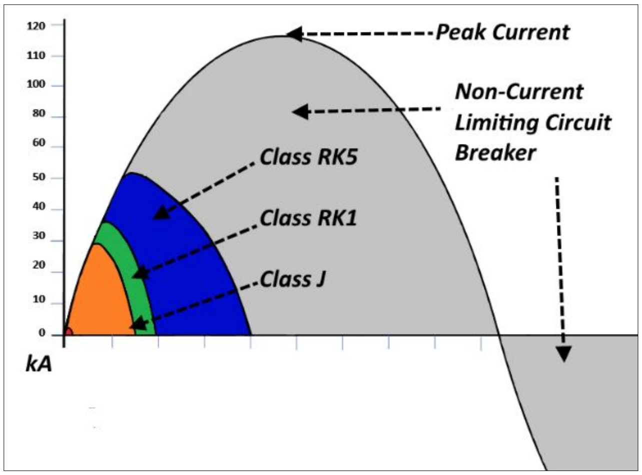

Fig. 5 Example Let Through Current Characteristics of MCCB, LV Fuses and SSCB (Ref. Fig. 6)

Therefore, the portion of I^2t energy is only a very small portion of the fault current seen in both the fuse and circuit breaker let through characteristic. In many cases the current will be less than 1,500A, even when the system short circuit current (unrestricted peak current) is as high as 200kA. Figure 5 rough illustrates the differences in let through current for various components. You will notice the let through current level for an SSCB is that very small portion at the left bottom portion of the graphic. Figures 8 and 9 provide the details of the current release through a typical SSCB.

The increased speed of an SSCB results in the significant reduction of the peak let through current and the let through thermal energy, I^2t. For example, an SSCB with a let through current of 1500A and a clearing time of 0.000049s, the I^2t is only $110A^2s$.

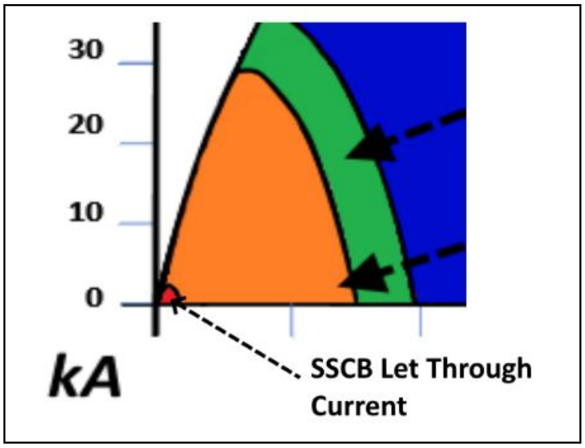

Fig. 6 Example Let Through Current Characteristics of SSCB

III. IMPACTS TO ASD LIFE EXPECTANCIES

Any load that is subjected to high or repeated let through current and ultimately high let through thermal energy are at risk of primary, secondary and/or collateral damages.

Interestingly, both the National Electrical Code (NEC) [4] and the Standard for Electrical Safety in the Workplace (NFPA-70E) [9] both define a circuit breaker as a device designed to open and close a circuit by nonautomatic means and to open the circuit automatically on a predetermined overcurrent without damage to itself when properly applied within its rating. It states nothing about protecting the connected load.

Now one can allude to the fact that a circuit breaker primary purpose is to provide current limiting protecting the load. If we review the content of both referenced documents regarding Current-Limiting Overcurrent Protective Devices. These are devices that, "*…when interrupting currents in its current-limiting range, reduces the current flowing in the faulted circuit to a magnitude substantially less than that obtainable in the same circuit if the device were replaced with a solid conductor having comparable impedance…*" [4]. The word substantially is very vague in relationship to the actual overcurrent devices presently being applied. Some of the switching and clearing characteristics of these devices, can result in having fault current magnitudes almost as high as the peak available currents.

A. *Transient Recovery Voltages*

One aspect of overcurrent protection, that is rarely discussed, is in the area of Transient Recovery Voltage (TRV) resulting from the collapsing of the current arc during a high fault current interruption. When the arc is ultimately extinguished, there is a result over-voltage condition caused by high switching frequencies in the arc. Figure 7 illustrates the extent of damage to a power module cause by a high TRV.

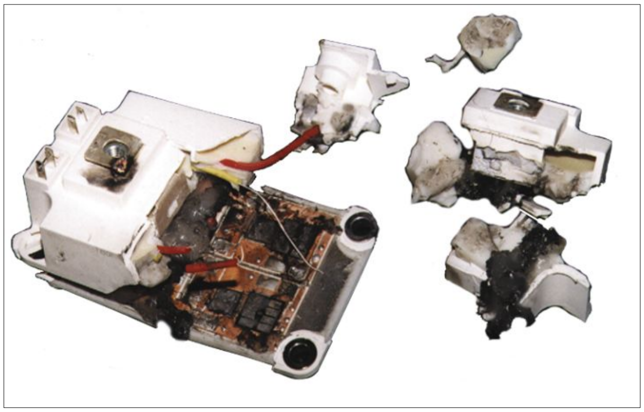

Fig. 7 Typical Resultant IGBT Damage Due to High TRV

These high-level transients can be high enough to cause collateral damage to the ASD. These transient over-voltages can also be caused by high switching frequencies of drives themselves, by inductive switching within a facility or outside utility switching, from poor power quality, or by mother nature (lightning). A TRV higher than the maximum voltage rating of the insulated-gate bipolar transistors (IGBT), used in most modern ASDs, will irreversibly damage the IGBT and eliminate its own self-protection characteristics. In this condition the drive may not be able to shut down on its own. The IGBT is not a "fail-safe" component. This is to say that if the IBGT module fails (avalanche mode) it will put the circuit into short circuit condition and allow the DC link capacitor bank to quickly discharge through the shorted IGBT. High fault current will lead to the melting of the bonding wires used internally and ultimately could cause the IGBT case to rupture. This case rupture will most certainly ruin the drive and surrounding components within it, making it unrepairable. Prior to the SSCB, the only protective device which could clear high fault currents fast enough to prevent some case ruptures from occurring, were some high-speed fuses.

B. *The Impacts of High TRVs on the Surge Protection Devices used on the Input to an ASD*

Many ASD vendors will include various surge protection devices on the line connection side of their ASD. In most cases, these will be varistors. A varistor needs to absorb the energy expressed on it by any temporary over voltages, switching surges, or lightning impulses. The manufacturing of varistors has many variables, one of them being the grain sizes and grain boundary characteristics of the materials used. When constructed for use, there are generally nonuniform microstructures within the materials. These nonuniform microstructures result in some wide variability of the varistor's current handling capabilities and related energy absorption capabilities under certain and different conditions. These variabilities can in turn have a direct relation to different failure modes within an ASD, which include electrical punctures, physical cracking, and even thermal runaway of the varistors.

Cracks in any varistor may occur because of its basic material make up, which is a very hard ceramic like material. High-amplitude surges of fault energy are effectively like hitting a ceramic coffee cup with a hammer. Enough hits may result in complete and catastrophic damage to the varistor.

Another aspect of a varistor's protection capabilities is when high-amplitude surges, that are just high enough to begin damage propagation, begin to puncture its internal molecular structure resulting in a failure over time. Generally, this type of destruction happened in small varistors when the current is relatively low but of long duration. The overall effect to the varistors is that the varistor begins to overheat. Continued degradation of the varistor's internal materials can raise the temperature to the point of thermal runaway due to the material's negative temperature coefficient of resistivity.

C. The Impacts of High TRVs on Capacitors used is ASDs

Nearly all low voltage ASD designs include the use of electrolytic capacitors. These devices are one of the most failure prone devices within the ASD power structure.

Capacitors can be damaged in many ways including from external as well as internal faults. For example, the resulting steep voltage waveform associated with a shorted IGBT or when the internal dielectric or the internal surge protection device can no longer withstand the applied voltage, it will break down and cause a failure. Failures typically result in a low impedance path producing a current that may generate excessive heating and pressure within the capacitor. This pressure rise in the capacitor enclosure (case) will cause a violent case rupture and extensive damage to the ASD.

The amount of physical damage to an ASD will be relative to the amount of energy the capacitor(s) have stored and how fast that energy is either charged or, in most fault modes, discharged.

IV. EXTENDING THE LIFE OF AN ASD

As outlined in Section IV, there are many modes of damage to an ASD that can result from interruption of high fault currents and the resultant high TRVs. The intensity or amplitude of these transients, on the input an ASD, have a very significant impact on the possible repairability and life expectancy of an ASD.

Standards like UL 61800-5-1 guide both vendors and users on the allowed degrees or definition of the levels of personnel protection that a product compliant to this standard must be provided, (See Table I). The intent of this standard was to require the ASD vendor to create specific internal faults, which mimic the typical faults that have traditionally resulted from high intensity surges applied on the ASD.

If you consider the vast differences related to the let through current between overcurrent switching devices, a typical example is shown in Figure 5 and 6, it is obvious that significant protective benefits are achieved when an SSCB is employed. These benefits are achieved for both regular current-switching as well as fault current interruptions where the SSCBs protective characteristics provide a huge reduction of the electromechanical stresses normally applied and their associated impact on a connect ASD.

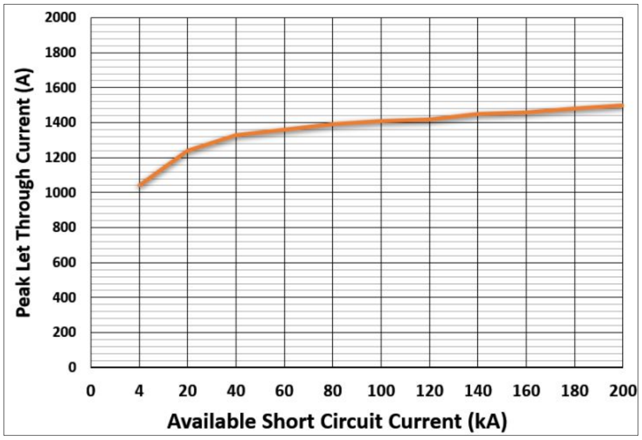

Fig. 8. Typical Let Through Current of an SSCB

The lower the level of fault let through current, the lower the possibility of additional drive damage and collateral damages. This reduction in current could be the difference between and ASD being return to service after an intermittent fault versus being completely replaced due to collateral damage making it inoperable and/or unrepairable.

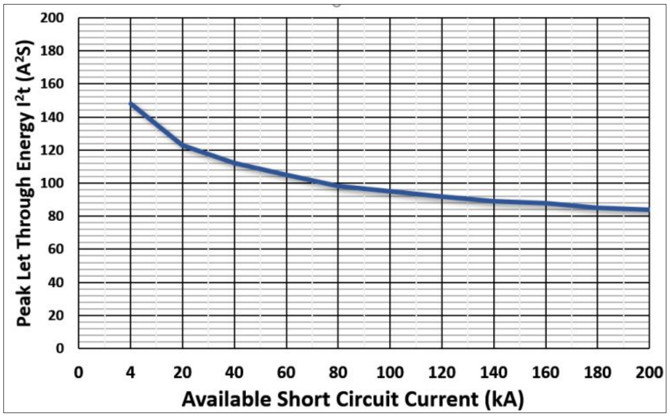

Fig. 9. Typical Let Through Energy (A^2s) of an SSCB

Independent testing has been performed to evaluate the overcurrent protective characteristics of the SSCB, when applied as the line side protective element for an ASD.

A. Test Results of the SSCB Protection Capabilities

Testing was performed where one of the rectifier diodes in an ASD was shorted while the drive was operating to provide current and voltage to a connected load. The SSCB immediately determined a faut event was in progress and the SSCB opened on an overcurrent event. This test was performed a total of eight (8) times under the same operating modes. In every case the SSCB opened removing harmful let through energy from the ASD.

For this type of diode test procedure, when high speed fuses or an appropriately sized MCCB are applied, at least one or more of the input diodes would fail.

Another area discussed earlier, where significant damage can occur in an ASD are the bus capacitors. Case ruptures of a capacitor case will generally case catastrophic damage to the ASD.

Another test was performed to validate other levels of performance the SSCB can provide. This test used the same ASD used for the diode test and was re-configured to create a short across one of its bus capacitors. The ASD was restarted, and power was reapplied to the connected motor load. Immediately on the short circuiting of the bus capacitor, the SSCB sensed the fault and rapidly disconnected the ASD from the line. This test was repeated a total of six (6) times.

In every case, when power was reapplied from the line by the SSCB, the ASD restarted the motor and performed normally, restarting as if nothing had occurred.

The failure modes of some bus capacitors could result in the rupture of the capacitor's casing. This type of failure can cause extensive internal collateral damage to the ASD, rendering the ASD unusable and sometimes unrepairable.

V. ADDITIONAL ASSOCIATED CAPABILITIES USING THE SSCB

Beyond the traditional overcurrent protection capabilities of the SSCB, this technology brings with it a host of other aspects of protection and control functionality that cannot be provided by the traditional overcurrent protection methods employed today.

A. Dynamic and adjustable time current curves

The abilities of any given overcurrent device to provide circuit or component protection are defined by its protective time-current characteristic curves. High-Speed fuses and a traditional MCCB provide fixed high fault current and overload capabilities. Newer MCCBs with electronic tripping elements, provide some level of adjustability to these protection capabilities. However, the adjustments to their curves are generally of a relatively coarse nature compared to the more finite settings possible within an SSCB. These much more finite selections can be made due to the high sampling rate within the signal processor within the SSCB.

These protection curves predict the behavior of circuit protection devices in both slower, lower overcurrent conditions, and higher, faster over current conditions. In the case of the SSCB, these curves are provided with finer adjustability, providing for closer system and load protection coordination. Choosing an appropriate trip curve for your application provides reliable circuit protection, while limiting nuisance or false trips. The advantage of the ultra-fast interruption capabilities, of the SSCB, is reduced stresses expressed to the connected load under fault conditions.

In reference to the typical protection curve characteristics shown in Figure 10, there are unique advantages that the SSCB provides compared to present MCCB technologies.

Figure 10 not only illustrates the very fast interrupting capabilities of the SSCB, (see red line in the figure), but it provides very finite adjustments within various portion of its protection capabilities. Because of the fully digital nature of the product, along with the high signal sampling rates within the SSCB, these very finite adjustments to all areas of the protection curve can be made. This provides the user with the ability to provide very custom and selective protection to any attached load.

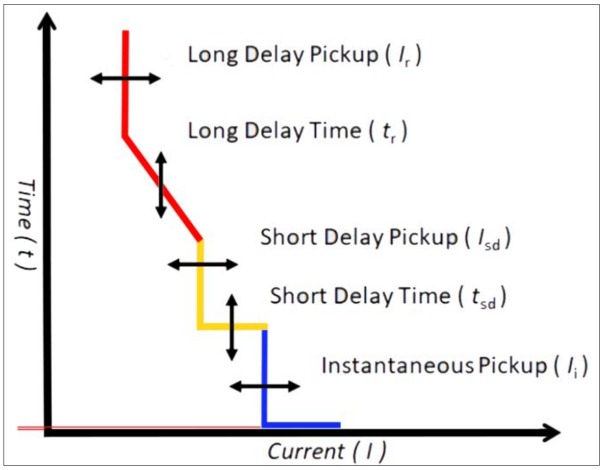

Fig. 10 SSCB Adjustable Protection Capabilities

B. Remote Control, Diagnostics and LOTO

Using common industrial communications means, the SSCB can become an integral part of a complete and autonomous industrial network. SSCB users can continue to modernize their enterprise-wide infrastructures utilizing the abilities of the SSCB. These abilities include remote opening, closing and tripping along with an ability to perform a LOTO, using the integral air gap disconnect, and through the interrogation of the device status, power elements and on-device data analytics.

C. Power Monitoring and Data Analytics

Similar to MCCB technology utilizing digital elements, the present generation of SSCB technology has the ability to provide complete metering capabilities including voltage and current measurements with a +/-1% accuracy along with KW and KWH at a +/-2% accuracy. Each power module is also equipped with a resistance temperature detector (RTD) providing thermal data from each phase, as well.

Most SSCB products include a listing of the last trip event variables is also stored locally. This power metering, thermal data and trip data can be accessed locally or remotely using an optional communication interface providing the user the opportunity to review nominal and abnormal event information, for analytic computations, related to process efficiencies or interruptions.

VI. OTHER SSCB CONSIDERATIONS

As outlined earlier, there are many significant advantages for the use of solid-state circuit breakers. However, as with the application of any new technologies there are other considerations surrounding their use.

A. The Characteristics of a Semiconductor

In the true sense of the term, a semi-conductor is not a true conductor of electrical energies, possessing an electrically conductive characteristics lying somewhere between a true conductor versus an insulator. Therefore, as with any conductor that is not a true conductor, there is a factor of energy lost associated with the conduction of electrical energy through it. These losses are expressed from the device as heat energy. An ASD is a good example of how the use of semiconductors require the control and management of semiconductor losses.

These losses, their characteristics and amplitude, are a function of electrical properties of the semiconductor materials utilized in the switching element and the amount of current flowing through the device. Presently, the most common material used for solid-state circuit breakers is silicon carbide (SiC). This technology provides a good balance between efficiencies and losses. Another technology also be reviewed for these types of applications is germanium arsenide (GaAs). This element provides a different and unique efficiency versus losses profile, which shows progress in terms of improved efficiency based on specific current profiles.

As with any electrical component, especially any enclosed element, the management of losses is an important characteristic of the device. In the case of the SSCB, a static heat sinking material is typically used in combination with the SSCB to dissipate the heat energy especially when the device is running near its 100% rating.

B. Customizing the Characteristics of a Semiconductor

The characteristics of a given single component or element can be modified by doping the base element through the application of other materials and the application of various electrical fields or light energies during manufacturing. This doping process allows the technology maker to customize the characteristics of the switching device to optimize its characteristics for given applications, for example current switching versus signal amplification.

C. Future Application Opportunities

An application area that must be considered with the use of SSCB technologies are centered around loads with high in-rush characteristics, such as the current profile associate with energizing a transformer load, capacitors or the current profile associated some large direct motor load applications.

There is positive side to these considerations. Because of energy sensing techniques and the computation capabilities on-board of the SSCB, high speed current profile analysis can be achieved and the SSCB can determine the application environment and react accordingly. These and other capabilities will be added in future generational releases of the SSCB technology.

Using these advanced analytical techniques contained within the control system on-board the SSCB, custom current profiling can be achieved, such as those associated with soft starting a motor load.

Additional research is forecasted to optimize application performance for other current profiles.

VII. CONCLUSIONS

The protection abilities of the SSCB were defined and explained, in a comparative form, relating this technology's protection characteristics to those of traditional MCCB and high-speed fuses, when used for line side protection of an ASD. Because of the SSCBs superior level of power element sampling rate, its computational and metering abilities, along with its high-speed solid state switching methods, the SSCB provides the best and most selective levels of protection for almost any connected load and specifically for the superior protection characteristics required for ASD line protection.

The application of an SSCB, on the line side of any ASD, will provide the user the best level of protection for the ASD, eliminating some of the detrimental current switching characteristics associated with the other technologies discussed. This protection should facilitate much better ASD uptime performance, increase mean time between failures, reduce the possible need ASD repairs, and the possible elimination for the need to replace an entire ASD unit. All of these aspects adding significant beneficial effects to the user's enterprise.

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IX. VITAE

John A. Kay, C.E.T. (M'94, SM'98, F'12), received his degree in Electrical/Electronic Engineering Technology from Conestoga College, Kitchener, Ontario in 1977. He has authored a wide variety of award-winning technical papers and other technical articles and manuals related to MV electrical control and protection systems, arc resistant equipment and infrared technologies. Several of his papers have been published in the IEEE IAS Transactions and the IAS magazine. He is a Fellow member of the IEEE, the Industry Application Society and actively involved with the IEEE Pulp and Paper Industry Committee, serving as the chairman of the executive board, on the conference committees and on several sub-committees. He serves on several other technical groups and participated on the local planning committees for the 2011 IEEE-PCIC, 2002 IEEE-PPIC and serves on the IAS executive board as the Process Industry Department Chairman. Mr. Kay is also an active voting member of the IEEE Standards Association (SA). He has won several IEEE paper awards and was awarded a Meritorious Service Award from the IEEE Pulp and Paper Industry Committee (PPIC), as well as an Outstanding Technical Contributions and a Safety Excellence Awards from the Petroleum and Chemical Industry Committee (PCIC). He was recognized by the Ontario Association of Certified Engineering Technicians and Technologists with a George Burwash Langford Memorial Award for contributions in the fields of engineering and applied science technology. Mr. Kay is a Certified Engineering Technologist, in the province of Ontario.

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