

VINTAGE LOW-VOLTAGE MOTOR CONTROL CENTERS – REPLACE OR UPGRADE?

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Abstract - Low-voltage motor control centers are universally applied in process industries. These electrical assemblies are perhaps one of the most dynamic in industry, ever changing as low-voltage motor loads are constantly added and modified in response to necessary process revisions and upgrades. As existing low-voltage motor control centers (MCCs) approach 40 to 50 years age, industry users are challenged with a decision to replace vintage MCCs approaching their end of life or consider upgrade of existing assemblies. This paper will discuss upgrade versus replace alternatives, addressing UL 845 North American industry standard requirements and how this affects design, installation and maintenance of both upgraded and new MCCs. Application issues including considering the cost of replacing load cables versus re-use of existing cables, high-resistant pulsing ground systems and opportunities for process improvements and network communications that leverage the latest technology will be discussed. Finally, a case study comparing the alternative of replacing an existing MCC versus a field upgrade based on changing out all exiting starter and feeder circuit breaker units and an estimate of the total installed cost for both MCC replacement and upgrade for this application will be reviewed.

Index Terms – Motor Control Center, UL 845, Life cycle extension, High resistance grounding, Motor management relays.

I. INTRODUCTION

Today's global production in the process industries continues to expand. Capacity additions are springing up in a few key strategic areas, aimed at balancing increasing demand and a fixed supply. The prospects of new capacity installations that will successfully apply state-of-the-art technologies are exciting, offering the step-change potential to improve site productivity, reliability and safety. That said, because many existing plants in industry are not operating at design capacity, the fact remains that most global demand will continue to be served from existing facilities. Many existing plants were first commissioned 40 to 50 years ago and some existing systems might be approaching end of life today. Industrial plant operators of existing sites will need to focus on considerations regarding equipment replacement versus upgrades for electrical power distribution and control systems.

Electrical power in most industrial manufacturing plants is the most ubiquitous asset of the production process, while also being arguably one of the most overlooked. The reason for this

is simple; electrical power is presumed to be reliable and available, until it is not. Most production facilities in the upper quartile for reliability and safety have rigorous and detailed preventive maintenance procedures in place to assure "the lights don't go out" unexpectedly. These include programs to complete testing during scheduled rotational outages, such as dissolved gas analysis of transformer liquids and testing of trip performance for power circuit breakers, as well as infrared scanning of electrical connections to check for hot spots and insulation breakdown.

Although a robust preventive maintenance program of electrical control and distribution systems can be effective, the plan to continue this cycle year-after-year without implementing either a replacement or upgrade program for these valuable assets will put yesterday's productive plant on the future road to obsolescence and eventual closure. It's an obvious fact that legacy plant electrical systems, originally manufactured 40 and 50 years ago, cannot keep pace with the rapid changes in technology. Analogously, it is certainly possible the television purchased for personal use at home back in 1975 could still be in service today, through careful and meticulous maintenance and replacement of worn or failed components. Of course, considering the extraordinary shift in technology with high-definition LED network enabled televisions of today, it would be senseless to consider the time and cost to extend the life-cycle of the 44-year-old set. In this example, replacement is the only practical option.

II. APPLICABLE MANUFACTURING AND TEST STANDARDS

In today's modern engineered electrical systems, there are a host of assemblies that should be considered for either replacement or life-cycle extension upgrades. It is important to be familiar with the major components that serve as the building blocks of power distribution and control assemblies in industry. In North American markets the Institute of Electrical and Electronics Engineers/National Electrical Manufacturer's Association (IEEE/ANSI) and Underwriter's Laboratories (UL) Standards prevail. Three-phase engineered low-voltage MCC's are the focus of this paper, specifically 600 VAC low-voltage motor control centers manufactured and tested to UL 845 "Standard for Motor Control Centers" [1]. Typically, these assemblies include a steel supporting structure with individual compartments that contain a protective device such as an air magnetic molded-case circuit breaker and a contactor (vacuum or air-magnetic). Each circuit breaker and contactor typically includes a protective relay to assure either cables or connected motor loads are protected in the event of an overload or system short-circuit condition. These assemblies also include main

copper bus-bars used as current-carrying conductors, connecting the incoming power source to the multiple devices that serve and protect individual electrical loads. Although the structure and bus components of both medium-voltage and low-voltage distribution and control assemblies are similar, considerations involving their end of life replacement are somewhat different. This paper will address replacement versus upgrade considerations related only to low-voltage motor control centers.

One other industry standard relevant to this review is IEEE Standard C37.20.7 "Guide for Testing Metal-Enclosed Switchgear Rated Up to 38kV for Internal Arcing Faults". Low-voltage MCCs are optionally available as arc tested to this Standard, which was recently updated in 2017. The arc testing requirements are individually defined in multiple Annex documents in the Standard, each applying to a unique type of assembly. For low-voltage motor control centers (LV MCCs), arc test procedures as outlined in Annex H of IEEE Std. C37.20.7-2017 are applicable. Other than this "add-on" arc resistant test requiring a more robust assembly with heavier gauge steel, bolts and latches, traditional steel enclosures for LV MCCs manufactured today are very similar to designs from 40 years ago. The main bus-bar for these assemblies also has not appreciably changed. Typically, the bus system includes flat copper bar conductors for each of three electrical phases, with multiple bars per phase being required to support higher bus ampacity ratings.

III. REPLACEMENT CONSIDERATIONS

Consistent site maintenance practices to assure both the LV MCC steel structure and the bus system have not been neglected are essential. If one or both has degraded or been compromised over time, replacement of the assembly is recommended. Examples of compromise for these parts of the assembly would be environmental contamination, rust, water ingress and breakdown of insulation between energized phase conductors or a phase conductor and ground. If the structure and/or bus system is at end-of-life and replacement is the necessary and recommended option.

Before implementation of a replacement plan, careful project planning is necessary to assure the project is successful. Consideration of the required time to completely replace existing equipment will necessarily impact production. Access to remove the existing assemblies and bring in the new equipment must be considered. One often overlooked issue involved is the cable terminations to existing loads. New assemblies are unlikely to match in location for existing line and load cable terminations. This may require that the project scope include pulling all new cables, which improves overall reliability but adds cost in materials, labor and lost production. If existing outgoing cables to the LV MCC motor loads are run in individual conduits, careful consideration regarding the conduit condition and the required number of cable bends should be reviewed. If motor cables are routed through open cable tray, removing existing cables and installing new may present added challenges dependent on the cable routing. Even if existing conductors can be reused, there is risk in disrupting existing terminations that were first made perhaps 30 to 40 years ago. Oftentimes, especially for larger conductors, aged insulation systems can crack and become compromised during a replacement project. This would then require new cable to be

pulled and terminated, adding significant labor and materials cost in replacing the original cables.

IV. REVIEW OF STANDARDS PRIOR TO LV MOTOR CONTROL CENTER REPLACEMENT

As mentioned previously, the manufacturing and test standard for LV MCC's applied in North American markets is UL 845. Although the authors are not suggesting that industry users study the details regarding this Standard, being familiar with UL 845 is useful in better understanding the scope and available ratings for this class of engineered electrical assembly. One recently developed Standard which is recommended by the authors is IEEE1683-2014 [2]. The document, titled "IEEE Guide for Motor Control Centers rated up to and including 600 V AC or 1000 V DC with Recommendations Intended to Help Reduce Electrical Hazards" was recently created by a working group of engineers from multiple manufacturing industries, consultants and manufacturer's. Note that this document is an IEEE Guide, not a Standard. Unlike UL 845, IEEE 1683 does not define specific construction and test requirements or specific features, rather the document addresses considerations around LV MCC installation, considering the site power system and electrical safety criterion. The Guide also explains the benefits and limitations of certain LV MCC features, offering guidance around common considerations for particular features. The authors suggest review of the IEEE1683, as well as [3] and [4] which offer valuable detail regarding choices and outcomes in selecting a LV MCC based on recent industry applications.

V. LIFE-CYCLE EXTENSION CONSIDERATIONS

A. *Overdutied Assemblies*

If the steel structure and bus have been well maintained over the years, upgrading existing low-voltage MCC assemblies can often be a viable alternative. That said, the user will still need to assure the originally installed assembly is properly rated. Over the course of the last several years, many existing manufacturing facilities in industry have improved working conditions for employees by a renewed focus on electrical workplace safety. Driven in part by improved standards for safety, including NFPA70E-2018 "Standard for Electrical Safety in the Workplace", an enhanced awareness and recognition of both electrical shock hazards and electrical arc flash hazards has emerged. This standard requires existing facilities to complete and, every five years update, an accurate model of the plant electrical power distribution system. This includes completion of a short-circuit, coordination and arc flash study, with the end deliverable being warning labels affixed to each of the "openable" electrical panels that identifies the shock hazard, arc flash hazard, working distance boundaries and appropriate personal protective equipment (PPE) required for persons working on or near the panel while energized. One unintended consequence of these system studies has been a realization of some overdutied electrical equipment in existing plants. LV MCCs have been one of the more prevalent examples of existing overdutied electrical assemblies.

Many of the vintage LV MCCs installed between the 1950's and 1980's have lower bus bracing/short circuit current ratings. Vintage MCCs from this era typically include mechanical bus bracing rated from 35,000 to 50,000 symmetrical amperes.

Conversely, today's designs typically have ratings up to 100,000 symmetrical amperes. System studies resulting from current modeling of existing industrial facilities might for instance, result in a system available fault current of 46,800 amperes at a vintage MCC installation of a product installed in the 1960's with a maximum 35,000 rating. Of course, when the facility was originally built, there was not an error in selecting the MCC's to be installed. Instead, over the course of several decades, facility loads, and system power sources change, resulting in what once was adequately sized electrical equipment to now be underrated, or overdutied.

In extending the life of existing LV MCCs in a facility, it's possible to increase the assembly bus bracing and interrupting rating so the MCC can continue to provide safe and reliable operation. Some field service engineering organizations that are typically a service arm of a low-voltage MCC manufacturing company offer the capability to modify existing bus bracing in order to support higher short circuit ratings. For the user, it is important to select a reputable firm with a solid track record of experience to perform these services. Although it will likely be difficult if not impossible to document that the modified assembly will successfully pass original factory tests, in most cases a software model exists that validates a higher rating based on engineering calculations. In some cases, when the service organization is from the same supplier as the original supplied equipment, documentation of current or updated bus bracing designs versus the originally installed equipment will be supported by factory testing using bus support insulators as supplied in the current design product. Should the field modified assembly include upgraded short circuit ratings require third-party certification and UL label, a follow up field inspection would be required to validate ratings against the manufacture's design testing. The authors recommend consultation with the original equipment manufacturer before proceeding with any field-based upgrades of any LV MCC assembly.

B. Starter and Circuit Breaker Units

After the structure and bus have been thoroughly inspected and possibly modified to assure conformance and compatibility with the existing system, individual component ratings then must also be investigated. Beyond the enclosure and bus bar system, the other major component in any MCC assembly is the multiple starter and feeder circuit breaker units that serve various downstream loads. Smaller units are typically withdrawable, connected at the structure vertical bus via power stab connections, while large units tend to be fixed-mounted. Fig. 1 shows the component elements of a starter unit, this from a vintage MCC assembly that is no longer available. However, replacement units still can be supplied in support of this vintage assembly. As shown in Fig. 1, individual components in the starter unit from the upper left of this image include: A circuit breaker, in most cases a magnetic only molded case design, manufactured and tested to UL Standard 489 [5]. These devices are typically factory sealed with few replaceable parts. Although routine maintenance of molded case circuit breakers is important, the topic is beyond the scope of this paper and the authors recommend review of [6] and [7] regarding best practices in maintaining these components. The next component rotating clockwise from Fig. 1 is the three-phase stab assembly. The stabs consist of spring-loaded copper conductors that connect the starter unit incoming power to the MCC vertical bus bars. Stab assemblies are unique to the



Fig. 1 Components of a Low-Voltage Motor Control Center Starter Unit

original MCC manufacturer and it is critical that this component be ordered as original equipment. Following this is the motor starter, consisting of a magnetically operated contactor and a motor overload protective relay. Most vintage motor overload relays employ one of two antiquated means to protect the AC motor based on overcurrent resulting in excess heat of a resistive element in the phase current path. One of these is a bi-metal element; two dissimilar metals that deflect to engage a trip bar to open a contact to de-energize the contactor. The other is a solder-pot element that includes a melting alloy which again, upon melting actuates a mechanical movement which in turn de-energizes the contactor. Both deploy three heater coils in each of the three phase current paths which are sized based on motor full load amperes. On an over-current condition, the heater coil deflects the bi-metal or melts the solder alloy, resulting in a mechanical movement that in turn deenergizes the contactor. Other devices in the image include an internal control power transformer and pilot devices mounted on the starter unit door. The center image shows the complete unit assembly which also includes unit control and power wiring, control terminals, a handle mechanism to open and close the molded-case circuit breaker and painted steel "wrapper" used as a means to bolt the unit components together into the common sub-assembly.

C. High Resistant Grounding Upgrades

Although high resistant grounding systems are typically not installed in LV MCCs, any industrial site considering upgrade of existing motor control centers should also consider system grounding. Most low-voltage installations in process industries prior to the 1980's were designed based on solidly grounded systems. For these systems, low-voltage motor control centers were connected at the incoming section from a three-phase 3-wire system that included three phase conductors from a wye-connected transformer secondary winding. For traditional solidly grounded systems, the transformer neutral is connected to system ground. Because 600-volt class low-voltage metal enclosed switchgear typically distributes power to downstream

LV MCCs, the ground termination for solidly grounded systems necessarily is made at the transformer secondary. Thus, three phase conductors from the switchgear feeder circuit breakers are connected at incoming lugs of the LV MCC and the control center structure enclosure is then connected to ground at the facility ground grid. Assuming sufficient integrity of the system ground grid, a phase-to-ground fault at the MCC or at a downstream connected motor would result in a phase to neutral fault. Because the transformer neutral is at ground potential, a downstream phase to ground fault would result in a line to neutral system fault at 277 volts for a 480-volt wye connected transformer source. Loss of service continuity caused by protective circuit breakers tripping during a ground fault along with a growing awareness of arc flash hazards has rendered most legacy solidly grounded systems obsolete.

The advantages of upgrading existing industrial facilities to include high-resistance grounded (HRG) systems have been well documented in technical papers including [8] and [9]. As shown in the Fig. 2 schematic, HRG systems differ from solidly grounded systems with the addition of a fixed resistance connected between the transformer neutral and system ground. This resistor is typically sized such that a downstream phase to ground fault will result in no more than 5 amperes flowing via the ground grid back to the transformer neutral. Obvious advantages here are that the first unintentional line to ground fault at the downstream LV MCC or motor results in no trip condition and no arc flash event. Typically, current is measured between neutral and ground or voltage across the grounding resistor, and an alarm is annunciated, notifying maintenance personnel of a downstream faulted feeder. At this point, a pulsing contactor is opened and closed on approximately 2 second intervals, switching additional resistance in and out of the neutral to ground connection. While the pulsing contactor is oscillating, and the system is still running, maintenance operators use a hand-held clamp on ammeter to locate the ground connected load. The special window-type ammeter encircles all three phase conductors and will register pulsing current of the faulted load, versus ungrounded three-phase loads that will of course sum to zero. Measurements can be taken on the outside of conduits, busways or grounded raceways while plant systems remain energized and operational.

Although converting existing solidly grounded systems to high-resistance grounded systems is not directly related to upgrading vintage low-voltage motor control centers, this is considered a value-added system addition. Stand-alone HRG systems including the necessary resistors, contactors, relays and controllers are commercially available and these can be added as a system upgrade using floor mounted, wall mounted, or installation into existing low-voltage switchgear assemblies.

Given the many operational advantages of HRG systems applied in industry today, there remain some drawbacks. One deficiency of HRG systems is the importance of locating and repairing the first grounded load before a second load is unintentionally grounded. Should this occur in a different phase from the first load, a phase-to-phase fault will typically result in an upstream protective device clearing the fault and taking the operation out of service. So, discipline to initiate the pulsing circuit and use the clamp-on ammeter to locate and remedy the fault in a timely manner is paramount. The authors remember one anecdotal story where the plant manager at a large-scale refinery was made aware from a first-hand experience of the

dangers when his maintenance staff ignored the first fault in a HRG system. As the story goes, he instructed the refinery electrician to wire a yellow pilot light signaling a HRG alarm into his office. He then summoned the entire electrical maintenance staff for a meeting in his office where he explained that if the yellow light ever turns on, it needs to be off within the next 24 hours or “heads will roll”. Another drawback to HRG systems is it can oftentimes be difficult and possibly dangerous in using the window-type clamp-on ammeter to trace the downstream fault. One cement plant operator suggested this can sometimes take days to trace. It also requires skilled and knowledgeable labor with proper personal protective equipment (PPE) to work around energized conductors.

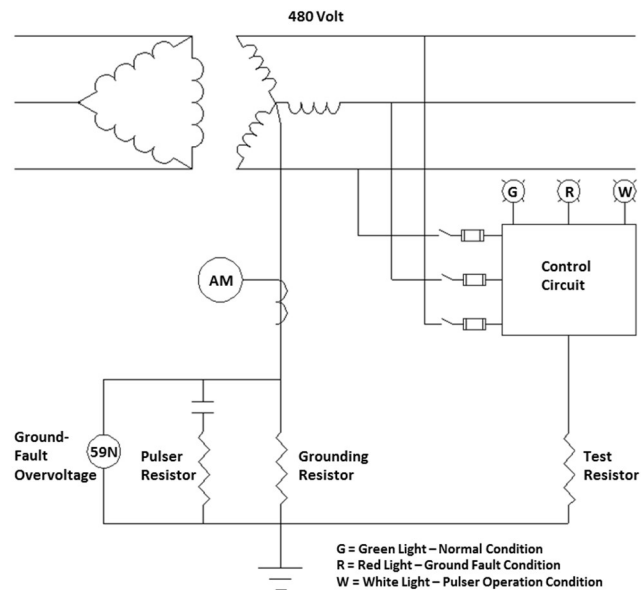


Fig. 2 Typical schematic for a low-voltage pulsing high-resistance ground system

New advancements in technology supporting HRG systems including [10] and [11] look to have promise. The addition of zero-sequence current transformers (ZSCT) at each power circuit breaker in low-voltage switchgear distributing power to LV MCCs is one good addition. The ZSCTs can be wired to a door-mounted ammeter on the switchgear panel, allowing maintenance persons to begin the pulsing contactor sequence, then quickly identify which downstream MCC has the faulted load. In some current version of HRG systems, ZSCT inputs can be directly wired back to an HRG relay which can then annunciate on a dedicated display panel which MCC has the faulted load. Similarly, ZSCTs can be added to each individual motor starter unit in the LV MCC and wired back to a HRG relay. This allows nearly instantaneous identification of the ground-faulted load. However, the cost of adding this functionality to potentially hundreds of individual starter units at some point becomes a limiting factor.

VI. UPGRADE LV MCCS WITH NEW STARTER AND FEEDER BREAKER UNITS

Assuming the enclosure and bus system of a vintage low-voltage MCC is in good condition, the most frequently installed

and viable method of life-cycle extension is by replacing the existing starter and feeder circuit breaker units with new ones. Fig. 3 shows an image of a vintage starter unit from a now obsolete motor control center built in the 1960's next to a new replacement starter unit. Note that the replacement starter unit is a form-fit-function direct replacement for the vintage unit and that the old components have been replaced with new. In some cases, the replacement starter units can include additional components to enhance functionality of the vintage assembly; in this case, a unit mounted control power transformer and door-mounted Hand-Off-Auto selector switch and Motor Run light addition.

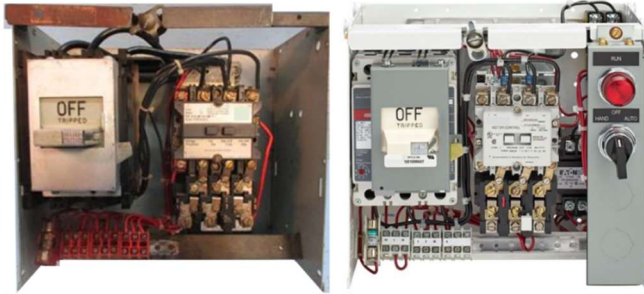


Fig. 3 Vintage design (left) versus current design (right) LV MCC molded-case circuit breaker

A. UL 845 Versus a Counterfeit Copy

The UL845 Standard mentioned previously applies not just to newly manufactured motor control centers, but also to replacement starter and feeder circuit breaker units. Just as new units are tested in new control center assemblies, replacement units must also be tested to meet UL 845 test requirements. Electrical testing defined in the Standard including heat-rise and short-circuit must be completed while the unit is installed in the MCC assembly. For upgrade of an obsolete motor control center, new replacement units must be tested in a vintage assembly originally produced by the equipment manufacturer. Manufacturers of UL 845 replacement units must test the combination of molded case circuit breaker, contactor, overload relay and cabling/connectors within the unit assembly to verify and then label the unit interrupting rating. For a true UL 845 replacement unit, the battery of testing performed is essentially the same as test requirements included for new MCC assemblies. Only after all tests are successfully completed can a UL 845 label be affixed to the unit, designating full compliance. Users should take great caution in specifying and purchasing MCC units from a reputable supplier, assuring the UL 845 label is clearly visible and certified test reports are included. Users should always ensure that replacement MCC units carry the short circuit current rating for the assembly it will be installed in.

Over the years a growing trend has emerged where unauthorized manufacturers have misrepresented replacement starter units to be installed in vintage MCCs as being fully factory tested to UL 845. Shops that specialize in assembling control panels typically offer UL 508 or UL 508A labels affixed to specialty control panels. Neither UL 508 nor UL 508A considers bus systems within a control assembly, nor do these address short-circuit and heat rise testing as defined by UL 845. Users should take great caution in specifying and purchasing

MCC units from a reputable supplier, assuring the UL 845 label is clearly visible and certified test reports are included. Installation of replacement units that have not been properly tested or are assembled with some used components can cause catastrophic failure during a fault, resulting in equipment damage, loss of production, injury or death of personnel.

B. Replacing the Circuit Breaker versus a Complete Starter Unit

Returning to the topic of the MCC interrupting rating, oftentimes a vintage motor control center will need attention not only to assure proper bracing of the main horizontal and vertical copper bus, but also the components included in the starter unit itself. As previously discussed, most vintage molded-case circuit breakers typically have lower interrupting ratings and upgrade of this component needs to also be considered. Like the power stab assembly, it is important to consult with the original equipment manufacturer or a qualified electrical services organization, to investigate the viability of a MCC upgrade using circuit breakers with higher interrupting ratings. Not just the breaker rating but also the size and form factor must be considered. The starter unit door-mounted handle mechanism will typically be mounted on the circuit breaker, so the location and movement of the circuit breaker handle must be compatible with the door-mounted mechanism. In some cases, new design molded-case circuit breakers with higher interrupting ratings can be installed in existing MCCs with sufficient short circuit ratings to address issues regarding overdutied installations.

Fig. 4 shows a current design molded-case circuit breaker versus one from nearly 50 years ago. Note that the new offering includes features such as finger safe terminals and a push to trip test button, available as standard with a 65,000-symmetrical ampere interrupting rating. Although the form factor and breaker operating handle location for the vintage and new circuit breaker are identical, simply installing the new breaker in place of the old is not recommended. The issue here is that the withstand rating of the subassembly is based on the combination of both the circuit breaker and the motor starter functioning together. The UL 845 test defines this combination rating. As previously mentioned, vintage magnetic starters have traditionally used heater coils for motor overload protection, offering an impedance path to limit fault currents during short-circuit conditions. This limitation gives the circuit breaker magnetic trip element time to actuate and successfully



Fig. 4 Vintage design (left) versus current design (right) LV MCC molded-case circuit breaker

clear the fault. New magnetic starters nearly universally apply on-board current transformers with sophisticated electronics to sense motor overload and a host of other abnormalities to protect the motor and driven load. In the absence of the additional resistance from the vintage heater coils, the circuit breaker may not successfully clear a higher-level fault. As defined in the UL 845 Standard, both the circuit breaker and the motor starter/protective relay are interdependent and must be tested together.

C. Technology Advancements in Motor Protection

Over the past several decades, advances in electronics have accelerated the functionality of overcurrent circuit protective devices and compact adjustable frequency drives (AFDs) are now routinely installed in low-voltage motor control centers. Current design motor overload relays have evolved to function as intelligent motor protective devices that continuously monitor positive and negative sequence motor phase currents to establish a precise thermal model of the machine's windings. These deliver an order of magnitude of improved motor protection and functionality. Recent papers including [12] discuss case history's involving low-voltage motor control center installations where new motor management relays with enhanced functionality have been installed. The latest offerings include advanced protective features in a small, network communications ready package. Referring to Fig. 5 as a typical current design device, a measurement module includes integral

current transformers allowing three-phase power conductors to connect between the switching contactor and three-phase motor terminals. Voltage terminations are also made at the base module that support functionality beyond legacy motor protective relays including under-voltage, under-load and pump cavitation, along with metering of phase voltages, amperes and power in watts and vars. A base control module communicates new available data via a host of communication networks, the most prominent in industry today being Ethernet/IP. An optional user interface module is also used for local control and monitoring as desired. One important added capability of the on-board microprocessor included in the base control module is in locating a grounded motor feeder in a high resistance pulsing ground system as discussed previously. Since the measurement module of each relay includes three integral current sensors, special functionality of the new relay has been added to recognize when the HRG pulser has been activated, and then report not only which motor feeder but also which phase of the faulted feeder has a ground fault. This new functionality greatly reduces added complexity in current design HRG systems which require additional zero-sequence current transformers (ZSCT) wired back to a HRG relay at each individual LV MCC motor starter unit as discussed previously [10,11].

Application of the latest designs of these motor management relays deliver a step-change in motor protection versus legacy controls installed in vintage equipment. More importantly, the availability of real-time data measuring phase currents and voltages for every driven load offers a new platform of functionality that will be transformative for industry. Without question, the added capability of network connectivity can serve as an enabler to assure any existing industrial plant, even a plant with 40 to 50 old legacy electrical systems, can be positioned to compete with new plants utilizing the latest technologies. Industry users can utilize network enabled systems to deliver an abundance of available data and extract useful information to improve system reliability, uptime, efficiency and safety. Today's fourth industrial revolution is characterized by a transition from the manual, sequential value chain in manufacturing to an information rich digital core enabled by new developments in smart sensors, cloud computing and the Industrial Internet of Things (IIoT). Several existing industrial plants including some from the author's company have recently completed successful life-cycle extension projects including upgrades low-voltage MCCs and other electrical power distribution and control assemblies. These have clearly leveraged the latest in network enabled systems, offering a platform in support of the coming new era of Digital Transformation. Table I offers suggested decision criteria in reviewing the options to replace or upgrade existing low-voltage MCCs as discussed in this section.

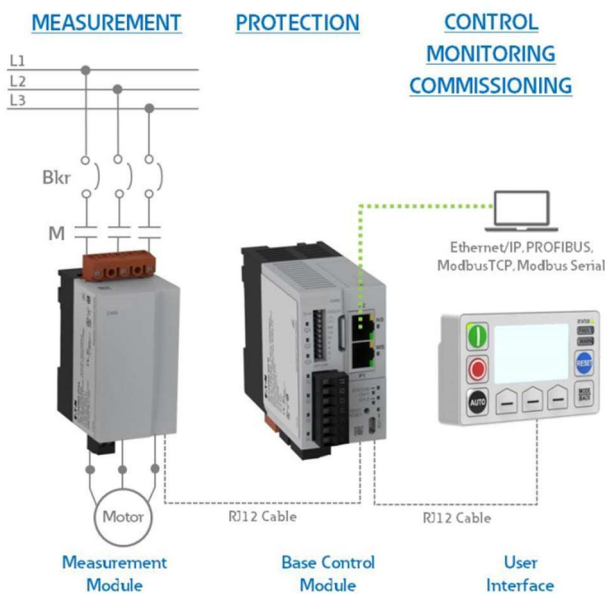


Fig. 5 Typical microprocessor-based motor management relay

TABLE I					
DECISION CRITERIA FOR REPLACE VERSUS UPGRADE					
Alternative	Initial Cost	Installation Cost	Cost to Maintain	Reliability/Maintainability	Required Downtime
Replace Existing Assembly	High	High	Low	Maximized	Very High
Upgrade Existing Assembly Rating	Moderate	Low	High	Moderate	High
Refurbish Existing LV MCC Starter Units	Low	Moderate	Moderate	Minimal	High
New LV MCC Starter Units	Moderate	Low	Low	High	Lowest

VII. CASE HISTORY: REPLACEMENT VERSUS UPGRADE

One industrial lithium processing plant the U.S. State of North Carolina recently evaluated the alternative to replace an existing 45-year-old LV MCC versus upgrade with new UL845 starter units. The existing plant, originally commissioned in the 1970s considered replacing the vintage 8-structure assembly shown in Fig. 6 with a replacement assembly using the latest designs available. Complete replacement of the assembly

would require removal of existing MCC top-mounted conduits for both incoming and outgoing cables of the existing 8-structure assembly as shown in the image of the line-up. In both the replacement and the upgrade alternatives considered, the decision was made to upgrade legacy bi-metal motor overload protective relays with a current microprocessor-based motor management relay, capable of network communications via Ethernet/IP. Included in the upper section of Table II is an esti-

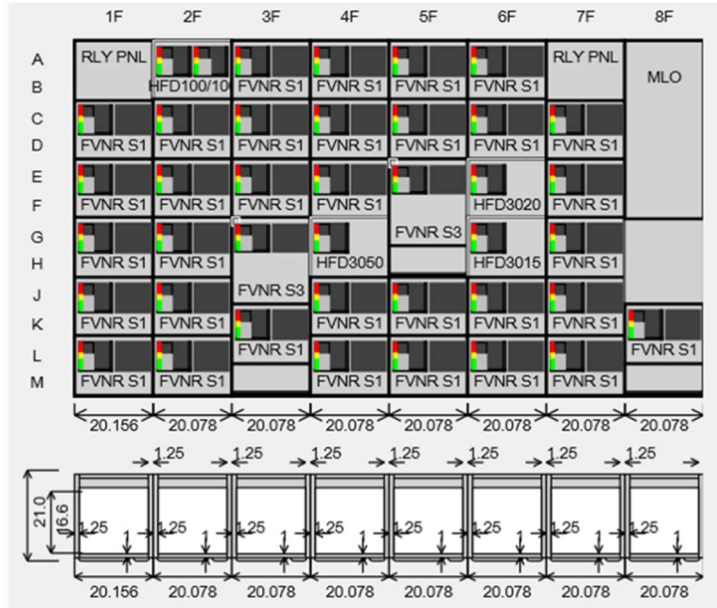


Fig. 6 Existing 45-year-old LV motor control center (left) and supplier proposed layout of replacement assembly (right)

TABLE II REPLACE VERSUS UPGRADE OF LV MCC					
	Labor Hours	Labor \$/Hour	Material Cost	Outage Cost	Totals
Purchase new 8 Structure Replacement LV MCC assembly			\$63,642		\$63,642
Dismantle/Remove existing MCC assembly	48	\$100			\$4,800
Install new 8 Structure Replacement LV MCC assembly	48	\$100			\$4,800
Rewire existing in & out cables/conduits	18	\$100			\$1,800
Pull Ethernet comm cables and wire to mill fiber network	16	\$100			\$1,600
24-hour mill downtime at \$22,000/hour				\$528,000	\$528,000
Total LV MCC Replacement Cost					\$604,642
Purchase replacement MCC starter/breaker units					
Full-Voltage Non-Reversing NEMA Size 1 (Qty 33)			\$95,618		\$95,618
Full-Voltage Non-Reversing NEMA Size 3 (Qty 2)			\$8,320		\$8,320
Dual 100A/100A Feeder Breaker (Qty 1)			\$2,417		\$2,417
Single 100A Feeder Breaker (Qty 3)			\$5,748		\$5,748
Purchase Ethernet switches (3)			\$1,800		\$1,800
Remove existing MCC starter/breaker units	8	\$100			\$800
Install replacement MCC starter/breaker units, terminate cables	16	\$100			\$1,600
Install Ethernet switches (three)	8	\$100			\$800
Pull Ethernet comm cables and wire to mill fiber network	16	\$100			\$1,600
8-hour mill downtime at \$22,000/hour				\$176,000	\$176,000
Total LV MCC Upgrade Cost					\$294,702

mate of both the labor and material cost to remove and replace the existing LV MCC assembly including the addition of new updated network cables that would be connected at the newly installed communicating MCC manufactured and tested to the UL845 Standard including upgraded motor management relays. This is compared in lower section of Table II with an estimate the labor and material cost to upgrade the existing assembly, leaving the existing structure in place and installing new UL845 replacement NEMA Size 1 and Size 3 starter units, and single/dual feeder circuit breaker units.

Note that although the first cost to purchase a new 8 structure replacement LV MCC is lower than the UL845 replacement starter and feeder breaker units, the total installed cost of the upgrade is lower. The most significant cost impact in the replacement scenario is the extended required downtime. In this case, plan for an estimated 24-hour outage to replace the vintage MCC would be reduced to 8 hours if the existing MCC remained in place and new starter units were installed. Experience has proved there is not much opportunity to do prep-work while the existing assembly is energized. After the scheduled outage begins, more labor hours will be expended pulling both power and control wires and carefully labeling each to assure they are re-routed into the new LV MCC after it is installed. Punching or drilling for conduits to be pulled back into the new vertical structures can be a challenge. Further, there are many required terminations which not only add labor hours but also increases the chance for human error. It's possible that exiting conductors could be damaged or not long enough to make new terminations which could require pulling new conductors back to the driven load. Note that this analysis is intended to serve only as an example of the relative costs associated with a replace versus upgrade decision. Actual costs for materials, labor and facility downtime will vary based on actual site conditions.

VIII. CONCLUSIONS

Existing manufacturing plants in the process industries need to consistently focus on maintenance of aging assets to assure electrical systems continue to operate both safely and reliably. There are many existing facilities first commissioned 40 to 50 years ago where existing systems are approaching end of life. The need for continuous improvements in operational productivity requires a focused effort to analyze which systems must be replaced versus which can be upgraded. Existing low-voltage MCCs with structure and bus systems that have been well maintained represent potential opportunities for upgrade versus replacement. The user should consider original equipment ratings to assure sufficient interrupting capacity for the application. Also, a working understanding of the UL 845 Standard is recommended prior to execution of any project involving upgrade of an existing motor control center. With developments in technology, there are many opportunities to enhance the functionality of existing assemblies as a part of any upgrade project. Looking forward, plants will need to leverage network connectivity and find ways to take advantage of a newly realized wealth of readily accessible digital data, extracting the right information necessary to improve operations. This will involve more than just adding technology to the existing model. Instead, true digital transformation will likely involve the much more difficult task of rethinking the current business model and applying this to a new platform

supported by 21st century technologies. The path forward in many cases will not require a wholesale change out of existing systems, which is both cost prohibitive and simply impractical. Instead, a carefully planned program to upgrade existing systems is often a valid approach. Early alignment with key equipment suppliers and contractors to build a business case to review the replace versus upgrade alternatives followed by installation of network enabled systems can position any existing manufacturing business to move forward toward their Digitalization Transformation future.

IX. ACKNOWLEDGEMENTS

The authors wish to thank Mr. Brian McElligott of JH Kelly Construction and Mark Higginson of North Pacific Paper Company (NORPAC) in Longview Washington USA for contributions in completing the labor and materials estimates outlined in the replace versus upgrade total cost comparisons outlined in Section VII. of this paper.

X. REFERENCES

- [1] UL 845; "Motor Control Centers", Underwriter's Laboratories, Northbrook, IL U.S.A.
- [2] IEEE 1683-2014; "IEEE Guide for Motor Control Centers rated up to and including 600 V AC or 1000 V DC with Recommendations Intended to Help Reduce Electrical Hazards"
- [3] Valdes, M.E., Bugaris, R.M., Wellman, C.M., "The Making of IEEE 1683 - An Introduction and Behind the Scenes Look", 2015 IEEE IAS Petroleum and Chemical Industry Technical Conference, pgs. 1-8
- [4] Sauve, T.R, Anderson, R.P., Bower, T., Mickler, K.R. "Designing and specifying MCCS to reduce hazards and risks, using IEEE 1683", Conference Record, IEEE IAS Petroleum and Chemical Industry Technical Conference, 2017, pgs. 387-396
- [5] ANSI/UL489 Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures, 2016
- [6] IEEE Standard 1458 Recommended Practice for the Selection, Field Testing, and Life Expectancy of Molded Case Circuit Breakers for Industrial Applications, IEEE IAS 2005
- [7] Higginson, M., Durocher, D.B., 'Proper Application & Maintenance of Molded Case Breakers to Assure Safe and Reliable Operation', Conference Record, IEEE IAS Pulp and Paper Industry Technical Conference, 2009, pgs. 102-113
- [8] Beltz, R.D., Peacock, I., Vilcheck, W. "High-Resistance Ground Retrofits in Pulp and Paper Mills", IEEE Industry Applications Magazine, 2001, Vol 7, Issue 2, pgs: 19-27
- [9] Panetta, S., McPhee, A., Legette, T., Perich, E. "Converting Solidly Grounded Transformers to High Resistance Grounded Systems; Practical Applications Study", IEEE IAS Pulp, Paper & Forest Industries Conference, 2016, pgs. 41-44.
- [10] Bapat, A., Hanna, R., Panetta, S. "Advanced Concepts in High Resistance Grounding", IEEE IAS Petroleum and Chemical Industry Conference, 2012, pgs. 1-9.
- [11] Locker, A.S., Scarborough, M.S. "Advancements in Technology Create Safer & Smarter HRG systems", Conference Record, IEEE IAS Pulp and Paper Industry Technical Conference, 2009, pgs. 102-113
- [12] Durocher, D.B., Hussey, M.R., Belzner, D., Rizzi, L; "Application of Next Generation Motor Management Relays to Improve System Reliability in Process Industries", IEEE Transactions on Industry Applications, March/April 2019.