Best Practices for Motor Control Center Protection and Control

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BEST PRACTICES FOR MOTOR CONTROL CENTER PROTECTION AND CONTROL

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Abstract—Low-voltage motor control centers (MCCs) are numerous and consume a large portion of maintenance and operator interaction in an industrial power distribution system. The extensive human interaction with these low-voltage (less than 1,000 V) circuits makes a low-voltage MCC a location of significant potential hazard. The large number of low-voltage MCC circuits results in significantly more human interface time with low-voltage MCC equipment than with medium-voltage MCCs and switchgear.

Modern protection and control systems derived from medium-voltage (1,000 V to 38 kV) and high-voltage (38 to 765 kV) power systems have much to offer low-voltage MCC systems. Proactive maintenance indicators based on load characteristics, motor start characteristics, and thermal measurements are described. Time synchronization, modern Ethernet-based protocols, sequence of events records, oscillography (COMTRADE), monitoring and alarming for protection functions, and other previously standard features in medium- and high-voltage protective relays are available in modern low-voltage MCC protective relays. Increased safety in the form of advanced protection elements and arc-flash detection are now also available.

This paper focuses on the philosophy of a comprehensive low-voltage MCC protection and control system.

Index Terms—Reliability, motor control center (MCC), safety, arc-flash hazard, protection, automation, multifunction microprocessor-based relays.

I. INTRODUCTION

We do not have to look farther than the dashboard on a modern automobile to see opportunities for practical advancements in industrial motor control and protection. A simple turn of the ignition key begins a series of self-diagnostics on devices and systems critical to personal safety and vehicle reliability. Dashboard indicators provide the status of the antilock braking system, dual-master brake cylinder, and tire pressure. There are indicators for failures in safety-related light bulbs, including headlights, brake lights, turn signal indicators, and side lamps. Other indicators monitor lubrication oil and coolant levels, which are critical to preventing costly failures. An automobile mechanic can connect instrumentation to immediately download diagnostic data and failure codes to pinpoint the need for maintenance or corrective action. These advancements in sensors and instrumentation that enable continuous monitoring, self-diagnostics, and event logging are embedded in millions of automobiles on the road today and are helping make automobiles safer and more reliable. The technologies found in automobiles are making their way into industrial applications to enable advancements in safety and reliability, improve energy and raw material use, and reduce the costs and improve the effectiveness of maintenance resources.

These advancements are especially applicable toward improving the reliability of protective devices essential for arc-flash hazard mitigation. The recognition of arc flash as a unique electrical hazard has led to a new expectation for circuit protection devices: the safeguarding of personnel from the hazards of thermal burns and explosive blasts. Arc-flash hazards have changed the design rules for the analysis and protection of power systems. This has also led to a different expectation for electrical equipment maintenance: the assurance that overcurrent protective device pickup and trip characteristics used as the basis for arc-flash hazard analysis and the selection of hazard control measures, including personal protective equipment, perform exactly as designed. If these protective devices do not function as designed, the thermal and blast energy exposure can be orders of magnitude greater than expected. Unfortunately, early generations of protective devices can fail. The failure can go undetected until the next scheduled maintenance inspection. If an arc-flash event occurs, the thermal energy released can be orders of magnitude greater than anticipated. Technologies that enable the remote monitoring of current, voltage, contactors, and overload devices impact more than arc-flash mitigation. These technologies also help reduce exposure to electrical shock hazards by decreasing the need to troubleshoot and perform other maintenance tasks that place workers in close proximity to potentially hazardous voltages.

This paper describes a comprehensive low-voltage (LV) protection and control system for motor control centers (MCCs). This system is designed to provide increased safety, more selective protection, advanced event diagnostics, reduced cost, and higher reliability than previous technologies.

II. BACKGROUND

Prior to the 1990s, MCC units were electromechanical in design and typically included a contactor, thermal overload elements, and short-circuit protection. Local and remote indications were provided through hard-wired lights and signals to a programmable logic controller (PLC). The PLC then sent the state of the MCC buckets to the process control system (PCS). Status and control messaging between the MCC buckets and PLCs required extensive cabling between the MCC, PLC, and PCS for start and stop control and monitoring. It was not uncommon to need 16 control and metering wires per motor starter unit. Hence an MCC with 30 units could have required 480 wires, 960 terminations, sufficient terminal blocks, and a separate distributed control system (DCS) marshalling cabinet in the building.

Between 1990 and 2010, the concept of smart MCCs was developed by many manufacturers. The features of these systems mainly revolved around improving diagnostics, reducing wiring, and removing personnel from the immediate vicinity of dangerous voltages [1]. These MCC designs substantially reduced wiring by placing intelligent electronic devices (IEDs) in the MCC bucket and by using digital communications instead of hard-wired signals. At the core of these older, smart MCC designs were PLCs communicating via industrial protocols. The protection, metering, and control IEDs used in these older designs (from the last 20 years) were simple microprocessor-based multifunction devices with very limited capabilities.

The reliability, functionality, programmability, flexibility, and intelligence of these older, smart MCC protection, metering, and control IEDs were very limited when compared with modern medium-voltage (MV) and high-voltage (HV) microprocessor-based multifunction protective relays. Simultaneous to the evolution of the smart MCC systems, a vastly more sophisticated set of electronics, software tool sets, diagnostics, reporting, and communications methods were developed for the MV and HV electric power protection industry throughout the world. These more sophisticated protection IEDs have been used since 1982 in the MV and HV protection industry (1,000 V to 765 kV). These transmission-grade IEDs are subjected to severe environmental testing and reliability requirements, such as temperature, shock, and electromagnetic interference. The mean time between failures of these transmission-grade systems and products exceeds 300 years [2].

The features and reliability of the HV transmission and MV-grade products are becoming the new standard for LV protection and control products. It is in the best interest of industry professionals to bring the reliability, safety, and reduced cost of these transmission- and distribution-grade products and integration philosophies into LV systems.

A. Historical LV Motor Protection

Historically, the protection of LV motors was done with thermal overload elements and short-circuit interruption devices. Motor thermal overload elements were most commonly melting alloy overload relays. The motor current was routed through this alloy, and if the current exceeded a time-overcurrent threshold, the alloy melted. The melting of the alloy allowed an internal ratchet wheel to turn and open a set of contacts, thus opening the motor contactor. There was also some reset time, which was required to allow the alloy to cool and harden. This equated to the motor cooldown time.

Short-circuit current interruption was typically accomplished with a type of magnetic circuit breaker (or circuit protector) capable of interrupting cable fault currents. The fault current levels that the circuit breaker must interrupt were often larger than what a motor contactor (starter) could interrupt, so the circuit breaker had to directly interrupt the fault current on its own. Note that many magnetic circuit breakers were rated only to interrupt full fault current one time. After full fault current was interrupted, there was no guarantee that these circuit breakers would function correctly again.

B. What Is a Protective Relay?

The primary purpose of any protective relay is to identity events worthy of interrupting the flow of current. The following three classes of relays exist in the world today [3]:

1. Electromechanical relays that are constructed of wire, magnets, springs, dashpots, and steel components to detect anomalous events.
2. Solid-state relays that are constructed of silicon-based components built up as analog circuits (e.g., operational amplifiers) to detect anomalous events. All signals remain analog. No signals are digitized in these devices.
3. Microprocessor-based multifunction relays that convert analog currents and voltages to digital signals, which are processed to detect anomalous conditions. Only microprocessor-based relays have advanced diagnostic and communications features.

III. CHARACTERISTICS OF A MODERN LVMR

This section explains the basic characteristics and feature set of the modern microprocessor-based low-voltage motor relay (LVMR). Fig. 1 shows the typical implementation of the LVMR for a direct-on-line (DOL) started motor application.

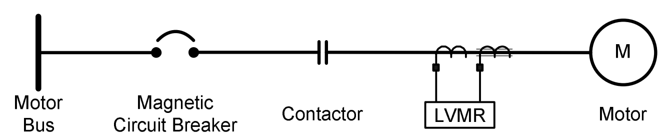

Fig. 1 Direct-Start Motor Application

A. Features of LVMRs

Many features differentiate the modern microprocessor-based multifunction LVMRs from older technologies. These features include the following:

1. Detailed event diagnostic reporting features, such as sequence of events (SOE), oscillography, motor start and stop reports, and load profiling. These features replace strip charts and oscilloscopes.
2. Onboard time-stamping of all events and settings changes. Simple Network Time Protocol (SNTP) time

synchronization is used to keep all the LVMRs time-synchronized.

3. An integrated power supply, which can be powered from 24 to 250 Vdc or 110 to 240 Vac sources (eliminating auxiliary power supplies in the cabinets).
4. Onboard arc-flash detection (AFD).
5. A small form factor. The devices must fit into the smallest LV MCC buckets.
6. Multiple Ethernet and serial ports. A clear demarcation line between process and electrical systems is easy to achieve on products with multiple communications ports.
7. IEC 61850 Generic Object-Oriented Substation Event (GOOSE) and Manufacturing Message Specification (MMS) protocols to take advantage of the simplicity and cost savings of Ethernet-based communication.
8. Communications protocols built directly into the main board of the unit. Firmware (not hardware) can be updated to enable new protocols.
9. Direct terminal block connections for temperature measurement, analog outputs, digital outputs, and optoisolated digital inputs. All digital outputs should be dry contacts because transistorized outputs are unsuitable for trip circuits.
10. Complete onboard diagnostics to determine if the power supply, microprocessor, memory, analog-to-digital converters, and other components are functioning properly.
11. Conformal-coated boards for the dirty and corrosive environments common in industrial LV applications.
12. A simplified setup from a web-based human-machine interface (HMI) mounted on the bucket front door.
13. Built-in metering with fundamental and harmonic data.
14. Complete onboard diagnostics to determine if the power supply, microprocessor, memory, analog-to-digital converters, and other components are functioning properly.
15. Programmability similar to a miniature PLC, including Boolean logic, analog mathematics, timers, counters, and programmable discrete and analog outputs for custom control and protection schemes.
16. Security in the individual LVMR that must include (at a minimum) multilevel password login and strong password protection schemes.

B. Direct-Start Motor Protection

The protection features of the modern microprocessor-based LVMR (see Fig. 2) commonly provide the following functions [4]:

1. DC offset and harmonics removal inherent with modern ac signal filtering techniques [5].
2. Full real-time symmetrical components in polar form phasors (magnitude and phase angle) and the metering of voltages (V_0, V_1, and V_2) and currents (I_0, I_1, and I_2).
3. Undervoltage and overvoltage (27 and 59) elements.
4. Underfrequency and overfrequency (81U and 81O) elements.
5. Load loss detection (37CP) element.
6. Power factor (55) element.
7. Phase reversal (47) element.
8. Loss-of-potential (60) element.
9. Instantaneous and time-overcurrent (50 and 51) elements.
10. Thermal (49T and 49P) elements.
11. Locked rotor detection (50PLR) element.
12. Load jam detection (50PLJ) element.
13. Current unbalance detection (46) element.
14. Breaker failure protection.
15. Motor lockout.
16. Negative-sequence overcurrent (50Q and 51Q) elements.
17. Motor starting and running (14 and 66) elements.
18. Variable frequency drive (VFD) protection.
19. Arc-flash detection (AFD) element.

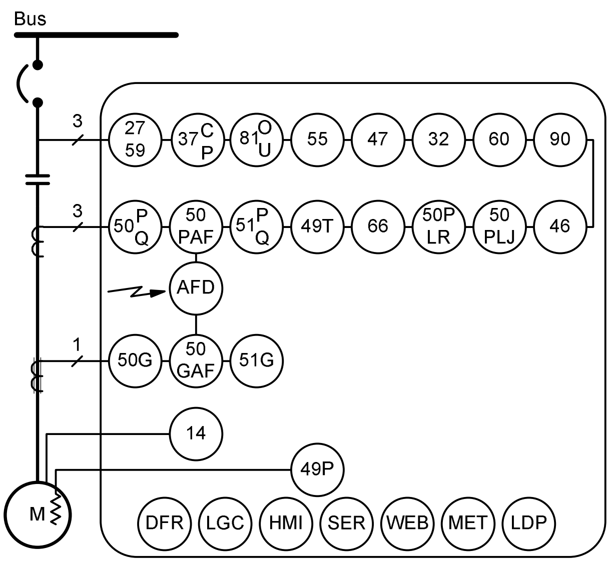

Fig. 2 Modern LVMR Functionality

C. Lighting Circuit Protection

LVMRs can also be used for lighting circuit or feeder protection. Note that in the list in Section III, Subsection B, the protection elements are provided for basic feeder protection schemes. These include phase, ground, and negative-sequence overcurrent protection; phase, ground, and negative-sequence time-overcurrent protection; and directional power and AFD elements.

Of particular interest is the opportunity to improve relaying sensitivity to prevent human electrocution and injury. Sophisticated protection schemes designed to prevent human electrocution, such as those mentioned in prior IEEE papers [6], can now be implemented by any user. These schemes can be implemented by using programmable logic in the LVMR, high-speed relay-to-relay communication, and sensitive zero-sequence elements.

D. Variable Frequency Drive Protection Enhancements

Many low-cost VFDs do not have sufficient motor protection, metering, automation, controls, or communications capabilities. Modern microprocessor-based LVMRs fill these gaps. A typical one-line diagram for such a system is shown in Fig. 3.

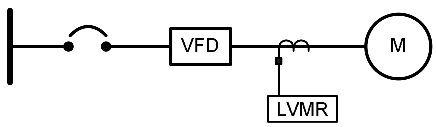

Fig. 3 Enhancing VFD LV Motor Protection

In the VFD operating mode, the thermal model and overcurrent protection elements use root-mean-square (rms) current magnitudes that include both the fundamental and harmonic content. This is in contrast to normal motor and feeder protection modes that only use the fundamental frequency magnitudes via the long-standing method of cosine filtering [5].

With self-cooled motors, a reduction of the motor speed also reduces the cooling air flow. Sustained reduced-speed operation can result in the motor overheating. Modern LVMRs provide thermal protection throughout the VFD speed ranges.

E. Arc-Flash Protection

Electrical hazards that can result in human injury or death commonly come in two forms: arc flash and electric shock. For the maximum in personnel safety, there are a large number of schemes available that use the positive (I_1), negative (I_2), and zero-sequence (I_0) quantities calculated in an LVMR.

The AFD element in a protective relay can provide a significant reduction in the hazardous incident energy from an arc fault [7]. The light produced by an arc flash provides a large-magnitude signal that is used in conjunction with overcurrent sensing to securely and reliably detect an arc fault. Upon detection of the arc-fault condition, the relay initiates the high-speed tripping of an upstream breaker to minimize the arc-fault duration and resultant incident energy. In the system we describe in this paper, the LVMR is capable of providing the entire arc-flash protection function, including light sensing, overcurrent sensing, and high-speed tripping.

The typical MCC implementation is vulnerable to arc faults upstream of the LVMR (e.g., on the contactor, fuse, busbar, or breaker). Consequently, it is also advantageous to sense the arc-fault overcurrent on the incoming feed to the motor bus while still sensing the light flash within the MCC bucket. Furthermore, LV MCCs typically use fuses, motor circuit protectors, or thermal magnetic circuit breakers within the buckets that are not tripped by a protective relay (only the contactor is opened by a relay). As a result, it is necessary to trip the incoming motor bus breaker to reliably clear the arc fault.

When a light flash is detected in an MCC bucket, high-speed IEC 61850 GOOSE messaging is sent from the LV protective relay to an upstream relay associated with the motor bus circuit breaker (52). If the upstream relay detects an overcurrent condition coincident with the MCC bucket light flash, a high-speed trip is initiated on the motor bus circuit breaker to minimize the arc-fault duration. A typical scheme for such a system is shown in Fig. 4.

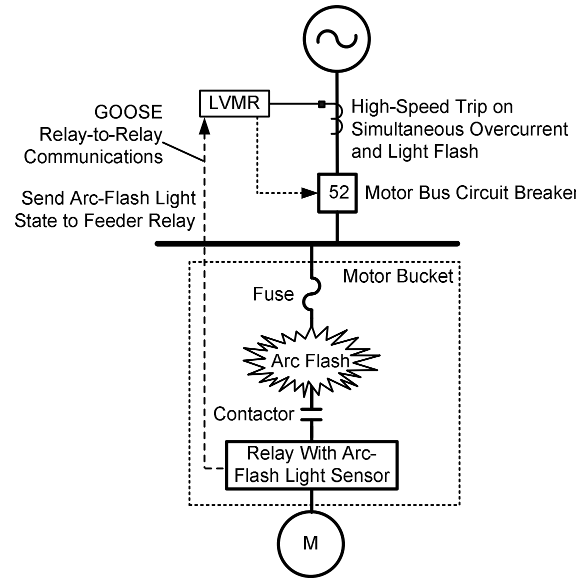

Fig. 4 Use of Relay-to-Relay GOOSE Messaging for Arc-Flash Protection

Tests during live arc-flash events with multiple relays prove that the careful design of relays is required for them to survive the harsh environment of the arc-flash plasma cloud. This environment includes very high temperatures, bright light, ionized air, strong magnetic fields, flying molten metal, and mechanical shock. Table I shows the end-to-end detection and trip times measured during arc-flash testing at a high-current laboratory. The test methodology is similar to that described in [8] but with an LVMR instead of a feeder relay.

TABLE I
SUMMARY OF GOOSE ARC-FLASH TRIP TIMES

	Trip Time (milliseconds) From Application of Current
Minimum	4
Maximum	13

The microprocessor-based LVMR must survive an arc-flash event long enough to trip upstream breakers. The LVMRs must be designed and tested to survive an arc-flash event if they are to effectively sense an arc flash and trip an upstream breaker. This is an onerous task that requires ruggedized design principles that far exceed the norm in the industry.

Significant testing of the relays must be done in real arc-flash environments to ensure survival. Typical testing methods are shown in Fig. 5. Field tests have proven that even in a catastrophic arc-flash test event, at least four GOOSE messages indicating the arc-flash event are sent within 16 milliseconds. The total time from the start of fault conditions to an upstream relay having trip-rated contacts fully closed and conducting is shown in Table I. The variance between 4 to 13 milliseconds is caused by the asynchronous processing cycles of the microprocessor-based relays.

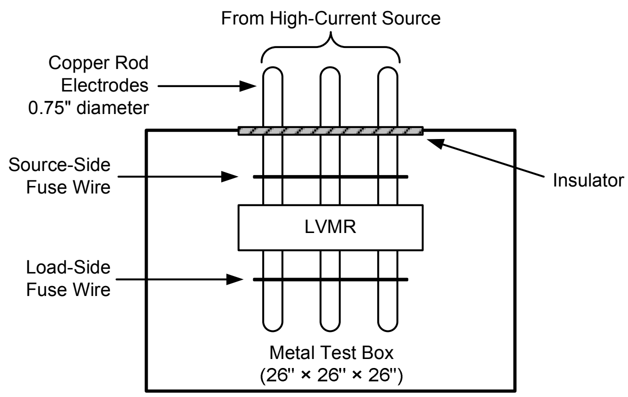

Fig. 5 Arc-Flash Test Box

F. Configuration and Commissioning of LVMRs

Operator handle interlocks may not allow a bucket door to be opened while live voltages exist in the bucket. This means that the front of the relay may not be available for configuration while it is in an energized state. All configuration can be done through the communications network when the bucket door is closed and the circuits are energized. This makes it imperative that simple, reliable, time-proven, and diverse methods exist to configure and test the microprocessor-based LVMR. Modern devices are configured and commissioned through one or more of the following:

1. Simple, user-friendly, embedded web server.
2. Remote configuration through the communications network.
3. Diverse communications media options, such as serial terminal session, File Transfer Protocol (FTP) Transmission Control Protocol/Internet Protocol (TCP/IP) file transfer, or Telnet TCP/IP.
4. Full configuration without any software through a menu-driven bucket-mounted HMI.
5. Portable hand-held device settings transport.
6. Global relay settings software management tools.
7. Manual configuration using the command prompt (via Ethernet or serial communication).

G. Hardened Equipment Specifications

LVMRs are applied in harsh physical and electrical environments; thus, they must withstand vibration, electrical surges, fast transients, and extreme temperatures. The type-test standards that the devices must meet include the following:

1. 15 g vibration resistance (IEC 60068-2-6:1995).
2. Shock resistance (IEC 60255-21-2:1988).
3. Cold tolerance at –40°C for 16 hours (IEC 60068-2-1:2007).
4. Steady-state damp heat (IEC 60068-2-78:2001).
5. Cyclic damp heat (IEC 60068-2-30:1980).
6. Dry heat (IEC 60068-2-2:2007).
7. High-potential dielectric (IEC 60255-5:2000 and IEEE C37.90-2005).
8. 15 kV electrostatic discharge immunity (IEC 61000-4-2:2008 and IEC 60255-22-2:2008).
9. Radiated radio frequency immunity (IEC 61000-4-3:2008 and IEC 60255-22-3:2007).
10. 2.5 kV common-mode surge withstand capability immunity (IEC 60255-22-1:2007).
11. IEEE C37.90 and IEC 60255 protective relay standards.

Additional organizations that commonly affect LVMR installations are the International Organization for Standardization (ISO), Underwriters Laboratory (UL), Canadian Standards Association (CSA), and the European Commission (CE).

H. Internal Self-Testing and Diagnostics

Modern microprocessor-based LVMRs must advise monitoring systems when they are having internal problems, such as failures in internal memory, power supply problems, input/output (I/O) board failures, current transformer (CT) or voltage transformer (VT) board failures, clock inaccuracies, or processing vectoring errors. Ultimately, the greatest advantage of any protection IED is that it can continuously confirm whether it is functioning properly.

LVMRs continuously run self-diagnostic tests to detect out-of-tolerance conditions. These tests run simultaneously with the active protection and automation logic and do not degrade the device performance.

The LVMR reports out-of-tolerance conditions as a status warning or a status failure. For conditions that do not compromise functionality yet are beyond expected limits, the LVMR declares a status warning and continues to function normally. A severe out-of-tolerance condition causes the LVMR to declare a status failure and automatically switch the device into a device-disabled state. During a device-disabled state, the LVMR suspends protection elements and trip/close logic processing and de-energizes all control outputs.

LVMR internal diagnostics must discern between hardware, firmware, or software alarm conditions. User-initiated events, such as settings changes, access level changes, and unsuccessful password entry attempts, must also be logged.

I. Event Diagnosis

The ability to diagnose and understand motor overloads, short-circuit trips, motor starts, and all other relay operations has proved critical in the protection industry. Having synchronized time signals to all IEDs in the LV MCC and throughout an industrial plant provides the ability to have comparable power system fault and disturbance event reports (oscillography), Sequential Events Recorder (SER) records, and time-accurate reporting for supervisory control and data acquisition (SCADA) analog and state-change records (SOE).

Being able to perform time-deterministic root-cause analysis of system events and combine report data from different microprocessor-based relays to calculate in real time the timing between occurrences related to the same incident has proved invaluable.

The types of event records commonly provided by an LVMR include the following:

1. Oscillographic recording using a built-in oscilloscope. Every event has an oscillography report for postmortem analysis.
2. Trip event reports, including special oscillographic reports of every trip or stall event.
3. SOE capture. The binary state of change of inputs, outputs, and internal digital variables.
4. Total harmonic distortion (THD) measurement.
5. Load profile report, which stores the metering quantities captured every few seconds into nonvolatile memory. This replaces slow-sample, long-duration strip chart recording devices.
6. Event summaries, which are shortened, simplified versions of oscillography reports (typically used for nontechnical management).
7. Event histories, which provide summaries of all recent load trips or jams.
8. Motor operating statistics report. This includes summarized information such as running data, start data, and alarm and/or trip data.
9. Motor start trending, which is a simple summary of all motor starts.
10. Motor start report, which provides a special oscillographic recording of every motor start.

J. Data Processing for Protection IEDs

Protection techniques based on the rms calculated values of current and voltage are inadequate for motor start applications. For example, rms calculated values do not reject dc and harmonic offsets due to transformer inrush. Techniques used in HV relays, such as the cosine filtering of sampled data, must be used to prevent nuisance misoperation of LV relays due to spurious dc and harmonics present in all power systems [5].

IV. CENTRALIZED SMART MOTOR CONTROL SYSTEM

A centralized smart motor control system (CSMCS) is recommended to provide a fully integrated, preconfigured LV MCC protection and control package. The CSMCS simplifies the configuration, commissioning, and testing of large numbers of LVMRs. The CSMCS is a preconfigured engineered solution for MCCs. The CSMCS replaces extensive cabling between relays, PLCs, remote terminal units (RTUs), and other controllers with a minimum count of industrially hardened, devoted-purpose LVMRs. Communication to each LVMR is done with a single Ethernet cable, implementing IEC 61850 GOOSE and MMS messaging from each relay to a centralized managed switch.

The CSMCS shown in Fig. 6 provides users with immediate real-time information on motor performance, centralized touchscreen HMI access to IEDs throughout the LV MCC lineup, and historical reporting and analysis. This networked CSMCS solution integrates the latest LVMR and incoming feeder relay for advanced motor protection, control, metering, and process automation.

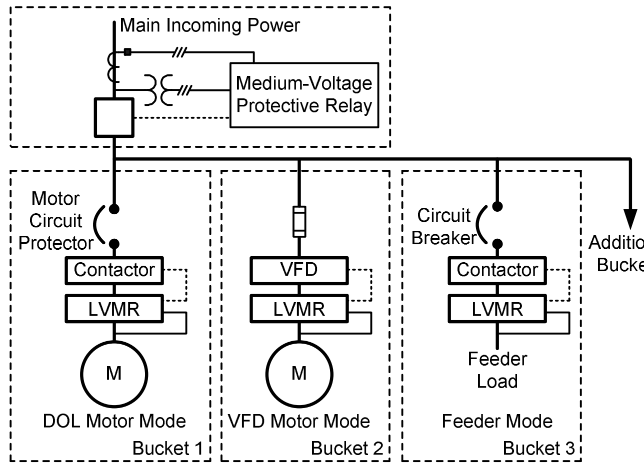

Fig. 6 CSMCS One-Line Drawing

Valuable motor and MV and LV system process data are automatically gathered, consolidated, and made available simultaneously to the PCS, power management systems (PMSs), and asset management systems. Fig. 7 shows the simplified communications hierarchy of the CSMCS.

The CSMCS is also a complete protection, control, and monitoring solution for an MCC. It provides process diagnostics that simplify maintenance by allowing users to detect and correct problems before they become critical, preventing damage and minimizing process downtime.

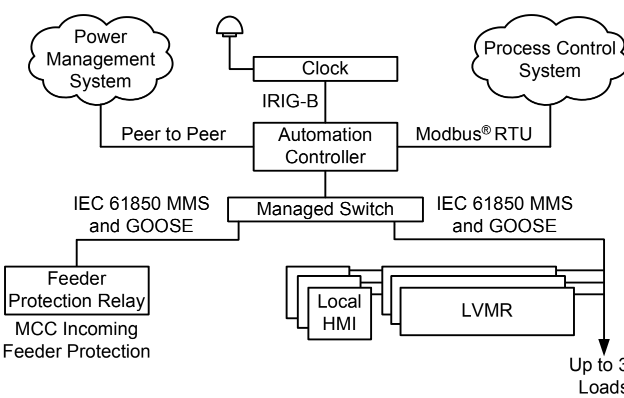

Fig. 7 CSMCS Concept

A. CSMCS Functions and Performance

The CSMCS uses standard integration and communications techniques that have been refined based on decades of utility and industrial electric power protection experience. Some of the attributes of the CSMCS include the following:

1. AFD that signals to initiate an upstream breaker trip signal less than 13 milliseconds from the detection of an arc-flash event anywhere in the MCC.
2. Ethernet communication between LVMRs.
3. HV- and MV-grade feeder protection at the main incoming section.
4. Control and monitoring of individual loads.
5. Complete status and metering data from each load and the entire motor bus.
6. Preconfigured bidirectional communication and interface to the plant PMS and PCS.
7. Preconfigured HMI systems, which provide basic system visibility via several options.
8. Factory preconfigured and programmed relays, controllers, and managed switches specifically for the CSMCS application.
9. Automatic configuration of the IEC 61850 configuration of IEDs when they are placed on an Ethernet network.
10. Remote PMS monitoring capability.
11. Subcycle remote trip operation response from remote PMS load-shedding schemes.
12. Engineering access to every IED on the Ethernet network.
13. Centralized event diagnostic software.
14. Instantaneous power metering from every relay to give real-time feedback about process operations.
15. Metering for tracking process energy costs and improving energy usage.
16. Standard data that include system faults, annunciation, motor thermal capacity used, motor load current, bus voltage, power, energy and percentage loading, motor operating statistics, motor start reports, and relay-stamped SER.

B. Multilevel HMI Annunciation

Critical for the long-term maintenance of an MCC are multiple levels of system annunciation. Should a central HMI fail, the local HMI on the front of the bucket is available. Installations requiring minimal visualization and diagnostics may have only a simple front-panel indicator. Installations requiring maximum visualization and diagnostics typically use a centralized HMI system. The three most typical HMI annunciation methods are as follows:

1. A small individual bucket HMI that provides cost-effective interface capabilities (see Fig. 8).
2. A medium individual bucket HMI that provides extensive and cost-effective interface capabilities (see Fig. 9).
3. A system-wide HMI (viewed on a local, remote, or portable computer) that provides system-level and drill-down status viewing and control for each load (not shown).

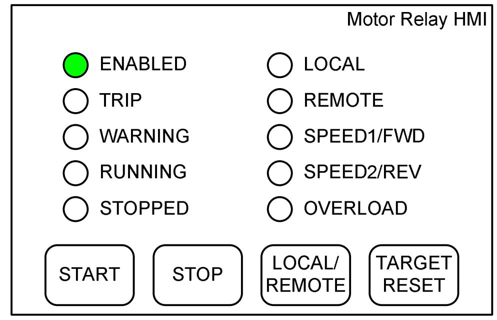

Fig. 8 Small Bucket Individual LVMR HMI

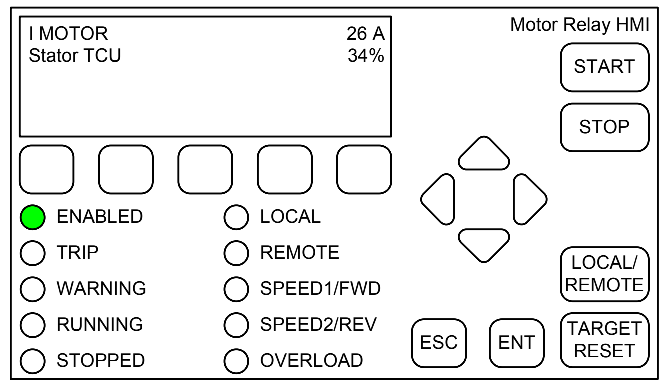

Fig. 9 Medium Bucket Individual LVMR HMI

C. Communications Architectures

In order to reduce cost, it is recommended that all LVMR devices support at least a daisy-chain Ethernet solution, as shown in Fig. 10. For maximum network redundancy and reliability, the preferred solution is for the LVMR to communicate to dual switches in a dual-star arrangement, as shown in Fig. 11. Dual-star networks are common for extremely critical functions, such as load shedding [8].

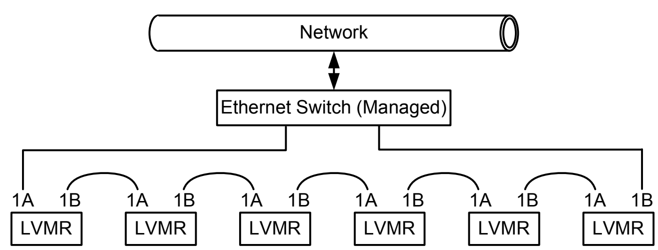

Fig. 10 Daisy-Chain Architecture for Minimum Cost

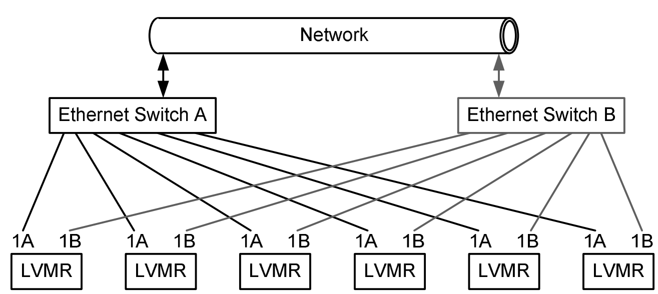

Fig. 11 Dual-Star Architecture for Maximum Reliability

V. LABOR AND ECONOMIC CONSIDERATIONS

Due to the volume of LVMRs installed in many plants, the total cost of ownership must be factored into any decision to use new LVMR or CSMCS technologies. There are several proven strategies, concepts, and technologies that should be considered in any economic or return-on-investment calculation. These include the following:

1. What is the warranty for the equipment and components?
2. What is the field measured product reliability and quality?
3. What is the total cost to production and maintenance for a failed LVMR?
4. What is the reputation and history of the manufacturer supplying the system?
5. Is it possible to order components installed with the default configurations and logic of the end-user facility?
6. What is the historical failure rate of similar components in the end-user facility?
7. What has been the customer support response time?
8. Are there sufficient diagnostic tools available to help find the root cause of problems?
9. Will the system prevent injuries to personnel?
10. How does the technology fit into the safety program?
11. Are there skilled personnel available locally to set the devices?
12. What do long-term maintenance agreements cost?

VI. STANDARDIZATION AND SIMPLIFICATION

Industries with limited engineering talent do not commonly have the resources to devote to designing a detailed CSMCS solution. The experience required to adequately design a full solution can be significant. Skills in communications systems, protection schemes, and programmable logic are required. These skills within an organization are often better devoted to larger tasks. To address this issue, many corporations have chosen a standardization program to simplify the design, ordering, manufacturing, testing, installation, and commissioning of such systems.

To facilitate the needs of end users to standardize, CSMCS solution providers must be able to order all the affiliated equipment with standard settings that meet specific end-user needs. These settings are usually sufficient for an MCC manufacturer with no additional engineers to pass a full factory acceptance test without having to adjust any settings in any devices.

Once these factory-ordered solutions are delivered and installed in a plant, commissioning the system per true field conditions is required. For fast and basic protection, it is most convenient to enter motor nameplate data directly into the basic settings display. For more complex protection requirements, which are typical of large or unusual motors, it is appropriate to use more flexible and advanced methods. For example, the web-based interface is a convenient and easy method for electricians and technicians to configure, commission, and monitor the LVMRs.

VII. CONCLUSION

The following points capture the essential takeaways about a comprehensive LV MCC protection and control system:

1. Comprehensive feature sets in the LVMR increase reliability, improve safety, and reduce the operating costs of LV MCC systems.
2. The system reduces motor failures with advanced protection elements.
3. Direct-start motors, lighting circuits, and VFD-driven motors are protected by a single LVMR model.
4. Arc-flash detectors built directly into the LVMR and advanced protection strategies are used to reduce the incident energy of events.
5. Simple, reliable, and time-proven methods of configuring, commissioning, and communicating with the LVMR must be supported.
6. Ruggedized designs and thorough type-testing of LVMRs improve the reliability of an LV MCC system and reduce process downtime.
7. An LVMR with internal testing and onboard diagnostics immediately identifies if the protection and control system is functioning.
8. LVMRs with several different types of event records aid in the diagnosis of motor overloads, short-circuit trips, and motor starting problems.
9. Cosine filtering of sampled data in an LVMR prevents spurious events caused by rms calculation techniques.
10. End users save money and time with a preconfigured, standardized CSMCS solution.
11. Due to the volume of LVMRs installed in many plants, the total cost of ownership must be factored into any decision to use new LVMR or CSMCS technologies.

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IX. VITAE

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