Introduction
Over the past decade, advances in the functionality of motor and circuit protective devices have accelerated rapidly, easily doubling technological development for these same devices over the past century. Protection of three-phase, low-voltage and medium-voltage induction motors 40 yr ago included a motor overload relay that consisted of a resistive heater element in the current path, deflecting a bi-metal (two dissimilar metals fused together) during motor overcurrent conditions, which
then mechanically engaged a trip bar to disconnect the source voltage before a motor overload failure. Today’s motor protection/motor management relays are based on sophisticated electronics. New intelligent motor protective devices proliferate the industry. These offer an order of magnitude in higher functionality and complexity. This article will discuss a common sense approach for leveraging the benefits of enhanced functionality in motor control and motor control centres (MCCs) through plant automation, while optimising the level of complexity, to ensure cement plant maintenance and operations continue to be as productive as possible.

Motor overload protection is at the heart of newer design protective relays. Integral current transformers sense load current in each of three phases, converting motor load current to a logic level signal employed by microprocessor controllers using algorithms to develop a thermal model of the driven load. The electronic protection model is designed to ensure the motor load condition does not approach the damage curve of the machine, as published by the manufacturer. Although the level of protection has significantly improved, the basic response of a protective trip on thermal overload before machine damage has not changed. With individual phase current sensing, a host of other advanced protective features are now also routinely available, including protection for phase current imbalance, loss of phase, and ground fault current. As an additional capability, some load-specific protective features, such as undervoltage or overvoltage, allow users to programme alarm or trip conditions should the motor load fall outside an anticipated operational parameter. Some new motor protective relays also include the capability to accept and continuously monitor phase voltage inputs. Of course, adding voltage inputs also allows for additional protective functions, such as phase loss, phase reversal, voltage imbalance, and under-voltage trip. Although many of these added protective features are included as nice-to-haves, each will typically require users to commit some degree of time and effort to setting up specific protections. For instance, if undervoltage protection is desired, an undervoltage current level for alarm and/or trip needs to be preprogrammed.

In addition to protective functionality, a host of monitoring/metering capabilities are also included in today’s motor protective relays. In pyroprocessing and a few other, more critical, process load applications, the availability of instantaneous and historic information for values such motor phase currents, real energy (kilowatt-hours), power (kilowatts), motor efficiency, and motor start time/count can also be important. This new functionality offers a marked improvement over older legacy systems that required additional current transformers (CTs) or kilowatt (kW) transducers, which added cost and space in MCC cubicles. The ability to trend parameters, such as current or kW, in the plant control system offers maintenance a powerful troubleshooting tool. Trends indicating abnormal fluctuations, or consistently higher or lower than normal values, help to isolate process or mechanical issues. Again, legacy systems required an electrician to connect instruments to manually measure current and kW values at the motor controller, exposing them to potential arc flash hazards; an important safety benefit that should be considered. Some more advanced relays include time clocks that feature a time stamp to mark trip conditions in real time, and capture critical values of voltage and current at the time the trip event occurred. Pre- and post-trip oscillography, in some designs, allow experienced power systems engineers to re-trace waveforms before the trip event and diagnose a probable cause of failure. Unlike trip settings, monitoring of electrical and other system parameters typically does not require setup before operation. This said, added terminations for voltage are required
and making a wrong connection will likely result in a device trip or incorrect metered values.

Adjustable frequency drives (AFDs) and motor protection offer the ability to control the voltage and frequency to an induction motor, delivering infinite speed control. Many process areas in cement apply AFDs for low- and medium-voltage motors. Because drives include real-time instantaneous control of motor torque across a span of multiple frequencies, motor protection for induction motors is best managed by microprocessors included in the AFD regulator. Suffice to say, any of the protective, monitoring, and metering functions, along with several others, are resident in the AFD controller. If motor overload protection external to the AFD is required for applications where a single variable frequency drive (VFD) is controlling multiple motors, the frequency specification of the intelligent motor protection relay must be considered.

Selecting the right network
With a host of new protection monitoring and metering functionality in today’s motor protection, perhaps the most important consideration is the selection of a suitable network to ensure information is accessible across the facility and, for multi-site cement producers, across the enterprise. For new installations, networks based on open architecture have almost completely replaced earlier proprietary networks supported by single suppliers. According to recent industry data, industrial ethernet networks account for 46% of global installations, an annual growth rate of 22%. Fieldbus networks account for 48% of global installations, but these are growing at only 4% per year. Wireless networks account for the balance of 6% of installations, with a growth rate of 32%. An undisputed trend for industry applications, including cement, is a shift away from fieldbus networks, such as DeviceNet and PROFIBUS, and toward ethernet-based networks, such as ethernet/IP, Modbus TCP, and PROFINET. Cost per point and throughput are the drivers fuelling this growth.

Today’s advanced motor protection relays generally include network connectivity to a host of popular networks. The trend is away from a device that is compatible with only one network, and toward a modular approach, where the relay can support a host of different communication cards that are compatible with industrial networks. The primary value proposition behind industrial networks was historically wire savings. Input/output (I/O) modules of programmable logic controllers (PLCs) could easily be located near field devices, and a network facilitated information transport back to a host computer with minimal wires. Today, networks provide connectivity from communicating field devices, such as advanced motor protection relays and AFDs, along with discrete I/O, to upstream supervisory distributed control systems (DCS), supervisory control and data acquisition (SCADA) systems, and PLCs to control plant processes.

In the industrial Internet of Things (IIoT) world, information is ubiquitous and high-speed networks offer the means to share information needed to improve system efficiencies, reliability, and workplace safety.

A simple block diagram of a commercially available advanced motor management relay is shown in Figure 1. A modular design provides mounting flexibility in the MCC withdrawable unit. The design includes a base control module, a measurement module, and an optional user interface module. The measurement module is connected downstream of the incoming overcurrent protective device (shown as a circuit breaker) and the motor contactor (M). Embedded current transformers in the measurement module provide motor current measurement, and terminals at the top accept direct voltage inputs for each of three phase voltages. Motor measurement data is passed electronically to the base control module, where motor management, protection, and network communications are performed. The plant user may optionally send networked and/or local control signals directly to the device via a network, the user interface, or onboard I/O, instead of hardwiring discrete control circuits to the relay. The base control module uses both user-configured protection and command inputs to control the motor contactor (M). An optional user interface module is the final systems module, which is typically door mounted at the MCC. This provides easy access for the operator to set and monitor all protection parameters and interrogate the base control module for data such as trip logs. Note also that the base control module includes a plug-in communications module at the upper right. A different network card is used to support the specified network protocol. In this case, the network module shown is compatible with ethernet/IP with device level ring (DLR) communications. This is a preferred ethernet configuration for process industries such as cement. Figure 2 shows the concept behind ethernet/IP with DLR. Ethernet is traditionally a home run topology, where each communicating device with
a network address is connected via RJ45 connectors and 600 Vt rated Cat 5 shielded twisted pair cable to an ethernet switch as shown. The DLR option allows a group of ethernet nodes to be connected in a ring configuration, and wired back to an intelligent switch. This delivers the benefit of a self-healing network, meaning if one node should be removed or dropped from the ring, the network will continue to communicate with the remaining nodes in the ring to the switch from the opposite direction. To support DLR topology, the base control module includes dual RJ45 connections, so one motor management relay with a unique ethernet/IP address can be ring connected to an adjacent relay back to the ethernet switch. One alternate application of DLR includes a home run connection to a central MCC ethernet switch, then a ring connection between multiple MCCs in the plant. This topology offers added flexibility, allowing multiple starters to be removed from the MCC for maintenance, without potentially impacting functionality of the control system.

After the motor protective relays, drives, and other devices are connected to the network, software integration tools generate descriptive I/O tags, and then import and provide aliases for them in the form of generic tags that reside in the PLC. Users should look for devices offering time savings integration tools such as add-on-instructions, which make it easy to import all device tags and take care of scaling parameters automatically. Some recently developed protective relays include software tools that allow configuration with any PLC or DCS controller, supporting a variety of industrial networks, including ethernet/IP, Modbus TCP, Modbus serial, PROFIBUS, and PROFINET. When connected to ethernet, each relay or drive includes web pages for configuring, monitoring, and control.

Given the extensive amount of data available from the intelligent motor protection devices, first time users may elect to monitor as much operating information as possible back to the host controller. However, care should be taken when defining what specific information the end user is interested in, as it is important to consider bandwidth limits and performance requirements of the selected industrial network.

MCC configurations
Current designs of low-voltage MCCs offered in North America and built to IEEE/ANSI standards, as well as those offered in South America, Asia Pacific, and Europe, Middle East and Africa, built to IEC standards, are available with advanced motor protection relays. Figure 3 shows a current design IEC assembly with a withdrawable module that includes the modular motor management relay shown in Figure 1. Factory assemblies will include network communication modules based on the cement producer’s selected network. One best practice is to specify factory acceptance testing (FAT) of new MCCs. During the factory test, communication cables and network addresses should be set to ensure functionality as expected, before installation in the field. If the PLC planned for use in the process is available, factory acceptance testing can also include some rudimentary tests to ensure the system programme functions as expected. One should take advantage of a scheduled FAT to perform these tests with the automation group or systems integrator, as this extra step will greatly reduce the required time for field commissioning.

Although the basis for this discussion assumes a new assembly is installed, some manufacturers of MCCs can supply replacement motor starter modules to be retrofitted into existing MCC structures. This allows existing incoming power and motor cables to remain in place, along with the legacy steel structure and copper bus, while controls are updated with the latest functionality, extending the useful life of the existing control assemblies.

A look forward
There is no argument that the added functionality of newer motor management relays offers improved motor protection and access to a host of electrical parameters that ultimately improve plant reliability and productivity. New device algorithms in development use electrical motor current signature analysis to detect electrical and mechanical system problems. Developments focused on detecting load issues, such as broken rotor bars, vibration, and impending bearing failure, will offer a host of predictive diagnostics capabilities, collectively referred to as a complete ‘system wellness’ portfolio. Industrial networks coupled with the IIoT will allow information to become a driver toward automation solutions, improving plant safety, efficiency, and productivity. With the advantage of a new plant, or when a new process is added, an opportunity exists to take advantage of the latest technology. Conversely, older plants, which have expanded over several decades, will likely contain several vintages of multiple disparate systems that represent more of a challenge.

Improvements in operations, asset protection, safety, reduced installation, and savings over conventional I/O hardware, should justify the incremental cost for selection of intelligent motor protection hardware vs conventional overload relays and hardwired control systems interface. As with any new technology, management will need to recognise the need to invest in human assets and provide the required training for local plant maintenance personnel responsible to support this new technology.

References