Configuring Microprocessor-Based Relay Systems for Maximum Value

Overlooking custom relay programming undermines relay upgrade investments and jeopardizes system protection.

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Executive Summary

In the event of a fault, protective relays protect electrical systems, equipment, and people from serious damage and injury. For the most effective protection, many utilities and industrial facilities are replacing aging electromechanical relays with new generation microprocessor-based relays. This retrofit is fast and cost-effective. The new relays deliver a host of benefits, including increased system reliability, improved control, event recording and reporting capabilities, reduced maintenance, simplified regulatory compliance, enhanced communication, arc flash mitigation, and improved protection.

Unfortunately, many owners fail to maximize the protection and value afforded by their new microprocessor-based relay systems. They may lack the time and/or skill to appropriately configure relay settings and logic to best meet their facility's requirements. Or, they may simply be unaware of the importance and benefits associated with customizing relay logic.

Qualified protection and/or integration engineers have the expertise to design and implement relay logic settings to ensure the required protection for an operation. They can also help identify the specific relay features, capabilities, and configuration for optimum system protection. These features include arc flash mitigation capabilities, lockout settings supporting increased safety and security, event recording capabilities for the purposes of expediting troubleshooting, and motor/generator protection features, which assist in preventing nuisance tripping—all while ensuring maximum protection for a facility's most critical assets.

In addition to customizing specific microprocessor-based relay capabilities, skilled integration engineers can also help utilities and industrial facilities design their microprocessor-based relay protection systems in such a way as to fully leverage the inherent benefits of the relays and maximize each relay's value. This includes taking advantage of the multi-function capabilities in each relay to proactively eliminate redundant components and minimize the potential for multiple points of failure. It can also include capitalizing on each relay's self-testing features to improve reliability of all system components, simplify NERC compliance, and reduce maintenance time and costs. Finally, skilled integration engineers can program communication processor functions such as the Real-Time Automation Controller (RTAC) from Schweitzer Engineering Laboratories (SEL) to integrate and concentrate information from a wide variety of microprocessor-based devices and make the data accessible via a web-based HMI display for both visualization and unparalleled control of system data.

This paper takes a closer look at the capabilities and advantages of these often underutilized microprocessor-based relays. It demonstrates how experienced protection and integration engineers can make the most of the features to help utilities and industrial facilities obtain the greatest level of protection for their electrical systems while maximizing the value of their relay upgrade investments.

Introduction

The many advantages of new generation microprocessor-based relays as compared to electromechanical relays are well-documented and well-known among designers of electrical protection systems for utilities and industrial facilities. From increasing system reliability, to simplifying troubleshooting, to reducing maintenance costs and saving space, microprocessor-based relays provide superior system protection along with cost and efficiency advantages. Not surprisingly, when aging electromechanical protective relays approach obsolescence, many facilities choose an easy, affordable retrofit solution: an upgrade to microprocessor relays.

Microprocessor relays are computer based and use programmable logic. The logic dictates how the relay will perform its main duty—protecting the electrical system. For example, if a fault is detected, the protective relay will respond by tripping and potentially locking out a breaker, preventing major equipment and system damage.

Most relays come pre-programmed with the manufacturer's default logic settings. While these settings do provide a basic level of system protection right out of the box, they are rarely ideal for meeting the facility's specific protection requirements. Furthermore, the pre-programmed settings represent merely a fraction of the relay's potential functionality. Beyond primary protective capabilities, a single microprocessor-based relay can be used to control, manage, and automate portions of the electrical system. In fact, each relay offers literally hundreds of potential settings that can be configured to provide a completely customized protection scheme and system control solution.

Some of the programmable logic capabilities built into microprocessor-based relays include:

- Event recording
- Enhanced communication
- Advanced metering
- Load data recording
- Remote control
- Automatic controls
- Interlocking with other relays
- System monitoring
- Equipment monitoring
- Maintenance data recording
- Arc flash reduction
- Continuous self-monitoring

Each of these capabilities can be constructed from hundreds of available digital points within the relays and configured to provide maximum system protection and advanced function and control to meet specific utility or facility requirements.

Relay Customization Oversights and Errors

While the potential functionality of a microprocessor-based relay is incredibly vast, many of the relay's capabilities and advantages often go unrealized. This happens for a number of reasons, including:

- **Lack of owner awareness.** Custom relay configuration has only recently become an option.
- **Simple oversight.** Owners may overlook the need for relay customization and programming during the estimating, bidding and specification processes.
- **Lack of knowledge and expertise.** Engineers may not have the skill levels needed to program relays, or the designers and installing electricians may be unfamiliar with the relay's capabilities.
- **Complexity issues.** Custom programming can sometimes cause the system design to become overly complex. For simple applications, the effort needed to configure all the available features would not be worthwhile.

Even when facilities and utilities do customize relay logic, the programming may not be completed properly. This can lead to a wide range of protection system problems. If the integration engineer does not have a good understanding of the nuances of the electrical system, logic settings may lead to repeated system shutdowns, becoming a source of frustration for asset and facility managers. In these cases, the managers often revert to less sophisticated or default logic settings just to keep the system running.

Whether a lack of custom relay logic and programming is due to oversight or error, failing to properly configure relays can diminish their value. Worse, it can put assets at risk and leave the electrical system vulnerable to significant damage in the event of a fault.

The Role of the Integration Engineer

The key to leveraging the full range of microprocessor-based relay capabilities and optimizing system protection is to work with experienced integration engineers. These engineers should have the expertise to properly configure each relay to meet the utility or facility's unique objectives. In addition to configuring logic settings and performing the actual programming, skilled integration engineers can be instrumental in educating utilities and facilities about the relay's many capabilities. The engineers can assist in identifying and selecting the relay features and settings that will be most important based on electrical system configuration and the customer's unique protection scheme.

To ensure the best custom logic results for each facility, the integration engineers at Emerson Network Power's Electrical Reliability Services (ERS) typically begin each logic development process by determining the owner's project requirements. Requirements include how the protection system should respond in the event of a fault, how protective relays should communicate with other systems, and what functions (in addition to protection) the relays should perform.

Ideally, this process considers the needs, requirements and specifications of:

- Utility
- Owner/operator
- Local jurisdictions
- Industry standards (JCAHO, MSHA, NEC, FERC)
- Engineer of record (Basis of Design/ Sequence of Operations)
- Equipment manufacturers (motors, transformers, cables, breakers, switchgear)

It should also consider issues relating to:

- Human Machine Interface (HMI)
- Short circuit coordination and arc flash study
- Automation
- Redundancy (N+1, +2, etc.)
- System requirements (life safety, information/data, mechanical process, critical care, manufacturing)
- Fail-safe provisions
- Manual operation
- Maintenance

Reviewing the above considerations will help integration engineers determine the features and design logic necessary to transform each relay into an intelligent, sensitive sentinel capable of delivering the highest quality protection for an electrical system. Engineers can also build as much functionality as needed into each relay to meet the full scope of customer requirements and maximize the value of the relay investment.

While project requirements will obviously be unique for each facility or utility that upgrades to microprocessor-based relays, ERS has indentified a number of relay features and capabilities that almost always improve protection schemes and add value to the relay system. The remainder of this paper takes a closer look at these opportunities.

Four Programmable Relay Settings Every Facility Should Implement

1	Arc Flash Mitigation Capabilities
2	Lockout Settings
3	Event Recording Capabilities
4	Motor/Generator Protection Features

1. Arc Flash Mitigation Capabilities

Many microprocessor-based relays include an optional protection feature for arc flash detection. This feature can immediately respond to arc flash incidents by detecting a combination of excess light and current. The feature can help workers avoid devastating injury and prevent costly equipment damage.

To determine if this relay feature is needed in a specific environment, protection engineers can complete an arc flash hazard analysis to identify the potential for and location of possible arc flash hazards. Such an analysis may include recommendations to utilize microprocessor-based relays for additional arc flash protection. In these instances, the arc flash mitigation capabilities should be programmed into the protective relay, using logic to instruct the relay to immediately interrupt the circuit if developing arc flash conditions are detected.

Arc Flash Mitigation Case Study

Arc flash detection features within protective relays may also be used to help a facility achieve certain operating requirements. For example, ERS worked with a pulp and paper manufacturer that needed the ability to electrically calibrate and adjust its paper machine drives during operation. However, the calculated arc flash hazard risk level associated with working on the energized equipment exceeded hazard risk category (HRC) 4, making the equipment unapproachable while energized.

ERS first installed protective relays with arc flash detection at each drive to act as virtual main breakers, which provided transfer trip functionality to the upstream medium voltage feeder breaker through a high-speed logic processor relay. Then ERS designed a scheme that allowed the operator to select arc flash reduction settings, lowering the hazard from greater than HRC 4 down to HRC 1. This scheme allowed for real-time calibration and adjustment of the drive lineup without unnecessary risk and exposure to the operators.

In many cases, unknown component failures within the protection system will defeat any well-intentioned arc flash mitigation scheme. Intelligent system design can leverage the self-testing capabilities of modern relays to extend beyond just the relay and include all components within the relay control circuits. This ensures the entire arc flash hazard mitigation system is healthy. Such self-checking schemes include, but are not limited to:

- Breaker failure detection
- Trip coil monitoring
- Current transformer failure detection
- Loss of potential transformer detection
- Real-time communication verification between components and protection relays
- Control power monitoring
- Relay self-checks

2. Lockout Settings

When a breaker or transformer is tripped, reclosing the breaker automatically or remotely without first determining the cause of the trip can lead to overlooked or unidentified problems that could cause extensive equipment or system damage, or serious injury to workers. In the past, systems relied on 86 lockout relays to prevent such occurrences. Upon activation of a protective relay, the 86 lockout relay would toggle, trip a breaker, and block the subsequent closing of the breaker until an operator reset the 86 device.

Multiprocessor-based relays allow for 86 lockout relay functions to be moved into the relay logic, reducing the number of components in the system. While microprocessor relays can be configured so they will reset without first determining the cause of the lockout signal, this is not the recommended approach. For enhanced security and safety, the lockout should be configured to require an operator to manually interact with the relay and acknowledge the cause of the fault prior to resetting the lockout and reclosing the breaker. Programming the relay logic in such a way provides a means to further protect the system and worker from operator error while giving the operator the greatest chance of successfully determining the cause of the trip and facilitating the appropriate corrective action.

Lockout Settings Case Study

ERS configured the 86 relay logic as described above for a large semiconductor manufacturer. When a fault occurred within the system, the relay locked out the close order for the breaker. Despite the operator's efforts to close the breaker by using a manual close button and by jumping across outputs, the breaker remained locked out.

The lockout prevented closing into a grounded circuit, which ultimately could have led to extensive damage and downtime, system failure, and/or arc flash and injury. In addition to protecting the system, the lockout also allowed the customer to identify the need to provide additional operator training.

3. Event Recording Capabilities

Microprocessor-based relays offer built-in event recorders capable of capturing and time-stamping event information at one millisecond resolution. Following a fault, the relay can produce a report summarizing the sequence of operations prior to the event. Information collected by event recorders can include trip sequence, the amount of time a breaker was open, where the fault occurred, nature of the fault, pre-fault conditions, and power quality monitoring waveform. These details expedite troubleshooting and can help operators more quickly identify the root cause of a fault. Ultimately, faults are cleared quickly and safely, minimizing costs and downtime.

While event recorders are powerful tools, their output is only as good as their input. Put another way, event recorders record only what they are programmed to record. Integration engineers need to identify all elements that should be recorded in the event of a fault. Obviously, the more complex a relay system is, the more populated the event recorder should be. However, it's important to remember that event recorders have limited data capacity and will begin dropping old data from the file once that capacity is reached. For example, a synchronizing element may overfill the buffer when a generator is repeatedly synchronizing to a source, eventually pushing more important events out of the queue. Therefore, some elements should be left out of the event recorder depending upon how often they toggle.

Once the elements to be recorded have been identified, the relay must be programmed correctly. An experienced integration engineer will begin by creating a list of all inputs,

Event Recording Case Study

Properly programming an event recorder can help a facility identify the root cause of problems that could otherwise go unresolved, resulting in significant equipment and financial damage. This was just the case for a large semiconductor manufacturing facility. The facility receives power from a utility substation located outside the plant. As part of the facility's electrical protection system, ERS developed logic settings for a complex array of protective microprocessor-based relays throughout the distribution system, including programming the event recorder. Collaboration with the utility design engineers during construction ensured both systems worked together to adequately record enough information during a fault to allow for reconstruction of the event.

Just such an event occurred within the first year of occupancy, demonstrating the effectiveness of a well-designed event recorder. During four millisecond interruptions to the utility substation DC control power, the facility's automatic control system began to respond as if utility AC power was compromised, transferring to emergency systems. Post fault analysis reconstructed the event because the event recorder was programmed correctly. The root cause of the misoperation was identified and recommendations were made for immediate corrective action. Without the recorded information from the microprocessor-based relays, the problem likely would not have been resolved, compromising the facility's reliability and leading to significant and unnecessary expenditures for backup power and operation personnel's time.

enabled protection elements, user controls, and custom-built logic (i.e. CT Failure, PT Failure, etc.). The engineer will structure the event recorder for time stamp entries of event pickups, timers, inputs and outputs. Best practices call for the engineer to structure the high-speed data capture for trips, abnormal voltage, or currents to aid in event analysis during future trip investigations.

4. Motor/Generator Protection Features

A key advantage of microprocessor-based relays is their ability to ensure maximum protection for motors and generators, which often represent a facility or utility's most expensive assets. Microprocessor-based relays protect these critical assets much more effectively and efficiently than electromechanical relays and can also help prevent nuisance tripping.

Most industrial facilities, wastewater treatment plants, manufacturing facilities, and refineries operate a large number of motors, some of which cost tens of thousands of dollars. Large motors are expensive to repair or replace and lead times are long. Each motor can be effectively protected by one microprocessor-based relay. However, the features within the relay must be programmed correctly, per the motor manufacturer's specifications and motor load, taking into consideration the facility and how it operates.

Some motor protection relays allow for limiting the maximum starting time or maximum starts/hour to allow for adequate cooling of the motor during high-current, low-speed operations. Oftentimes, this function is underutilized or misunderstood and is either disabled or set to a value that does not adequately protect the motor. To take advantage of this function, protection engineers perform motor starting and load flow studies to determine the maximum motor start times that can be expected under the most restrictive conditions. Relays are then programmed to prevent damage but still allow for adequate start times without nuisance tripping.

Generator Protection Case Study

In the case of utilities, one microprocessor-based relay can provide better protection for a generator than multiple electromechanical devices, given that the microprocessor-based relay is programmed correctly. ERS effectively demonstrated this fact when it replaced more than 20 electromechanical relays with just two multiprocessor-based relays at a large hydro electric power plant.

Prior to the retrofit, protective relays were essentially non-functional. Over the years, the settings had been relaxed, because during cold weather, customers fired up their electric furnaces creating a current imbalance condition that caused the plant to nuisance trip. To avoid this nuisance tripping, the protective settings had been modified to the point that they provided almost no protection.

During a previous winter, heavy icing resulted in a tree falling on the line creating a single phase condition. Unfortunately, the electromechanical relay system did not have the ability to detect this event, and the generator fed the fault until winding failure occurred.

To address this system weakness, the new microprocessor-based relays were programmed to make use of protective elements, allowing for better detection of utility faults without nuisance tripping during abnormal conditions. This "intelligence" and "sensitivity" gave the plant operators additional control and helped prevent nuisance tripping while ensuring protection for the system in the event of a real fault.

Just two weeks after the installation, another tree fell on the utility distribution line. The microprocessor relay identified the threat to the system and triggered a trip, protecting the generator and providing a return on investment in just two weeks.

System Design Considerations

In addition to customizing specific relay settings, microprocessor-based relays have inherent advantages that can be leveraged to maximize the value of the relays. These advantages should influence the design of electrical system protection schemes and control systems.

Using Multifunction Relays to Reduce Potential Points of Failure

Microprocessor-based relays are designed to perform a wide range of functions in addition to their primary protective functions. These additional functions can include automation, metering and remote control. When system designers take advantage of these embedded ancillary features within the protective relays, multiple electrical system components can be eliminated from the switchboard, including auxiliary relays, wiring, timers, switches, trip coil monitors, and 86 lockout devices.

Designing the system in such a way saves costs by reducing the number of devices in the switchboard and decreasing the wiring and installation labor needed. This type of design also greatly improves the reliability and flexibility of the system.

Perhaps most important, eliminating redundant system components by leveraging relay functionality minimizes the potential for additional points of failure and/or weaknesses in the system—effectively increasing the mean time between failure (MTBF). In traditional system designs, each component in a switchboard could potentially fail undetected and compromise the entire system. But when these discrete components are eliminated (by programming their functions into the protective relay), there are fewer components to fail, and reliability is increased.

What's more, each microprocessor relay continuously monitors itself, as well as all of the embedded inputs, outputs, and logic, via self-test features inherent in the relays. System reliability improves because the relays can help identify problems and failures previously "hidden" in the switchboard the moment they arise, allowing issues to be corrected before a misoperation occurs. Should the relay itself fail, it has the capability to immediately "fail-safe," notifying system owners and operators and allowing action to be taken to protect the system.

To take advantage of the multifunctional capabilities of microprocessor-based relays, the utility or facility should work closely with the protection and control system designer to identify which components and devices can be programmed into the relays, and thereby, eliminated from the switchboard. The integration engineer will then program these functions into the relay and configure it to verify that all functions will be continuously self-checked.

Programming Real-Time Self-Monitoring, Testing, and Maintenance Capabilities to Simplify NERC Compliance and Reduce Manual Maintenance

As discussed in the section above, microprocessor-based relays include embedded self-test features. When automation, remote control capabilities, and other system components are integrated into the relays, these self-test features can be used to protect the entire electrical system.

In addition to improving system reliability and increasing MTBF, self-testing simplifies compliance with North American Electric Reliability Corporation (NERC) PRC-005 protection system maintenance program (PSMP) requirements for utilities. To verify that a utility's critical protection system components are operating as they should, NERC requires maintenance testing procedures, testing intervals, and documented test results. When a protection engineer approaches the design of the relay application with NERC requirements in mind, the relay's self-test features can be leveraged to automatically satisfy many of these requirements.

For example, the relays can be programmed to continuously monitor the internal health of components including DC circuits and trip coil circuits. They can also validate signal status, analog inputs, output circuits and communication links. The relays can even monitor breaker wear, status of transformer auxiliaries and ambient environmental conditions. System designers can further simplify NERC compliance by configuring the relays to work in conjunction with a communication processor and reporting software to automatically communicate results of the self-tests and generate reports used for NERC reporting.

NERC compliance is a concern only for utilities. But utilities and industrial facilities alike have a need to reduce maintenance time and costs. Maintenance concerns can influence the design of a relay application and self-testing features can be used to alleviate some of these concerns.

PRC-005-1 Transmission and Generation Protection Systems Levels of Non-Compliance	
LEVEL 1	Documentation of the maintenance and testing program provided was incomplete as required in R1, but records indicate maintenance and testing did occur within the identified intervals for the portions of the program that were documented.
LEVEL 2	Documentation of the maintenance and testing program provided was complete as required in R1, but records indicate that maintenance and testing did not occur within the defined intervals.
LEVEL 3	Documentation of the maintenance and testing program provided was incomplete, and records indicate implementation of the documented portions of the maintenance and testing program did not occur within the identified intervals.
LEVEL 4	Documentation of the maintenance and testing program, or its implementation, was not provided.

A traditional system with multiple electromechanical switchboard components can be complicated and unreliable. Such a system requires diligent calibration, maintenance, and repair to keep it functioning. When discrete components are eliminated and their functions are programmed into a microprocessor-based relay, there are fewer components to test and maintain. In addition, many inspection and testing procedures are performed automatically and continuously by the relays while the system is operating, reducing the need for manual testing procedures along with the scheduled downtime needed to perform the activities. Maintenance capabilities programmed in the relay can include verification, monitoring, testing, inspection, calibration and upkeep. A skilled integration engineer can program the relays to automatically perform manufacturer's specified maintenance activities for each function.

Maintenance and Compliance Case Study

ERS recently completed relay upgrades in four Colorado power generation stations for Tri-State Generation and Transmission Association, a wholesale electric power supplier that serves 44 electric cooperatives. While the main impetus for the project was to improve asset protection and reliability by replacing aged and faulty electromechanical relays with new microprocessor-based relays, ERS also designed the new protection system and configured the logic settings within the relays to deliver significant compliance-related and maintenance benefits.

Before the upgrade, it would take one Tri-State technician two weeks to perform relay testing. The tech would pull out the old electromechanical relays, put in the test set, perform the testing, calibrate and clean the relays, and replace them. Now, technicians simply need to verify that the relays are reading the right inputs and providing the right outputs. The time to complete relay testing has been reduced to just two or three days, significantly reducing overall maintenance costs.

Furthermore, ERS designed Tri-State's relay upgrade solution to allow Tri-State to more easily meet regulatory demands. Tri-State now produces the required test plans in a shorter time and with less manpower. In addition, they have complied with NERC requirements and have successfully avoided the problems associated with non-compliance, such as fines and penalties.

Programming Communication Processors for Improved Communication and Control

Microprocessor-based relays are designed to collect extensive data about a utility or facility's electrical system. To gain the maximum value from the data, some facilities are taking advantage of communication processors such as SEL's Real-Time Automation Controller (RTAC). These powerful automation platforms are capable of sophisticated communication and data handling.

Integration engineers can program a communication processor to use communication and control interface relays to poll protective relays, as well as other microprocessor-based devices, and gather information in real time. The system data is then transformed into interpretable information and made accessible to operators via a web-based HMI display. Easy access to data in a usable format facilitates remote monitoring, enhanced control, and better decision making, as well as faster, safer troubleshooting in the event of a problem with the system.

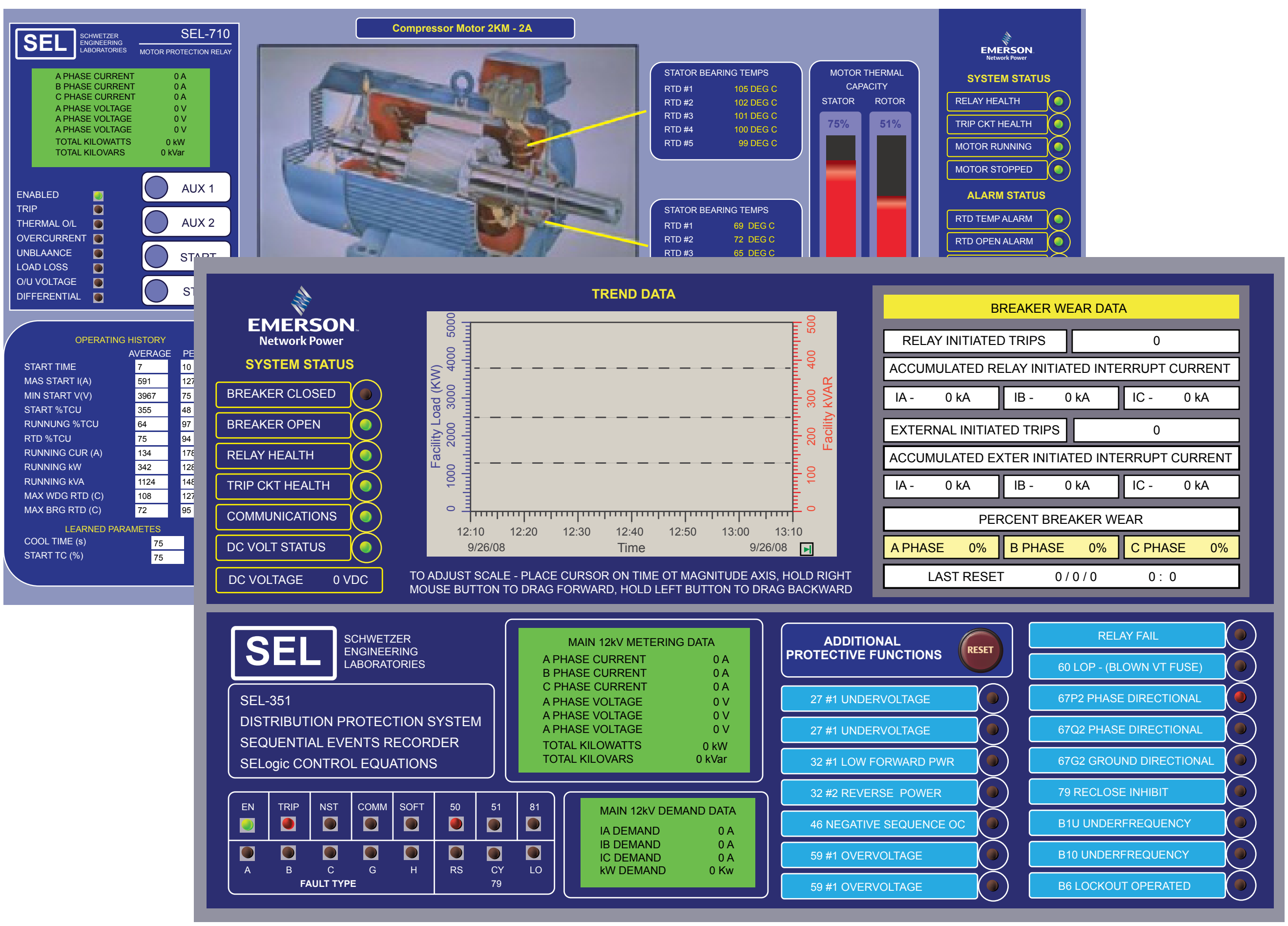

Figure 1. A customized HMI display like the above can provide system details such as overall trend and protection data, along with component-specific information.

In addition to bringing data from the electrical system to the operators, the communication processor can be configured in such a way to allow for remote controls to open and close breakers automatically or from the HMI. This capability enhances system protection and further reduces the exposure of an operator during equipment operations.

A communication processor can bring together protection, control, and communication in one device for a fully automated substation. But unlike microprocessor-based relays that come with default logic in place, a communication processor typically arrives as an empty box.

It's important to work with skilled integration engineers with advanced programming experience to ensure the processor works effectively and delivers maximum value. The integration engineer will need to build custom user logic and create the logic solutions in the processor's embedded logic engine. The engineers will also program the processor to collect event data from connected relays, communicate with other devices, and execute output logic for real-time controls. Finally, skilled integration engineers can assist in building custom HMI displays to facilitate system monitoring and control.

Communication and Control Case Study

ERS demonstrated the capabilities of an SEL RTAC during a retrofit project at a large defense manufacturing facility. The project entailed upgrading the entire medium voltage distribution relay system, including an automatic transfer control with a load shed scheme, utilizing one RTAC and several SEL feeder management relays.

Not only did the RTAC relay handle automatic transfers, but load shedding capabilities, manual interventions, and lockout schemes. System status and individual feeder relay metering data was also collected, scaled, and transmitted to a third-party proprietary control system for HMI display and customized monitoring of individual process energy consumption.

The internal logic functionality of the integrated protective relay system allowed for the removal of external components, such as power quality metering, automatic transfer controls, load shed controls, electromechanical lockout devices, manual control switches, and analog metering, fully leveraging the single-point failure benefits of this system. Not only was the system designed to allow for complete manual operation in the event of any system failures, but ERS also designed it to alert the facility in the event of failure, thus combining system protection with advanced control and communication and fully leveraging the capabilities of the RTAC.

Conclusion

Utilities and industrial facilities frequently make a critical mistake when upgrading to new generation microprocessor-based relays by failing to customize the relays' built-in programmable logic, thus forfeiting the relays' ability to properly protect the electrical system.

With the help of an experienced protection and/or integration engineer, utilities and facility owners can identify the features and capabilities within each relay that should be leveraged such as arc flash mitigation capabilities, lockout settings, event recording capabilities, and motor/generator protection features. Integration engineers can also help design the protection system in such a way as to take full advantage of the inherent capabilities and benefits of relays, including automation, metering, and remote control capabilities; self-testing features; and enhanced communication and control.

Only by investing in proper relay logic customization and programming can facilities ensure optimum protection for their electrical systems and simultaneously realize the full value of their microprocessor-based relay investment.

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