

Modernization of Mill Power Systems for Better Control and Visualization

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INTRODUCTION

Plant History

Founded in 1968, Cascade Steel Rolling Mills, Inc. (CSRM) is a steel manufacturing facility that turns recycled metal into high-quality finished steel products. Located in McMinnville, Oregon, their electric arc furnace (EAF) mini-mill produces a wide range of hot-rolled products, such as reinforcing bar (rebar), coiled reinforcing bar, wire rod, merchant bar, and other specialty products. A new melt shop was constructed and commissioned in 1990 through 1991, and a second rolling mill was installed in 1995 through 1996. The EAF was refurbished in 2004.

Background and Project Objectives

Protective relays provide protection, monitoring, and control for any utility or industrial power system and are essential for high-voltage (greater than about 70 kV), medium-voltage (between about 1,000 V and 70 kV), and low-voltage (less than about 1,000 V) circuits. Until 2010, all relays in the CSRM power distribution system were traditional electromechanical-type relays that did not provide communications, self-diagnostic functions, or (for evaluating a fault) operating data, event recording, or waveform capture.

The electromechanical relays at CSRM had a number of other operational limitations and challenges. Relay set points could not be readily changed to provide a maintenance setting. All of the medium-voltage switchgear and associated relays used 120 Vac control signals, requiring the use of a capacitive trip device (CTD) in order to provide dc power to operate the trip circuit. Determining the condition and state of operational readiness of the CTD was not easy and required opening the switchgear cell door to access the {PRESS TO TEST} pushbutton on the CTD. Also, every electromechanical relay required periodic calibration and maintenance in a potentially hazardous location.

In addition, the melt shop electrical and operations department wanted to have the ability to determine the EAF transformer winding temperature in real time. This would help reduce the tap-to-tap time at the EAF by giving personnel information that they can use to operate the transformer at a higher capacity during the last part of the heating cycle without the concern of damaging this critical, expensive asset.¹ This would increase throughput and cut production costs. Electromechanical relays have no means to calculate the transformer winding temperature.

Protective Relay Functional Requirements and Safety Features

To overcome the previously described issues, CSRSM staff decided to implement protection, control, monitoring, and visualization systems based on modern microprocessor-based protective relays and other associated components and software.

The relays were selected based on features, functions, cost, ease of use, configurability, and technical support. The relays had to be able to handle the required protection functions, provide troubleshooting from the front panel and remote connections, record the sequence of events of specified events, and capture waveform data during a fault. The relays had to communicate with other similar relays, relays from other manufacturers, a new supervisory control and data acquisition (SCADA) system, and the existing plant programmable logic controllers (PLCs) and SCADA system.²

Steel mill power systems inherently have a potential for very hazardous arc-flash events. Where appropriate, the selected microprocessor-based relays have built-in arc-flash detection, which can detect an arc flash and send a trip signal to a switchgear bus breaker within 8 milliseconds, greatly reducing the incident energy (and hence the potential for injury) of an event. Bare fiber and point sensors were connected to the relays and routed through critical locations in the switchgear main bus compartments, the fused disconnect switch cells, and the breaker cells. The relays use a combination of light sensing and fault current detection for fast response and false trigger (such as a camera flash) rejection. The new relays are mounted in a remotely located relay cabinet as far from the breakers as possible within the electrical room. This further enhances the safety of the application by physically separating personnel interfacing with the relays from the switchgear hazards.^{3,4}

HARDWARE INSTALLATION

The first microprocessor-based relays were installed in the Rolling Mill 2 (RM2) main metal-clad switchgear shown in Figure 1. These microprocessor-based relays replaced electromechanical relays as well as power metering units installed in the switchgear by the original equipment manufacturer.



Figure 1. RM2 switchgear and original instrumentation

Next, relays providing overcurrent protection and other functions were installed in the melt shop switchgear. Relays with arc-flash detection were employed in the medium-voltage switchgear, 480 V switchgear, and at the 12.5 kV/480 V transformer.

The original switchgear relaying, shown in Figure 2, consisted of one relay per phase plus one relay for ground detection.



Figure 2. Original melt shop relay configuration (protecting only one circuit)

All of the functionality of the four relays per breaker is now contained in one new relay per breaker, as shown in Figure 3.



Figure 3. Melt shop switchgear relay panel (with complete protection for five circuits)

New switchgear and relays were installed in five other areas of the plant, some indoors and some in outside locations, such as the compressor substation. Arc-flash-detection-equipped relays were installed in various areas where arc-flash potential exists, such as the switchgear breaker cell, the transformer medium-voltage termination chamber, the transformer low-voltage throat, and the 480 V metal-clad load center.

While converting from ac to dc control voltage did require new close coils on the circuit breakers and the removal of a rectifier from the trip circuit, there were the following benefits:

- The breakers can now be operated during a power outage.
- Because the spring charging motor operates on dc, power can be restored without manually charging the spring.
- The CTDs were eliminated.
- Breaker trip coil monitoring and trip circuit monitoring were added.

ENHANCED FURNACE PROTECTION, MONITORING, AND CONTROL

New relays were also installed at the EAF and at the ladle metallurgy furnace (LMF). These relays provide transformer protection and transfer critical data to an automation controller, which derives the winding temperature. The controller enters the directly measured top-oil temperature and current in the IEEE thermal model (described in IEEE Standard C57.91-1995) to calculate the winding temperature, which cannot be directly measured.

Two new relays were installed at the LMF, one on the high-voltage side and one on the low-voltage side of the transformer, to combine the functionality of the three original relays (undervoltage, overcurrent, and ground fault) and four transducers. The high-voltage relay took over all the protection functions and provides analog signals to the existing LMF PLC for current, voltage, reactive power, and active power. These signals are used for electrode regulation and power calculations in the PLC. The low-voltage relay provides visual indication of secondary current and analog signals to the LMF PLC and sends data containing transformer top-oil temperature to the new SCADA system.

Before the new relays were installed, four transducers were used to provide the analog reference signals to the PLC. Calibration of the transducers was always in question. Time-consuming calibration had to be done regularly. The new relays provide reference signals (that do not drift) to the PLC, eliminating another maintenance task.

The updates to the EAF were similar to those on the LMF, except that all of the functions formerly handled by the multiple electromechanical relays were combined into one current differential relay instead of three single-function electromechanical relays.

An automation controller/protocol converter was also installed near the furnace relays. It carries out the following functions:

- Connects the three serially connected furnace relays to an Ethernet network.
- Connects to all of the microprocessor-based relays throughout the plant to gather and process data and perform protocol conversion where necessary.
- Processes and transmits selected data to the SCADA PLCs via Modbus[®] TCP/IP.
- Calculates winding temperatures for the EAF and LMF and provides the calculated winding temperature to the respective PLCs.
- Provides a web-based human-machine interface (HMI) for the entire power system that is visible to multiple personnel simultaneously throughout the plant.

Figure 4 shows the HMI screen for the EAF and LMF power and temperature trends for one hour. In the upper plots, the top lines indicate active power while the bottom lines indicate reactive power for the respective furnaces. In the lower plots, the top lines show the calculated winding temperature while the bottom lines indicate the top-oil temperature. The water-cooled oil temperatures are relatively stable while the winding temperatures rise quickly when furnace heating takes place. These plots can be viewed by the production staff (or any other authorized personnel throughout the mill) to monitor these critical furnace parameters and optimize the heat processes for best process efficiency while protecting the transformers.⁵

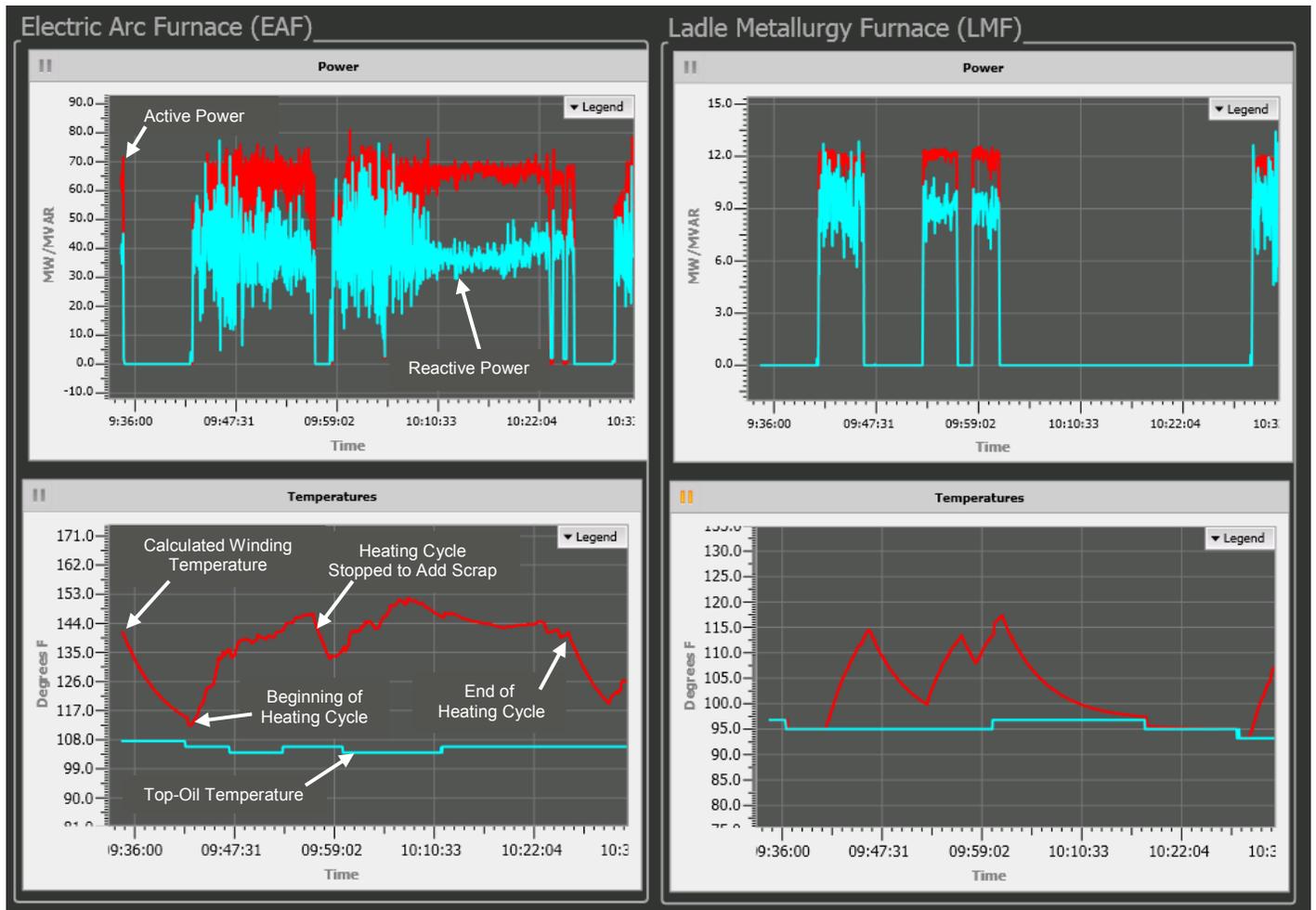


Figure 4. Furnace power and temperature trends shown on HMI screen

NEW SYSTEM BENEFITS AS APPLIED AT CSRM

Local Relay Status Visualization

Each new microprocessor-based relay has pushbuttons that allow the operator to open or close the associated breaker from the relay front panel, thereby allowing personnel to be located a safe distance from the switchgear when the breaker is being opened or closed. Personnel can also place the relay into maintenance mode or normal mode from the relay front panel. Light-emitting diodes (LEDs) are programmed to indicate the status of the breaker (open, closed, or one of several warning states) and the mode of operation (see Figure 5).

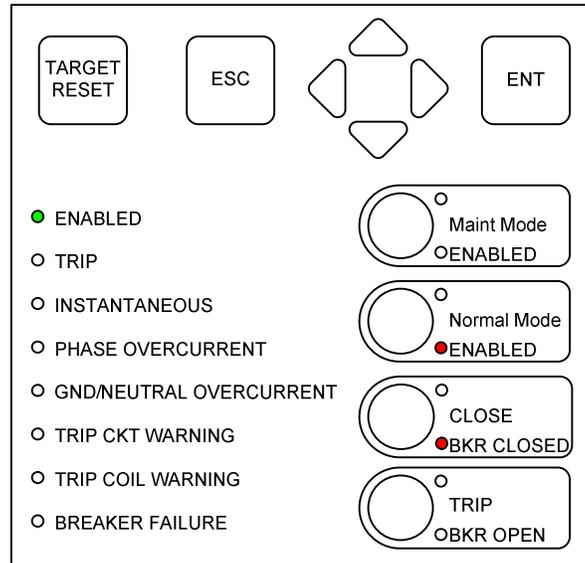


Figure 5. New microprocessor-based relay front panel

Circuit Wiring, Arc-Flash Detection, and Relay Diagnostics

All of the new microprocessor-based relays have the ability to detect failures in any part of the trip circuit. When the breaker is closed, the entire circuit is checked from one side of the trip output of the relay to the switchgear, through the trip coil of the breaker, and back to the other side of the trip output of the relay. A {TRIP CKT WARNING} LED on the front panel is asserted if a failure in the trip circuit is detected. Similarly, the trip coils are monitored when the breakers are open and a {TRIP COIL WARNING} LED is asserted if a failure is detected (see Figure 5). These important warnings, affecting the safety and reliability of the system, are also communicated to remote SCADA systems.

In much the same fashion as the electrical circuits, the optics of the complete arc-flash detection sensor loop are continuously and automatically tested with light generated by the relay. If the arc-flash detection system fails any of several diagnostic tests, the relay performs the following functions:

- Flashes the {TRIP} LED.
- Displays a warning that an arc-flash detection failure has occurred and the type of failure detected.
- Communicates a warning to the SCADA system.

Each relay also performs continuous self-tests for hardware and software problems. The software alarm asserts if personnel download a new configuration or request a higher level of configuration access. If the relay detects either situation, its status output is deasserted, alerting personnel. Hardware or software alarms are automatically displayed on the relay front-panel display and sent to the SCADA system.

All of the new relays are connected via the plant fiber backbone to the SCADA server and the automation controller. The server downloads and archives event information and waveform captures from all of the relays. The HMI displays one-line power distribution drawings with relay statuses as well as real-time three-phase voltage, current, and power, as shown in Figure 6. This provides a visual indication of the operational status of each relay. Because the HMI is web-based, it is viewable from any computer

with access to the industrial network and requires no fixed software clients. Automated messaging is being developed to notify selected plant personnel if a relay is in an alarm state.

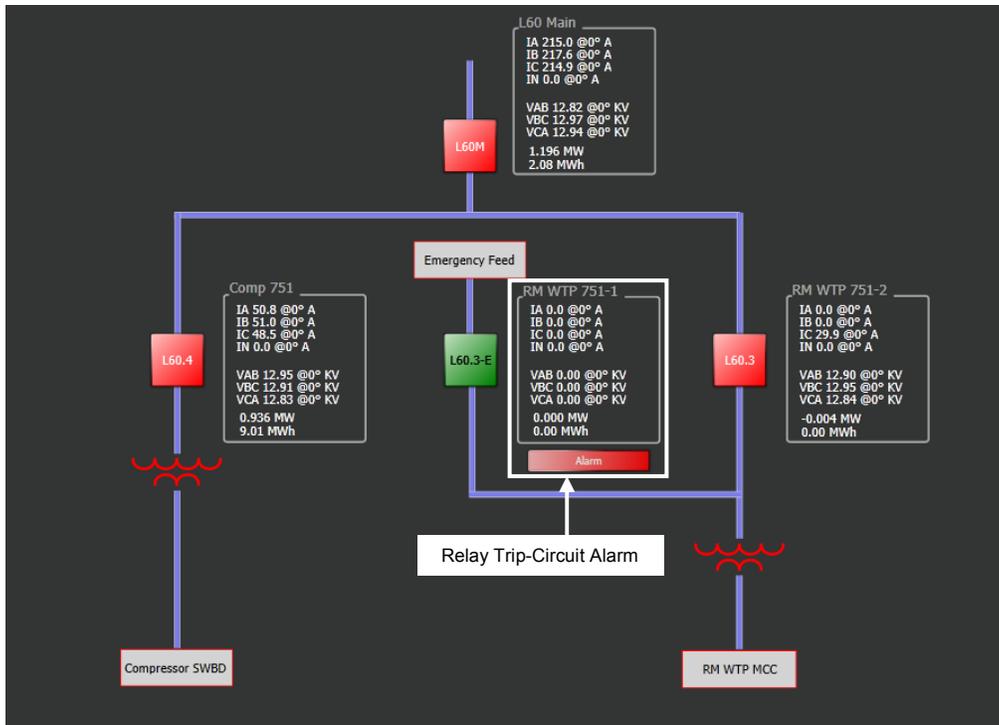


Figure 6. System one-line diagram on HMI display

The relay in Figure 6 is shown in the alarm state because it is not receiving feedback from the trip coil circuit. In this case, the relay correctly detects and indicates a problem with the trip coil circuit because the breaker is racked out and the breaker power connector is not connected.

The SCADA server is also able to provide personnel with a record of events for each relay, as shown in Figure 7.

Acknowledge <input type="checkbox"/>	Device Name	Location	Event Timestamp	Retrieval Timestamp	Retrieval Command Used	Event Type
<input type="checkbox"/>	MS 751-4	751A direct connect	12/31/2013 08:32:36.938000	12/31/2013 08:33:05.077000	CEV 1	Trip
<input type="checkbox"/>	Comp 751	751A direct connect	12/27/2013 08:04:31.810000	12/27/2013 08:06:03.115000	CEV 1	ABC T

Figure 7. SCADA server event summary screen

This provides a very quick method to check for any abnormal relay actions. In addition, the server also allows personnel to quickly connect with any relay on the network to check or change set points or to check the status of parameters within the relay.

All of the relays, the server, and the automation controller are time-synchronized to the plant network time server. This has made it simple to compare the event reports from the various devices and determine the exact times of events.

Cost and Convenience Improvements in Operations

The elimination of the costly and troublesome mechanical maintenance associated with the old relays has been described. In addition, now that the relays are all connected to the factory network, there is no need to travel to the relays located across the sprawling plant. Relay data and status can be monitored and settings can be quickly developed, downloaded, modified, archived, and compared with those from other relays from the comfort and safety of the office. Event records are collected and archived automatically on a central server.

CASE STUDY OF NEW CAPABILITIES

In August 2013, an unplanned, widespread, and costly power outage occurred at the melt shop and caster, involving a number of feeder circuits. Neither the root cause of the event nor its extent was initially obvious. Because all of the relay event recorder data were readily available via the SCADA server, a simple investigation determined that an actual overcurrent fault on a subcircuit in the

melt shop initially caused a medium-voltage breaker to trip. The relay appropriately de-energized, protected, and isolated the faulted circuit. A review of the sequence of events records for each of the three involved breakers revealed that the circuit feeding the entire melt shop and castor tripped approximately 6 minutes later due to incorrect technician action, not another fault. Table I, Table II, Table III, and Figure 8 show the digital and analog data captures from this event, showing the manual pushbutton actuation following the actual tripping of the faulted bus. The approximately 45-millisecond delay (nearly 3 cycles) between the trip signal and the collapse of current is the time required for the breaker to operate. This demonstrates an auxiliary benefit of the new relay event records: evaluation of actual breaker performance.

Table I. Data captured from relay on secondary (480 V) side of faulted transformer

Date	Time	Element	State	Comment
08/14/2013	20:15:06.266	50G1T	Asserted	Instantaneous ground overcurrent fault detected.
08/14/2013	20:15:06.266	51G1P	Asserted	Time ground overcurrent timer begins.
08/14/2013	20:15:06.266	TRIP	Asserted	Trip asserted, but this relay has no circuit breaker connection.
08/14/2013	20:15:06.270	OUT401	Asserted	Trip signal sent upstream to transformer primary side.

Table II. Data captured from relay on primary (12.5 kV) side of faulted transformer

Date	Time	Element	State	Comment
08/14/2013	20:15:06.287	TRIP	Asserted	Trip signal detected from relay on secondary side of faulted transformer.
08/14/2013	20:15:06.291	OUT401	Asserted	Faulted transformer tripped.

Table III. Data captured from relay on incoming feeder for entire melt shop

Date	Time	Element	State	Comment
08/14/2013	20:21:30.186	TRIP	Asserted	NA
08/14/2013	20:21:30.186	PB04	Asserted	Technician pressed {TRIP} Pushbutton 4 (PB04) in error.
08/14/2013	20:21:30.190	OUT401	Asserted	Entire melt shop tripped unnecessarily.

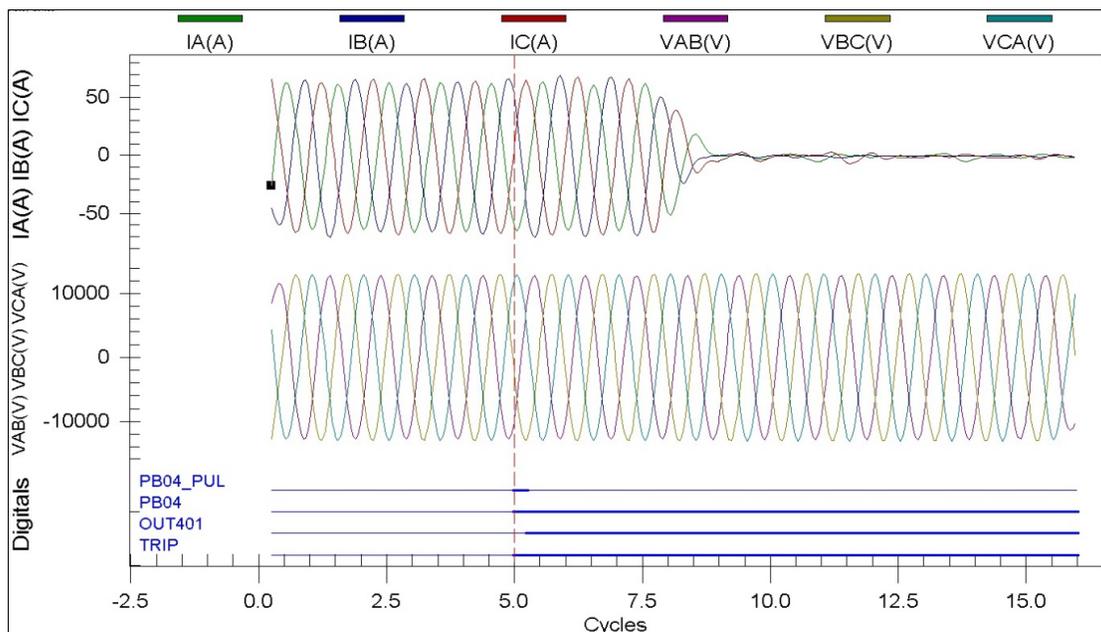


Figure 8. Analog waveform capture with time-aligned digital signals for manually operated trip of entire melt shop

This information showed that the extent of the blackout was caused by human error, not additional faults. Knowing this prevented any further delay in restoring power to the affected areas of the plant. In addition, the data were used to train electrical department staff on how to appropriately respond to any future events.

Had the old electromechanical relays been in place during this event, there would have been no information available to understand the sequence of events. Without this insight, no training would have been developed and the mill would have been exposed to the potential of another extensive and costly outage in the future.

CONCLUSIONS

The installation of modern, microprocessor-based protective relays and the associated communications infrastructure has greatly improved the safety and reliability of the extensive electrical power system at CSR. Arc-flash detection has been implemented at crucial locations, and personnel can now perform certain maintenance activities in locations physically removed from arc-flash hazards. A great improvement in continual system self-checks and event postmortem analysis has been realized. Maintenance costs have been greatly reduced, with most electrical system monitoring and control now possible without leaving the office.

CSR looks forward to the next steps: extending the new technology to the substations feeding the plant and eventually connecting the SCADA systems with those of the local electrical utility.

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